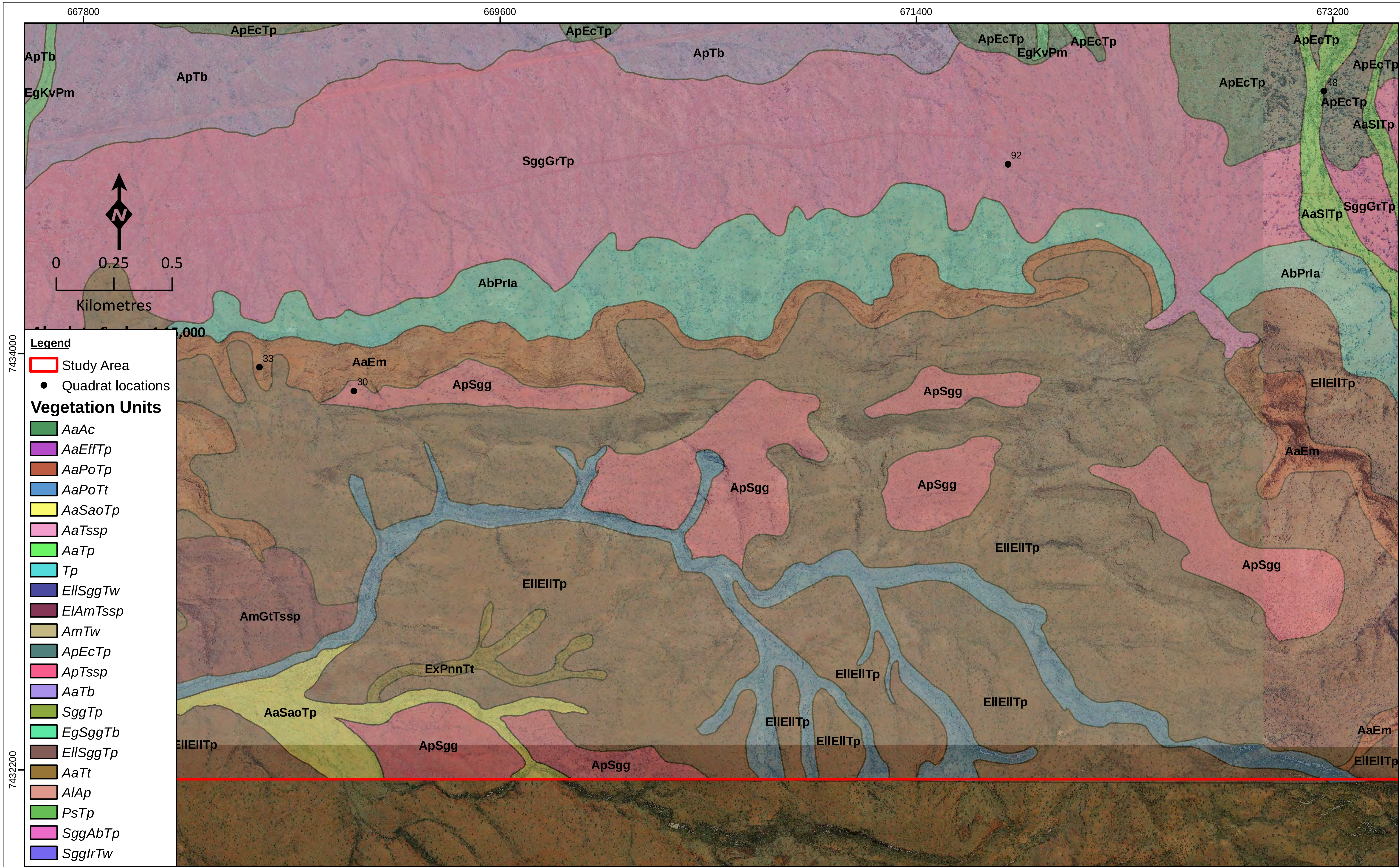


Figure: 5.17
Project ID: 1457

Drawn: CP
Date: 23/11/2012

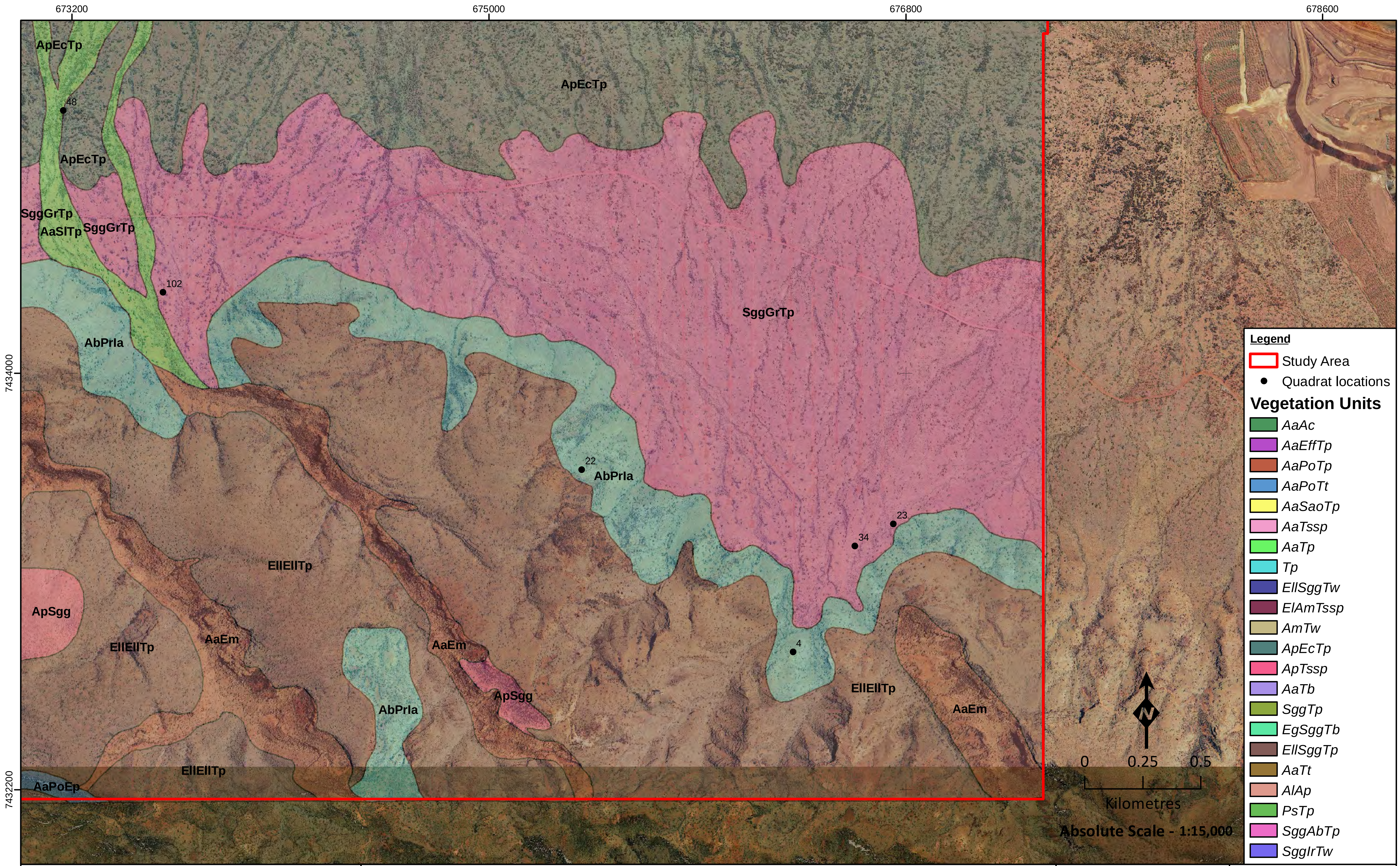
ecologia ENVIRONMENT

Vegetation Units within the West Angelas Study Area
Map D2

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: CP153

A3



ecologia ENVIRONMENT

Vegetation Units within the West Angelas Study Area
Map D3

Figure: 5.18
Project ID: 1457

Drawn: CP
Date: 23/11/2012

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: CP153

A3

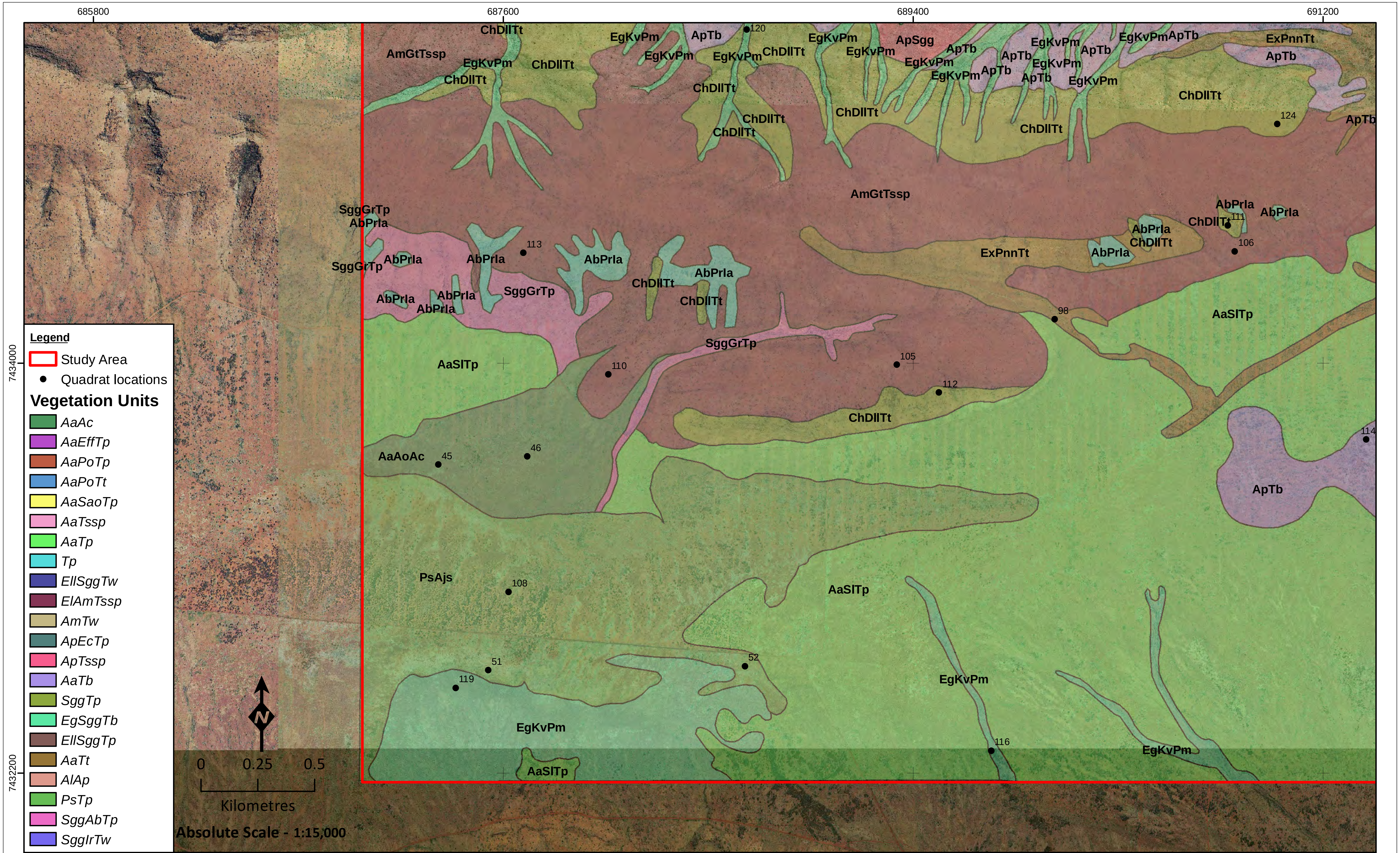


Figure: 5.19
Project ID: 1457

Drawn: CP
Date: 23/11/2012

Vegetation Units within the West Angelas Study Area
Map D5

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: CP153

A3

Vegetation Units within the West Angelas Study Area
Map D6

Figure: 5.20
Project ID: 1457

Drawn: CP
Date: 23/11/2012

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: CP153

A3

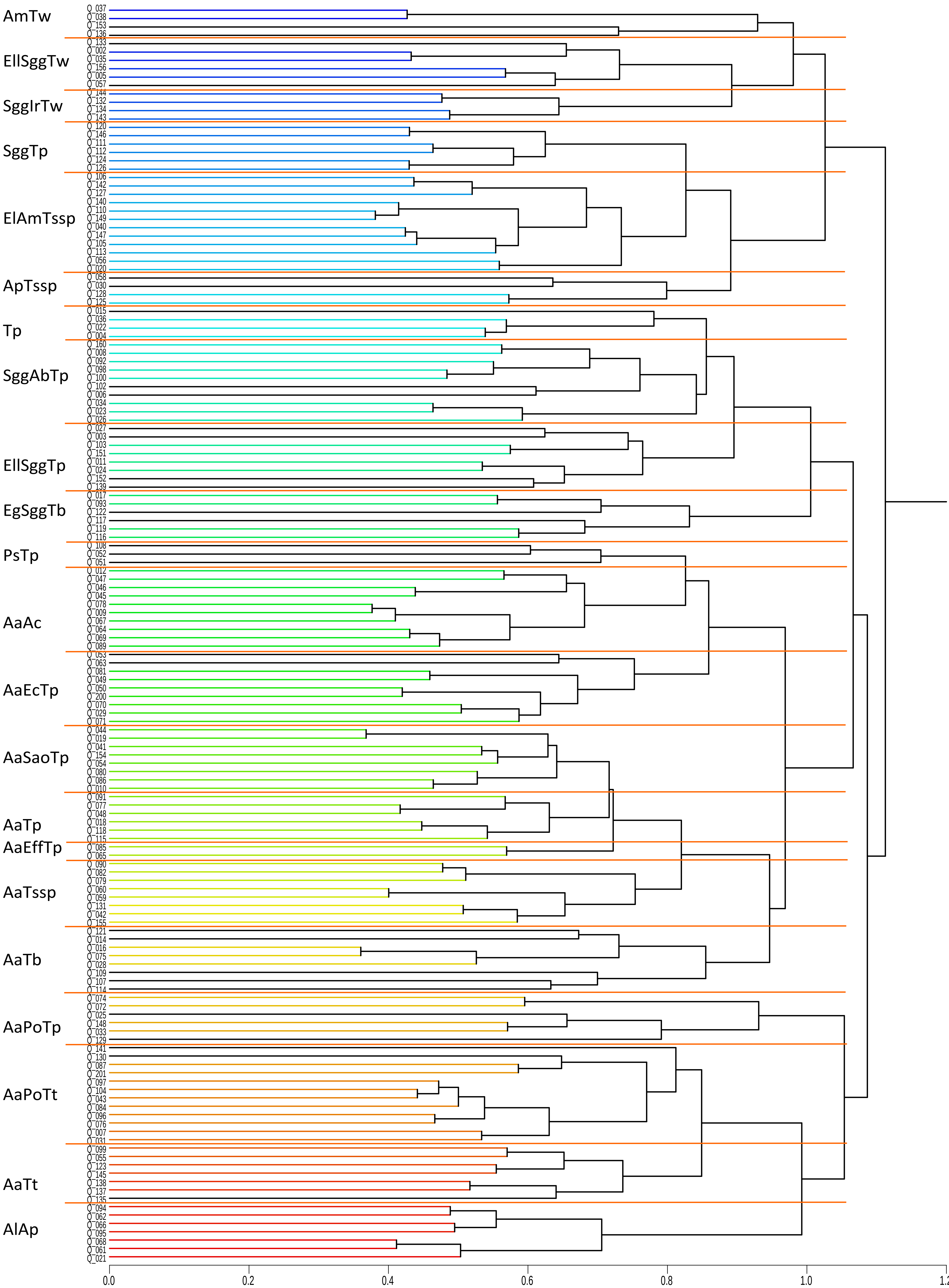


Figure 5.21 - Dendrogram of similarities between quadrats (SYSTAT)

This page has been left blank intentionally.

6 DISCUSSION

The significance of the vegetation and flora of the Study Area has been assessed at four scales: national, state, regional and local.

National significance refers to those features of the environment which are recognised under legislation as being of importance to the Australian community. Flora species and Threatened Ecological Communities (TECs) listed under the EPBC Act are regarded as nationally significant.

State significance refers to those features of the environment that are recognised under state legislation as being of importance to the Western Australian community. It includes species that are listed as Threatened under the WC Act and TECs and PECs listed by the DEC, or vegetation which supports fauna of scheduled status.

Regional significance addresses the representation of species and habitats at a biogeographical level. That is, species or habitat types that are endemic to the Hamersley sub-region or whose distributions are limited or unknown are considered regionally significant.

Vegetation and flora species are of local significance when their presence is confined to a very locallised area or a specialised habitat type that is not common in the local or regional contaxt and whose disturbance or removal may lead to local extinction.

6.1 FLORISTIC RICHNESS

Species richness is a fundamental measurement of community and regional diversity (Gotelli and Colwell 2001). It is the simplest representation of species diversity (Magurran 1988, Fowler and Cohen 1990) and is the basic indicator of diversity used for this survey.

Table 6.1 compares the floristic inventory recorded during the current survey to that recorded in other quadrat-based surveys conducted in the Pilbara. The most directly comparable survey was in 1998 of the Turee Study Area by ME Trudgen & Associates (1998) which was also a large scale survey. In ME Trudgen & Associates a larger area was survyed, encapusulating a greater range of habitats/landsystems which also resulted in a greater number of taxa recorded.

A comparison of survey intensity with that of the remaining previous projects is difficult due to the differing scales of survey sizes.

The survey intensity of the current study (0.85 quadrats/km^2) is considered adequate to the area surveyed; which is reflected in the high number of taxa recorded for its scale.

Table 6.1 – A Comparison of Floristic Richness of Study Area with Nearby Studies

Study Site	Date Surveyed	Number Quadrats Surveyed	Area (km^2)	Quadrats /km^2	Number Taxa Recorded	Number of Taxa/ km^2
Current study	June-August 2012	149	175	0.85	431	2.46
ME Trudgen & Associates 1998	May-Aug 2011	-	353	-	635	1.80
Biota 2010	May-12	37	10	3.70	262	26.20
Rio Tinto 2010	April-10	17	5	3.40	184	36.80
Biota 2006	May-04	41	19	2.16	429	22.58

6.1.1 Flora of National Significance

Lepidium catapycnon is the most significant taxon with regards to conservation status recorded within the current survey and is listed as vulnerable under the EPBC Act. Descriptions of the EPBC Act vulnerability codes can be found in Appendix D. Fourteen other collection points are lodged at the West Australian Herbarium, located within Western Australia and in close proximity each other. Based on collections from the current survey, this taxon is not abundant within the West Angelas Study Area, with 29 individuals from four locations recorded, however further targeted surveys have the potential to expand the known population. There is one known location from within the conservation estate.

Lepidium catapycnon appears to favour the outer edge of creek vegetation and rocky scree slopes that consist of orange-brown (terracotta) coloured clay-loam soil; and it is also favourable to areas where disturbance has exposed sub-soils, particularly of the calcareous type. Thirteen other locations of *Lepidium catapycnon* occur regionally within 40 km of the Study Area, suggesting that the taxon is likely to occur elsewhere within the Study Area (Figure 5.9 and Table 2.8).

The main threat to *L. catapycnon* is mining and exploration activities as its preferred habitat and the majority of recorded populations occur within mining and exploration tenements (Threatened Species Scientific Committee 2008). Processes which have been identified as potential threats to this species include roadworks, as it tends to prefer recently disturbed areas and colonises graded mining and exploration tracks (Threatened Species Scientific Committee 2008). The spread of the introduced species Ruby Dock (*Acetosa vesicaria*, which was also recorded within the Study Area) has been suggested to prevent establishment of this species in some areas (Threatened Species Scientific Committee 2008).

6.1.2 Flora of State Significance

Lepidium catapycnon, as above, is listed as Threatened (formerly Declared Rare Flora) under the WC Act.

6.1.3 Flora of Regional Significance

Thirteen Threatened and Priority Flora taxa were recorded by *ecologia* during the current survey: one Threatened (*Lepidium catapycnon*)*,* three Priority 1 species (*Aristida jerichoensis* var. *subspinulifera, Brachyscome* sp. Wanna Munna Flats (S. van Leeuwen 4662) and *Brunonia* sp. long hairs (D.E. Symon 2440), two Priority 2 species (*Aristida lazaridis* and *Eremophila forrestii* subsp. Pingandy (M.E.

Trudgen 2662), six Priority 3 species (*Acacia* aff. *subtiliformis, Indigofera* sp. Gilesii (M.E. Trudgen 15869)*, Rhagodia* sp. Hamersley (M. Trudgen 17794), *Sida* sp. Barlee Range (S. van Leeuwen 1642), *Themeda* sp. Hamersley Station (M.E. Trudgen 11431) and *Triodia* sp. Mt Ella (M.E. Trudgen 12739) and one Priority 4 species (*Goodenia nuda*). Seven of these have been previously recorded by RT (but not by the DEC) within the Study Area. Table 6.2 summarises the known distribution and abundance of these taxa from all sources, including DEC records. Based on current records of the Western Australian Herbarium (Florabase), of the 13 species recorded within Greater West Angelas, five are not represented within the conservation estate (*Aristida jerichoensis* var. *subspinulifera*, *Brachyscome* sp. Wanna Munna Flats (S. van Leeuwen 4662), *Brunonia* sp. long hairs (D.E. Symon 2440), *Indigofera* sp. Gilesii (M.E. Trudgen 15869) and *Triodia* sp. Mt Ella (M.E. Trudgen 12739). It is possible that future studies in conservation reserves may result in the discovery of these taxa within their boundaries, but as this is not a certainty, these taxa are considered more vulnerable to mining activities, as there is no locality in which a representative population of the species can be preserved.

Aristida jerichoensis var. *subspinulifera* is a Priority One taxon with six known locations within the Pilbara bioregion. It was collected within the West Angelas Study Area, with an estimated 1948 individuals from 44 locations. Previous records for this taxon indicate that it can become locally common in preferred habitat, which is present within hardpan sandplains within the Study Area.

Brunonia sp. long hairs (D.E. Symon 2440), Priority One, was collected from 10 locations in the current survey, with 20 individuals recorded. It tends to occur as scattered individuals growing on floodplains and rangelands in red sandy-clay soils. *Brunonia* sp. long hairs is taxonomically similar to *Brunonia australis sensu lato*, which is a phenotypically plastic species occurring in a wide variety of environments across Australia, and is highly variable with respect to the degree of hairiness (Carolin 1992). Current advice form the Western Australian Herbarium is that the two are likely to be amalgamated in the future (Hislop 2012, *pers. comm.*), but as this change has not yet been adopted by the Western Australian Herbarium, *Brunonia* sp. long hairs is considered distinct and regarded as Priorty Flora species for in this study.

Records of two taxa represent significant range extensions; *Corymbia zygophylla* and *Euphorbia schultzii*. These range extensions may reflect the boundary of the species habitat, but are also likely to result from a lack of collection and/or lodgement. One other taxon has been recorded for the first time in the Pilbara Bioregion: *Maireana lanosa*. It is not considered a significant range extension as it does not exceed 100 km in distance from a known record; but it expands the population occurrence in terms of regional distribution.

Table 6.2 – Regional Distribution of Priority Flora Recorded during the Current Survey

Species	Status	RT Locations in Study Area	*ecologia* Locations in Study Area	Number of Individuals Recorded	Florabase (regional) records	Bioregions of occurrence	Records within Conservation Estates	Recorded abundance elsewhere
Lepidium catapycnon	T	0	4	29	14	Pilbara	1	Isolated populations
Aristida jerichoensis var. *subspinulifera*	P1	0	44	1948	6	Pilbara	0	Locally common
Brachyscome sp. Wanna Munna Flats (S. van Leeuwen 4662)	P1	0	2	2	10	Gascoyne, Pilbara	0	Uncommon
Brunonia sp. long hairs (D.E. Symon 2440)	P1	0	10	20	3	Central Ranges, Pilbara	0	Uncommon
Aristida lazaridis	P2	1	3	23	3	Pilbara	1	Rare
Eremophila forrestii subsp. Pingandy (M.E. Trudgen 2662)	P2	1	1	1	4	Pilbara	3	Common
Acacia aff. *subtiliformis*	P3	0	3	250	11	Pilbara	1	Locally abundant
Indigofera sp. Gilesii (M.E. Trudgen 15869)	P3	37	23	232	16	Central Ranges, Pilbara, Tanami	0	Common
Rhagodia sp. Hamersley (M. Trudgen 17794)	P3	7	31	81	23	Gascoyne, Pilbara	2	Common
Sida sp. Barlee Range (S. van Leeuwen 1642)	P3	6	7	42	30	Gascoyne, Pilbara	5	Locally Common
Themeda sp. Hamersley Station (M.E. Trudgen 11431)	P3	3	7	3505	20	Pilbara	1	Locally Uncommon
Triodia sp. Mt Ella (M.E. Trudgen 12739)	P3	39	9	300	14	Pilbara	0	Locally Common
Goodenia nuda	P4	0	2	2	37	Gascoyne, Pilbara	1	Locally Common

6.2 VEGETATION OF CONSERVATION SIGNIFICANCE

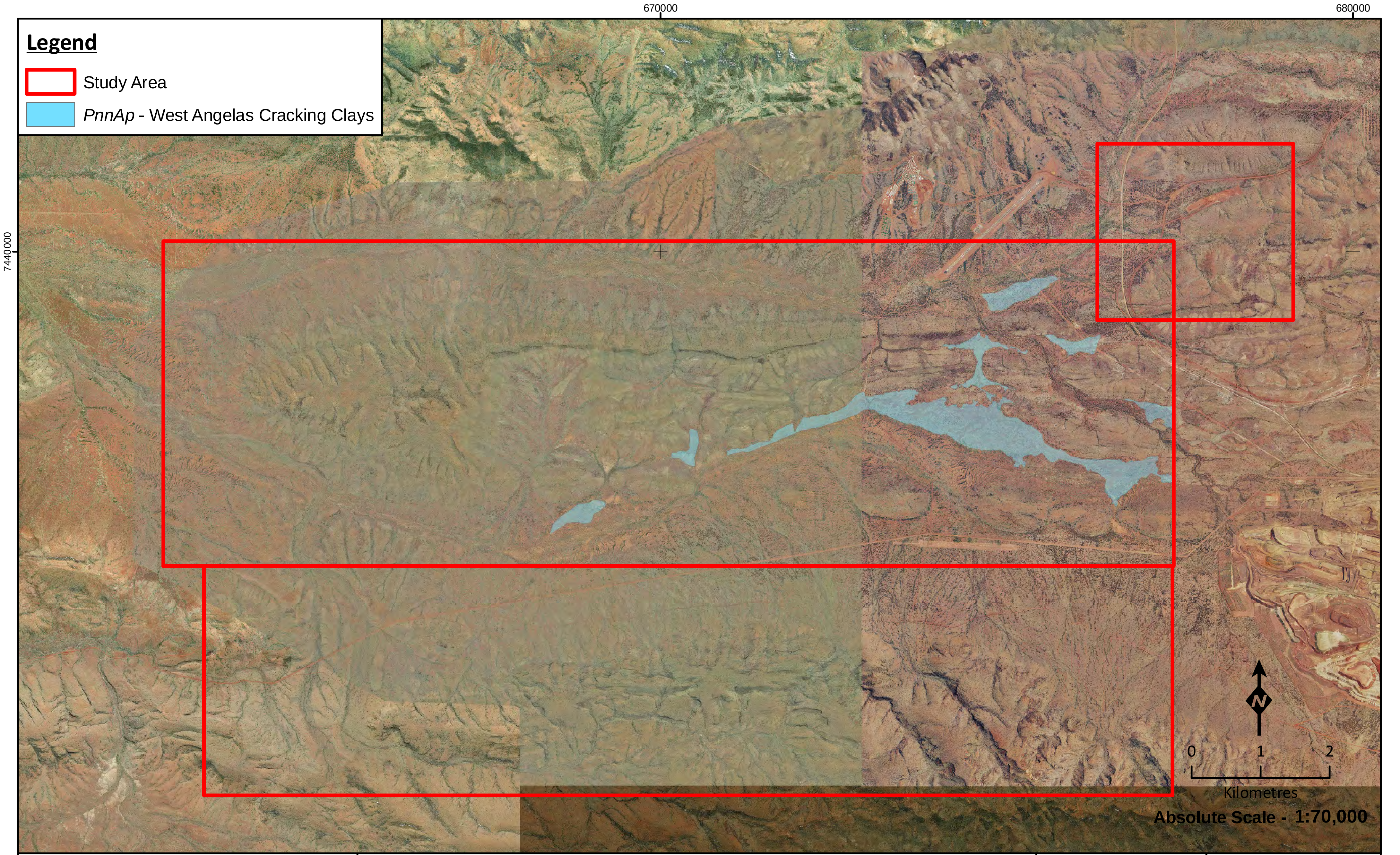
6.2.1 Vegetation of National Significance

National significance refers to those features of the environment which are recognised under legislation as being of importance to the Australian community. TECs listed under the EPBC Act are regarded as nationally significant. Currently, there are no nationally-listed TECs that occur within 40 km of the Study Area.

6.2.2 Vegetation of State Significance

State significance refers to those features of the environment that are recognised under State legislation as being of importance to the Western Australian community, in particular, communities listed as TECs or PECs. Ecological communities with insufficient information available to be considered a TEC, or which are rare but not currently threatened, are placed on the Priority list and referred to as PECs.

One Priority 1 PEC; West Angelas Cracking-Clays, occurs extensively within the Study Area (Figure 2.7). This portion of the Study Area was relatively accessible and no new areas of this community were observed outside of previously defined locations. The biggest threat to this PEC is from mining activities and associated infrastructure (Kendrick 2001). In this survey it was identified as vegetation unit *AlAp* (*Aristida latifolia, Astrebla pectinata* and *Brachyachne convergens* tussock grassland with isolated *Salsola australis, Boerhavia paludosa* and *Ptilotus nobilis* subsp. *nobilis* forbs) and covers an area of 302.23 ha (Figure 6.1). The PEC is officially described by the DEC as "open tussock grasslands of *Astrebla pectinata*, *A. elymoides*, *Aristida latifolia*, in combination with *Astrebla squarrosa* and low scattered shrubs of *Sida fibulifera*, on basalt derived cracking-clay loam depressions and flowlines". The vegetation unit *AlAp* shares the dominant grasses of *Aristida latifolia* and *Astrebla pectinata*, but the remaining species typical of the PEC were not present as dominants. However, *Sida fibulifera* was recorded in five of the seven quadrats of this vegetation type, although not in high abundances. *Astrebla elymoides* was not recorded at all within the study area. This species is known to occur in the West Angelas PEC but is difficult to identify later in the season when tussock grass heads have dicintergrated. Specifically for tussock grassland communties the survey timing may not have been optimal.



Distribution of PEC Unit *PnnAp* within the Greater West Angelas Study Area

Figure: 6.1
Project ID: 1457

Drawn: CP
Date: 23/11/2012

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: CP173

A4

Assessment of the significance at a state level of the vegetation of the Study Area is constrained by the lack of mapping across the state at a scale comparable to the mapping conducted during the current survey. The only source of vegetation mapping available across the state is that conducted by Beard (and in some instances co-authors) at a scale of 1:1,000,000. Beard attempted to map the vegetation as it would have been prior to European settlement (Beard 1976). Subsequently this dataset has been digitised and reinterpreted by the Department of Agriculture and Food to provide an estimate of current representations of these vegetation units (Shepherd *et al*. 2001). The spatial data provides an insight into the loss of vegetation as a result of settlement, its preservation within the conservation estate and its natural abundance. It has been used in the evaluation of conservation priorities for vegetation by the Northern Agricultural Region Native Vegetation Management Plan (Department of Environment and Conservation 2008), the Australian National Resources Atlas Biodiversity Assessment (Department of Sustainability Environment Water Population and Communities 2009) and the Biodiversity Audit of Western Australia (Department of Conservation and Land Management 2003).

Table 6.3 details the extent of these units within the Study Area, State and within land managed by the DEC. Table 6.3 shows that units 18 and 82 occur extensively and are relatively well represented within the conservation estate. The combined area of units 18 and 82 within the Study Area is <0.5% of their total representation and therefore the vegetation is well represented outside of the Study Area.

Table 6.3 – Representation of Shepherd Vegetation Units Within the State and Study Area

Shepherd/Beard Units		Area* in Western Australia (km^2)	Conservation Reserves		Representation Within the Study Area	
No.	**Beard Description**		**Total Area Within DEC Managed Lands** (km^2)	**Total Extent within Cons. Reserves (%)**	**Extent*** (km^2)	**Total Extent Within Study Area (%)**
18	*Acacia* open shrubland / Ptilotus mixed open forbland	199,807.3	12,440.8	6.2	89.7	0.04
82	Hummock grasslands, low tree steppe; snappy gum over *Triodia wiseana*	25,655.7	2,692.1	10.5	85.9	0.33

*The current Native Vegetation Extent dataset may contain some polygon errors such as overlaps (Department of Agriculture and Food).
** DEC Managed Lands as at June 2009

Vegetation is of conservation significance if it has "a role as a key habitat for threatened species" (EPA 2004, page 30). In this context the degree to which Priority taxa were localised to particular vegetation units was also assessed (Table 6.4).

Lepidium catapycnon (T) appears to have a high specificity to the vegetation unit *SggIrTw,* rocky hillslopes, accounting for 100% of all plants recorded. The vegetation unit *SggIrTw* is widespread in the study area (1,045 ha), and it is likely that the threatened species occurs in a particular habitat within the community. Nonetheless, this unit is significant due to the rarity of the species it supports. Similarly, *Aristida jerichoensis* var. *subspinulifera* (P1), although being present within 10 vegetation units, demonstrates a higher specificity to unit *AaTp* (sandy undulating plains) with 40.9% of locations and 57.9% of individuals recorded within this unit. *Indigofera* sp. Gilesii (M.E. Trudgen 15869) demonstrates specificity for the vegetation unit *SggTp,* rocky midslopes, with 47.8% of all locations and 31.9% of individuals recorded in this unit. *Sida* sp. Barlee Range (S. van Leeuwen 1642) favoured vegetation unit *AaPoTp,* which is only found in gullies and gorges, with 42.9% of the locations recorded in this unit.

Vegetation units *SggIrTw* (rocky hilltops) and *AaEcTp* (sandy plains) support five individual threatened and/or priority taxa. Collectively, these units account for eight out of the 13 Threatened and Priority Flora recorded in the survey: *Aristida jerichoensis* var. *subspinulifera*, *Brachyscome* sp. Wanna Munna Flats, *Brunonia* sp. long hairs, *Goodenia nuda, Indigofera* sp. Gilesii (M.E. Trudgen 15869), *Lepidium catapycnon*, *Rhagodia* sp. Hamersley and *Sida* sp. Barlee Range.

Table 6.4 – Assessment of Specificity of Priority Taxa to West Angelas Vegetation

Taxon	Status	Vegetation Unit	Records		Individuals	
			Count	%	Count	%
Lepidium catapycnon	T	*SggIrTw*	4	1.0	29	1.0
Aristida jerichoensis var. *subspinulifera*	P1	*AaAc*	5	11.4	201	10.1
		AaSaoTp	2	4.5	15	0.8
		AaTssp	1	2.3	5	0.3
		AaTp	18	40.9	1155	57.9
		AaEcTp	1	2.3	5	0.3
		AaTb	1	2.3	50	2.5
		EgSggTb	4	9.1	66	3.3
		AaTt	1	2.3	10	0.5
		PsTp	10	22.7	486	24.4
		SggIrTw	1	2.3	1	0.1
Brachyscome sp. Wanna Munna Flats (S. van Leeuwen 4662) PN	P1	*AaEcTp*	1	0.5	1	0.3
		PsTp	1	0.5	2	0.7
Brunonia sp. long hairs (D.E. Symon 2440)	P1	*AaAc*	1	10.0	5	13.9
		AaTp	1	10.0	2	5.6
		EllSggTw	1	10.0	2	5.6
		AaEcTp	4	40.0	9	25.0
		ApTssp	1	10.0	15	41.7
		EllSggTp	1	10.0	2	5.6
		SggAbTp	1	10.0	1	2.8
Aristida lazaridis	P2	*AaTp*	1	33.3	20	74.1
		AaTt	1	33.3	5	18.5
		PsTp	1	33.3	2	7.4
Eremophila forrestii subsp. Pingandy (M.E. Trudgen 2662)	P2	*AaTssp*	1	100.0	1	100.0
Acacia aff. *subtiliformis*	P3	*EllSggTw*	3	100.0	250	100.0
Indigofera sp. Gilesii (M.E. Trudgen 15869)	P3	*AaPoTp*	3	13.0	15	5.4
		ElAmTssp	2	8.7	27	9.7
		SggTp	11	47.8	89	31.9
		EgSggTp	4	17.4	45	16.1
		SggAbTp	1	4.3	2	0.7
		SggIrTw	2	8.7	101	36.2
Rhagodia sp. Hamersley (M. Trudgen 17794)	P3	*AaAc*	3	9.7	9	9.4
		AaEffTp	1	3.2	5	5.2
		AaSaoTp	2	6.5	6	6.3
		AaTp	6	19.4	13	13.5
		EllSggTw	2	6.5	4	4.2
		AaEcTp	2	6.5	8	8.3
		PsTp	8	25.8	29	30.2
		SggAbTp	1	3.2	2	2.1
		SggIrTw	6	19.4	20	20.8
Sida sp. Barlee Range (S. van Leeuwen 1642)	P3	*AaPoTp*	3	42.9	18	33.3
		EllSggTp	2	28.6	2	3.7
		SggIrTw	2	28.6	34	63.0
Themeda sp. Hamersley Station (M.E. Trudgen 11431) PN	P3	*AaTssp*	1	14.3	1000	28.3
		EllSggTw	1	14.3	500	14.1
		AlAp	5	71.4	2035	57.6
Triodia sp. Mt Ella (M.E. Trudgen	P3	*AaPoTp*	2	25.0	105	31.2

Taxon	Status	Vegetation Unit	Records		Individuals	
			Count	%	Count	%
12739)		*Tp*	2	25.0	82	24.3
		ElAmTssp	3	37.5	120	35.6
		SggTp	1	12.5	30	8.9
Goodenia nuda	P4	*AaEcTp*	1	50.0	5	71.4
		AaTb	1	50.0	2	28.6

6.2.3 Vegetation of Regional Significance

The regional inventory of the Pilbara Rangelands undertaken by Van Vreeswyk *et al.* (2004) and the Ashburton Rangelands surveyed by Payne *et al* (1982) provides some insight into the distribution of broad scale vegetation in a regional context. Of the seven land systems recorded within the Study Area, no single system represents more than one percent of the total land system mapped in the PIR and AIR. This indicates that each land system is represented well in a regional context.

6.2.3.1 Groundwater Dependent Ecosystems

Groundwater Dependent Ecosystems (GDEs) are defined by their dependence on groundwater for their continued survival. Dependence at any stage(s) during a lifecycle is considered sufficient to be defined as a GDE (Eamus 2009). Whilst some ecosystems may use groundwater reserves they may not be entirely dependent on them and hence are not defined as a GDE.

Of the four known types of GDEs described by Hatton *et al* (1998) (Terrestrial vegetation, River base flow systems, Wetlands and Aquifer/Cave ecosystems), only River base flow systems are present within the West Angelas Study Area. These ecosystems are characterised by the presence of species that have been found to rely on groundwater sources for water intake, known as phreatophytic species (Maunsell Australia 2006). Three species known to be phreatophytic are known to occur within the vicinity of the Study Area: *Eucalyptus camaldulensis* subsp. *refulgens*, *Melaleuca argentea* and *Eucalyptus victrix* (facultative phreatophyte). The degree to which *E. victrix* is an obligate phreatophyte is not well defined and may vary from location to location.

While *E. victrix* is the only phreatophytic species that was confirmed with reporoductive material within the West Angelas Study Area, *E. camaldulensis* is also known to be present along major drainage lines and is likely to occur within vegetation unit *AaPoTt*. This unit supports variable densities of *E. victrix* and therefore may be a vadophytic ecosystem (i.e. supporting plants that rely on moisture in the soil surface profile) or occasionally phreatophytic, and on this basis has been qualified as a potential GDE. Using the precautionary principles outlined in Position Statement 3, this vegetation unit is regarded as a potential GDE for this study. These vegetation units are localised to the Turee Creek area, which runs across the north of the Study Area (Figure 6.2).

6.2.3.2 Sheet-Flow Dependent Vegetation

Sheet-flow Dependent Vegetation

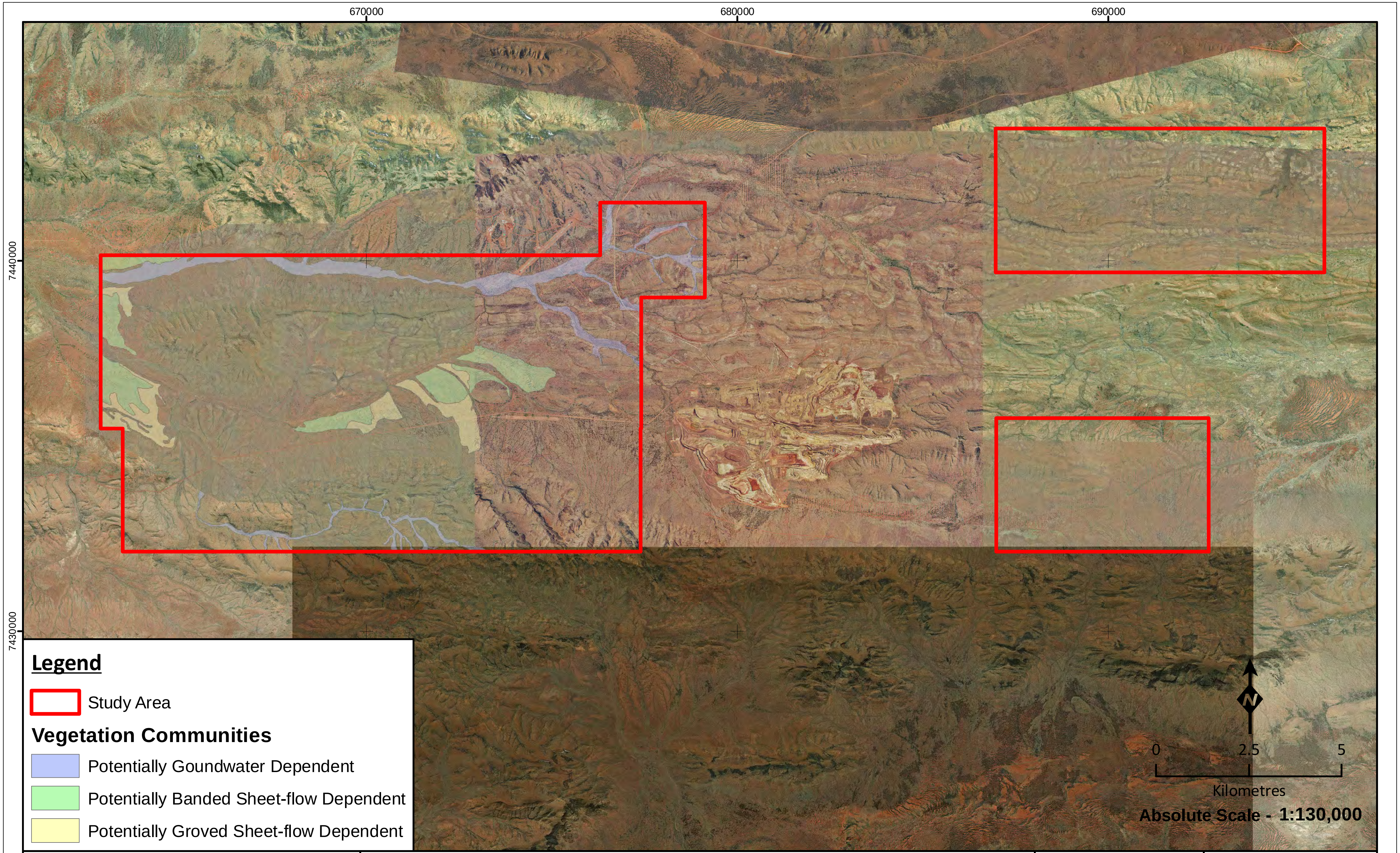
Groved and banded mulga communities growing on relatively flat plains are widely recognised as being dependent on patterns of surface water flow. The term "mulga" describes a group of *Acacia* species that were previously referred to as varieties of *Acacia aneura*. The species currently in this group include: *Acacia aneura*, *A. aptaneura*, *A. caesaneura*, *A. fuscaneura*, *A. incurvaneura*, *A. macraneura*, *A. mulganeura* and *A. pteraneura*. The species within the mulga group are bushy shrubs or trees ranging in height from 2-10 m, with considerable variation in growth form and phyllode morphology.

Sheet flows carry material (including seeds and other organic and inorganic debris) which is trapped by existing vegetation. his leads to the formation of a mosaic pattern of groves and banded vegetation with relatively bare areas in between. Thus the development and retention of mulga groves is directly dependent upon sheet flow. The different forms of Mulga (banded or groved) result from the position within the landscape and the availability of sheet flows of surface water. It is therefore thought that the susceptibility to alterations in sheet flow may also differ between banded and groved Mulga. However, both forms are potentially affected when sheet flow is disrupted within a landscape (University of Western Australia 2010).

Mulga has a root system that is adapted for taking up water from thin surface soils and has adaptations that concentrate soil water near the plant and conserve water within the plant. Consequently, the distribution and abundance of mulga is particularly influenced by soil moisture and the pattern of surface drainage (Paczkowska and Chapman, 2000). Construction can have an impact on sheet flow by creating a barrier on flow that increases the quantity of water on one side and decreases it on the other, or diverts the flow to a different area. Alterations to sheet-flow are likely to be greater in close proximity to the construction, but estimating impact is speculative and requires hydrogeological modelling. Until the shadow effect of a proposed development can be determined and the impact adequately assessed, a precautionary approach should be taken.

The diversion of sheet flow or concentration of sheet flow to particular areas is likely to deprive or waterlog soils, with deleterious impacts on mulga. Hence areas with very shallow topography, which commonly support mulga, are likely to be more susceptible. The current analysis has identified banded or groved mulga communities on shallow topography as potentially Sheet Flow Dependent Vegetation (SDV).

The vegetation unit *AaEcTp* (*Acacia* open woodland over *Eremophila* isolated shrubs over *Triodia* open grassland) supports groved and banded mulga communities and is considered likely to be sheet-flow dependent. The distribution of this unit is detailed in Figure 6.2. Other vegetation communities described in this survey are characterised by mulga species, but due to the fact that the trees do not occur in groved or banded patterns, they have not been included in the mapping.



ecologia ENVIRONMENT

Sheet-flow and Groundwater Dependent Ecosystems of the West Angelas Study Area

Figure: 6.2
Project ID: 1457

Drawn: CP
Date: 23/11/2012

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: CP150

A4

6.2.4 Vegetation of Local Significance

In a local context, vegetation can be considered significant if it is locally uncommon or is associated with habitats of local significance. Vegetation of local significance is not legislatively protected but is of conservation value if areas are restricted and have not been identified to occur outside the Study Area. The least extensive vegetation units locally are *AaEffTp* (141.54 ha) and *AmTw* (108.7 ha), which represent 0.80 % and 0.62% of the Study Area, respectively (Table 6.5).

Vegetation which supports rare flora is also considered locally significant. Vegetation units *AaPoTp, AaTp, SggTp* and *SggIrTw* all support Priority or Threatened flora. In particular, vegetation units *SggIrTw* (rocky hilltops) and *AaEcTp* (sandy plains) support five individual threatened and/or priority taxa. Collectively these units account for eight out of the 13 threatened and priority flora recorded in the survey: *Aristida jerichoensis* var. *subspinulifera*, *Brachyscome* sp. Wanna Munna Flats, *Brunonia* sp. long hairs, *Goodenia nuda, Indigofera* sp. Gilesii (M.E. Trudgen 15869), *Lepidium catapycnon*, *Rhagodia* sp. Hamersley and *Sida* sp. Barlee Range.

Table 6.5 – Local Extent of Vegetation Units within the West Angelas Study Area.

Unit	Landform	Vegetation Description	Area (ha)	% Total
AaAc	Floodplain/Drainage Line	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *Aristida contorta* sparse tussock grassland over *Pterocaulon sphacelatum* and *Ptilotus nobilis* subsp. *nobilis* isolated forbs.	505.39	2.87
AaEffTp	Rocky Midslope	*Acacia aptaneura* and *A. pruinocarpa* open woodland over sparse *Eremophila fraseri* subsp. *fraseri* and *Acacia marramamba* sparse shrubland over *Triodia pungens* sparse hummock grassland.	141.54	0.80
AaPoTp	Gully	*Acacia aptaneura* open woodland over *Ptilotus obovatus* isolated shrubs over *Themeda triandra* and *Eriachne mucronata* open tussock grassland.	319.01	1.81
AaPoTt	Sandy Floodplain	*Acacia aptaneura* open woodland over *Ptilotus obovatus* sparse shrubland over *Themeda triandra* open tussock grassland.	706.06	4.01
AaSaoTp	Floodplain/Drainage Line	*Acacia aptaneura* and *A. ayersiana* open woodland over *Senna artemisioides* subsp. *oligophylla, S. glutinosa* subsp. *glutinosa* and *Eremophila forrestii* subsp. *forrestii* sparse shrubland over *Triodia pungens* open hummock grassland.	447.27	2.54
AaTssp	Rocky Footslope	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *A. tetragonophylla, Senna glutinosa* subsp. *glutinosa* and *S. artemisioides* subsp. *oligophylla* isolated shrubs over *Triodia wiseana* and *T. pungens* open hummock grassland.	927.28	5.27
AaTp	Sandy Undulating Plain	*Acacia pruinocarpa, A. aptaneura* and *A. ayersiana* woodland over *Triodia pungens* open hummock grassland.	982.26	5.58
Tp	Rocky Midslope	*Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia pruinocarpa* isolated trees over *Senna glutinosa* subsp. *glutinosa, A. bivenosa* and *Ptilotus rotundifolius* isolated shrubs over *Triodia pungens* or *T. basedowii* or *T.* sp. Mt Ella hummock grassland.	975.86	5.55
AaTb	Rocky Hilltop	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *A. bivenosa* isolated shrubs *Triodia basedowii* and *T. pungens* open hummock grassland.	1,227.4	6.98
EllSggTw	Rocky Hilltop	*Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia aptaneura* open woodland over *Senna glutinosa* subsp. *glutinosa* and *S. artemisioides* subsp. *oligophylla* open shrubland over *Triodia wiseana* or *T. pungens* open hummock grassland	1,215.97	6.91
EllAmTssp	Rocky Hilltop	*Eucalyptus leucophloia* subsp. *leucophloia* and *E. gamophylla* open woodland over *Acacia maitlandii, A. hamersleyensis, Keraudrenia velutina* and *Senna glutinosa* subsp. *glutinosa* open shrubland over *Triodia wiseana* and/or *T. pungens* and/or *T. basedowii* open hummock grassland.	108.7	0.62
AmTw	Sandy Plain/Riverbed	*Eucalyptus leucophloia* subsp. *leucophloia* isolated trees over *Acacia maitlandii* sparse shrubland over *Triodia wiseana* and *T. longiceps* hummock grassland.	1,769.85	10.06
AaEcTp	Rocky Midslope	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *Eremophila caespitosa* and *Tribulus suberosus* isolated shrubs over *Triodia pungens* open hummock grassland	292.18	1.66
ApTssp	Gravely Plain	*Acacia pruinocarpa* and *Eucalyptus leucophloia* subsp. *leucophloia* open woodland over *Senna glutinosa* subsp. *glutinosa* and *A. maitlandii* isolated shrubs over *Triodia basedowii* or *T. pungens* or *T. wiseana* open hummock grassland.	,	8.60
SggTp	Rocky Midslope	*Eucalyptus leucophloia* subsp. *leucophloia* and *Corymbia hamersleyana* isolated trees over *Senna glutinosa* subsp. *glutinosa* and *Acacia maitlandii* sparse shrubland over *Triodia pungens* open hummock grassland.	210.6	1.20
EgSggTb	Floodplain/Drainage Line	*Eucalyptus gamophylla* and *Corymbia deserticola* subsp. *deserticola* open woodland over *Senna artemisioides* subsp. *oligophylla* and *Indigofera monophylla* sparse shrubland over *Triodia basedowii* and *T. pungens* open hummock grassland	309.52	1.76
EllSggTp	Rocky Hilltop	*Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia marramambra* open woodland over *Senna glutinosa* subsp.	2,491.87	14.16

Unit	**Landform**	**Vegetation Description**	**Area (ha)**	**% Total**
		glutinosa open shrubland over *Triodia pungens* open hummock grassland		
AaTt	Sandy Floodplain	*Acacia aptaneura* and *Eucalyptus xerothermica* woodland over *Ptilotus obovatus* isolated shrubs over *Themeda triandra* open tussock grassland	391.54	2.23
AlAp	Sandy Plain	*Aristida latifolia, Astrebla pectinata* and *Brachyachne convergens* tussock grassland with isolated *Salsola australis, Boerhavia paludosa* and *Ptilotus nobilis* subsp. *nobilis* forbs	302.23	1.72
PsTp	Sandy Plain	*Acacia aptaneura* or *A. ayersiana* open woodland over *Pterocaulon sphacelatum* and *Dysphania kalparri* sparse forbland with *Triodia pungens* open hummock grassland	174.39	0.99
SggAbTp	Gravely Plain	*Acacia pruinocarpa* and *Eucalyptus leucophloia* subsp. *leucophloia* or *Corymbia hamersleyana* isolated trees over *Senna glutinosa* subsp. *glutinosa, Acacia bivenosa* and *Gossypium robinsonii* open shrubland over *Triodia pungens* hummock grassland	1,539.18	8.75
SgglrTw	Rocky Hilltop	*Acacia inaequilatera* isolated trees over *Senna glutinosa* subsp *glutinosa* and *Indigofera rugosa* open shrubland over *Triodia wiseana* hummock grassland	1,045.87	5.94
		TOTAL	17,596.58	100

Shading highlights vegetation units considered to be of local conservation significance due to their rarity.

Shading highlights vegetation units considered to be of local conservation significance due to specificity of rare flora.

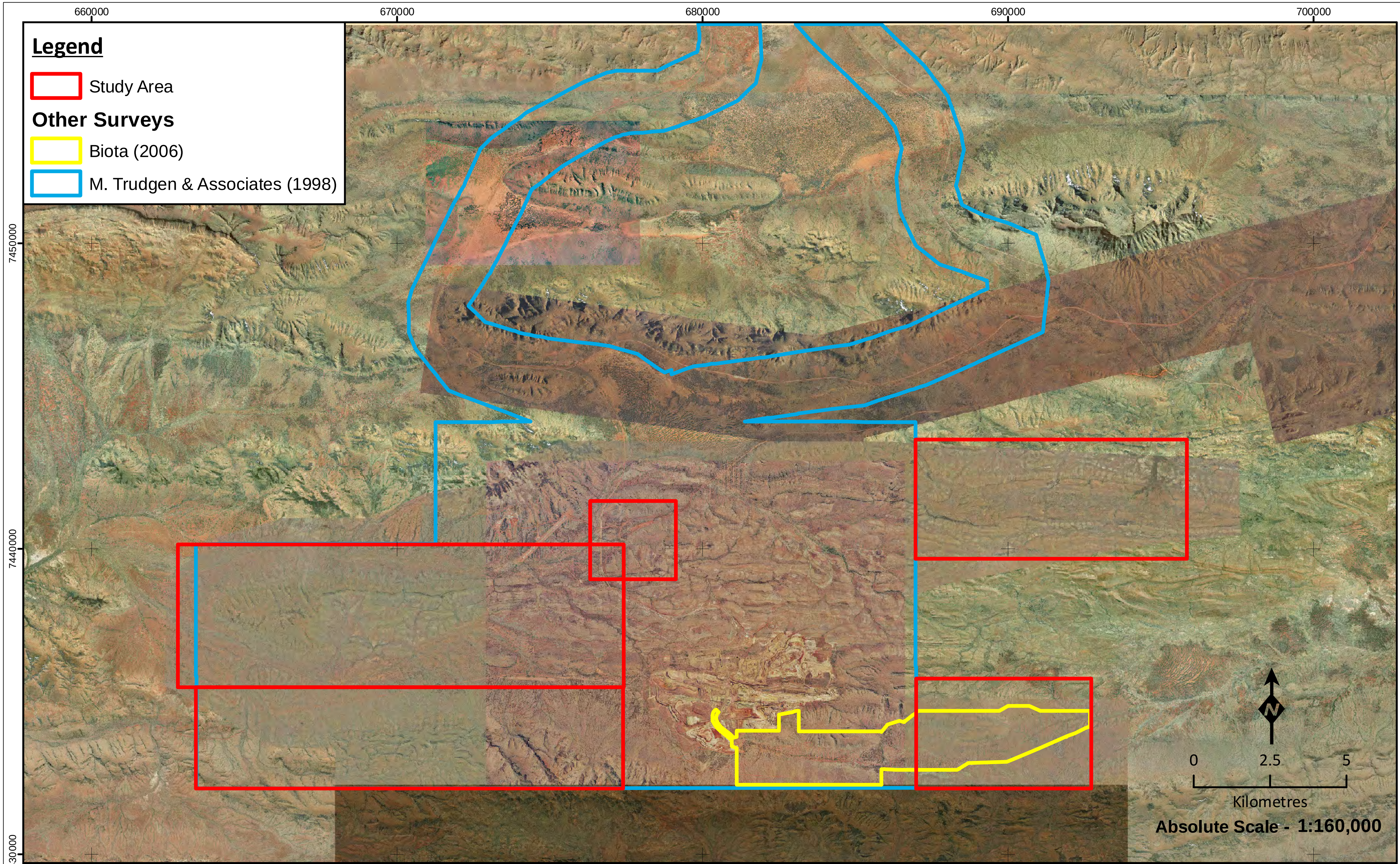
6.3 COMPARISON OF LOCAL VEGETATION COMMUNITIES

One hundred and fifty quadrats were used to define 22 vegetation units within the Study Area. All vegetation units from the ME Trudgen & Associates (1998), Biota (2006) and Biota (2010) surveys were compared with the current survey's data. The use of multivariate software SYSTAT™ was not possible in this instance as the species by site matrices were not available.

Vegetation communities were instead analysed by comparing the spatial data, vegetation descriptions and associated species to align the most similar units between each project. The species used to describe the vegetation units are paramount to the comparison, and it is possible, therefore, that the results drawn from this comparison would be different to results derived from species by site matrices data.

When vegetation units from the current survey (22 units from 150 quadrats) were compared to the ME Trudgen & Associates (1998) survey it was apparent that the quadrat density of the current survey allowed the majority of the vegetation to be mapped at a finer scale. Multiple vegetation units from the current survey were classified as the same under the broader units defined by ME Trudgen & Associates. The exception to this is the riverine/floodplain communities which were mapped at a finer scale by M. Trudgen & Associates when compared to the current survey. This is depicted in Table 6.6 where it can be seen that vegetation unit *AaPoTt* from the current survey is comparable to units 2cab, 2cac and 6/2ef from the ME Trudgen & Associates survey in the same area. The mapping boundaries of the ME Trudgen & Associates survey extended beyond that of the current survey resulting in just 29 of the 54 communities defined by ME Trudgen & Associates represented within the current Study Area. Table 6.6 depicts a comparison of units from each survey that are the most directly comparable, whilst also indicating regional distribution outside of the current Study Area.

Vegetation communities of the current survey were also co-analysed with units described in the 2006 Biota survey of Deposits E and F. The mapping of these two surveys was completed at a comparable scale and vegetation units corresponded well based on location, description and associated species as depicted in Table 6.7. Approximately 50% of the area surveyed by Biota falls outside of the current Study Area, although, of the 12 units described by Biota, 10 of the vegetation units identified in the current survey match well and are interpreted to be equivalent.



ecologia ENVIRONMENT

Location of West Angelas, M. Trudgen & Associates (1998) and Biota (2006) Study Areas

Figure: 6.3
Project ID: 1457

Drawn: CP
Date: 23/11/2012

Coordinate System
Name: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Unique Map ID: CP151

A4

Table 6.6 – Comparison of Trudgen & Associates Vegetation Units within the Study Area

***ecologia* 2012 Vegetation Units**		**ME Trudgen & Associates (1998) Vegetation Units**		**Area outside of Study Area (ha)**
Vegetation Unit	**NVIS level VI Description**	**Vegetation Unit**	**NVIS level V Description**	
AaAc	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *Aristida contorta* sparse tussock grassland over *Pterocaulon sphacelatum* and *Ptilotus nobilis* subsp. *nobilis* isolated forbs.	*6/2ef*	*Eucalyptus victrix* open woodland over *Acacia aneura* var. *longicarpa* scattered tall shrubs over *Enneapogon* sp. and *Eriachne benthamii* tussock grassland over *Eragrostis pergracilis* and *Aristida contorta*	978.55
		6adb215	*Aristida contorta* open annual tussock grassland	17.39
AaPoTp	*Acacia aptaneura* and *A. pruinocarpa* open woodland over sparse *Eremophila fraseri* subsp. *fraseri* and *Acacia marramamba* sparse shrubland over *Triodia pungens* sparse hummock grassland.	*5edaf*	*Acacia aneura* var. *longicarpa* and *Acacia rhondophloia* high shrubland over *Eremophila fraseri* ssp. *fraseri*, *Eremophila lachnocalyx* and *Eremophila exilifolia* shrubland over *Triodia pungens* open hummock grassland	0.00
AaPoTt	*Acacia aptaneura* open woodland over *Ptilotus obovatus* isolated shrubs over *Themeda triandra* and *Eriachne mucronata* open tussock grassland.	*2cab*	*Eucalyptus xerothermica* low open woodland over *Acacia pruinocarpa* scattered tall shrubs over *Maireana* spp. Scattered low shrubs over *Triodia pungens* open hummock grassland with *Themeda triandra* scattered tussock grass	81.79
		2cac	*Eucalyptus xerothermica* scattered low trees over *Acacia aneura* var. *longicarpa* and *Acacia* aff. *aneura* high shrubland over *Themeda triandra* and *Chrysopogon fallax* very open tussock grassland with *Triodia pungens* and *Triodia wiseana* scattered hummock grass	879.89
		6/2ef	*Eucalyptus victrix* open woodland over *Acacia aneura* var. *longicarpa* scattered tall shrubs over *Enneapogon* sp. and *Eriachne benthamii* tussock grassland over *Eragrostis pergracilis* and *Aristida contorta*	978.55
AaSaoTp	*Acacia aptaneura* and *A. ayersiana* open woodland over *Senna artemisioides* subsp. *oligophylla, S. glutinosa* subsp. *glutinosa* and *Eremophila forrestii* subsp. *forrestii* sparse shrubland over *Triodia pungens* open hummock grassland.	*5edacl*	*Eucalyptus gamophylla* scattered low trees over *Acacia bivenosa* and *Acacia pyrifolia* scattered tall shrubs over *Triodia pungens* and *Triodia longiceps* open hummock grassland	288.48
AaTssp	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *A. tetragonophylla, Senna glutinosa* subsp. *glutinosa* and *S. artemisioides* subsp. *oligophylla* isolated shrubs over *Triodia wiseana* and *T. pungens* open hummock grassland.	*5edb*	*Acacia ayersiana*, *Acacia* aff. *aneura* (narrow green), *Acacia* Aff. *catenulata*, *Acacia* aff. *aneura* (grey, bushy form) and *Acacia* aff. *aneura* (scythe-shaped) high open shrubland over *Maireana* spp. low scattered shrubs over *Triodia pungens* very open hummock grassland	2,762.56
AaTp	*Acacia pruinocarpa, A. aptaneura* and *A. ayersiana* woodland over *Triodia pungens* open hummock grassland.	*6adb26*	*Acacia* aff. *aneura* (scythe-shaped; MET 15,743), *A. pruinocarpa* scattered tall shrubs over *Triodia pungens* open hummock grassland with *Themeda triandra* scattered tussock grasses	231.33

ecologia **2012 Vegetation Units**		**ME Trudgen & Associates (1998) Vegetation Units**		**Area outside of Study Area (ha)**
Vegetation Unit	**NVIS level VI Description**	**Vegetation Unit**	**NVIS level V Description**	
		6adb213	*Acacia* aff. *aneura* (scythe-shaped; MET 15,743), *A. pruinocarpa*, A. aff. *aneura* (grey, bushy form; MET 15,732 high shrubland over *Eremophila forrestii* subsp. *forrestii* scattered shrubs over *Triodia pungens* very open hummock grassland	246.47
Tp	*Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia pruinocarpa* isolated trees over *Senna glutinosa* subsp. *glutinosa, A. bivenosa* and *Ptilotus rotundifolius* isolated shrubs over *Triodia pungens* or *T. basedowii* or *T.* sp. Mt Ella hummock grassland.	*5edae*	*Scaervola acacioides* open shrubland over *Triodia pungens* open hummock grassland	108.22
EllSggTw	*Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia aptaneura* open woodland over *Senna glutinosa* subsp. *glutinosa* and *S. artemisioides* subsp. *oligophylla* open shrubland over *Triodia wiseana* or *T. pungens* open hummock grassland	*8bj*	*Acacia aneura* var. *longicarpa* and *Acacia pruinocarpa* high open shrubland over *Acacia pyrifolia* and cassia *oligophylla* scattered shrubs over *Triodia wiseana* and *Triodia pungens* open hummock grassland	2,875.92
EllAmTssp	*Eucalyptus leucophloia* subsp. *leucophloia* and *E. gamophylla* open woodland over *Acacia maitlandii, A. hamersleyensis, Keraudrenia velutina* and *Senna glutinosa* subsp. *glutinosa* open shrubland over *Triodia wiseana* and/or *T. pungens* and/or *T. basedowii* open hummock grassland.	*5kdm1*	*Eucalyptus leucophloia* scattered low trees over *Triodia* aff. *basedowii* and *Triodia pungens* open hummock grassland	2,582.85
		5kdm2	*Eucalyptus leucophloia* and *Corymbia hamersleyana* low open woodland over *Acacia maitlandii* scattered shrubs over *Triodia wiseana* open hummock grassland	1,147.37
		5edac	*Eucalyptus gamophylla* scattered low trees over *Acacia bivenosa*, A. pyrifolia scattered tall shrubs over *Triodia pungens* open hummock grassland	3.35
AaEcTp	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *Eremophila caespitosa* and *Tribulus suberosus* isolated shrubs over *Triodia pungens* open hummock grassland	*6adb26*	*Acacia* aff. *aneura* and *Acacia pruinocarpa* scattered tall trees over *Maireana* spp. scattered low shrubs over *Triodia pungens* open hummock grassland with *Themeda triandra* scattered tussock grass	231.33
AaTb	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *A. bivenosa* isolated shrubs *Triodia basedowii* and *T. pungens* open hummock grassland.	*6adb232*	*Acacia aneura* var. *longicarpa* high shrubland over *Rhagodia* sp. Hamersley, *Ptilotus obovatus* open shrubland over *Digitaria brownii* scattered tussock grassland	201.59
SggTp	*Eucalyptus leucophloia* subsp. *leucophloia* and *Corymbia hamersleyana* isolated trees over *Senna glutinosa* subsp. *glutinosa* and *Acacia maitlandii* sparse shrubland over *Triodia pungens* open hummock grassland.	*5kdm3*	*Eucalyptus leucophloia* scattered low trees over *Acacia pruinocarpa* scattered tall shrubs over *Triodia pungens* open hummock grassland	209.82

***ecologia* 2012 Vegetation Units**		**ME Trudgen & Associates (1998) Vegetation Units**		**Area outside of Study Area (ha)**
Vegetation Unit	**NVIS level VI Description**	**Vegetation Unit**	**NVIS level V Description**	
EgSggTb	*Eucalyptus gamophylla* and *Corymbia deserticola* subsp. *deserticola* open woodland over *Senna artemisioides* subsp. *oligophylla* and *Indigofera monophylla* sparse shrubland over *Triodia basedowii* and *T. pungens* open hummock grassland	*5eda*	*Corymbia deserticola* scattered low trees over *Acacia bivenosa*, *Acacia pruinocarpa* and *Hakea chordophylla* scattered tall shrubs over *Cassia prunosa* scattered shrubs over *Triodia* aff. *basedowii* and *Triodia pungens* open hummock grassland	1,898.14
SggAbTp	*Acacia pruinocarpa* and *Eucalyptus leucophloia* subsp. *leucophloia* or *Corymbia hamersleyana* isolated trees over *Senna glutinosa* subsp. *glutinosa, Acacia bivenosa* and *Gossypium robinsonii* open shrubland over *Triodia pungens* hummock grassland			
EllSggTp	*Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia marramambra* open woodland over *Senna glutinosa* subsp. *glutinosa* open shrubland over *Triodia pungens* open hummock grassland	*5edad*	*Eucalyptus leucophloia* low open woodland over *Acacia* aff. *aneura*, *Acacia pruinocarpa* and *Acacia aneura* var. ?*aneura* open scrub over *Eremophila lachnocalyx* scattered shrubs over *Triodia pungens* open hummock grassland	199.33
		5kd3r	*Eucalyptus leucophloia* low open woodland over *Acacia pruinocarpa* scattered tall shrubs over *Triodia pungens* open hummock grassland.	0.00
AlAp	*Aristida latifolia, Astrebla pectinata* and *Brachyachne convergens* tussock grassland with isolated *Salsola australis, Boerhavia paludosa* and *Ptilotus nobilis* subsp. *nobilis* forbs	*8db/8dc*	*Astrebla pectinata*, *Astrebla elymoides* and *Aristida latifolia* open tussock grassland	166.06
		8dd	*Sida fibulifera* low scattered shrubs over *Astrebla squarrosa* tussock grassland	0.00

Note: Comparisons are based on aerial imagery and vegetation descriptions. Species by site matrices were not available for data comparison.

Table 6.7 – Comparison of Biota (2006) Vegetation Units within the Study Area

Ecologia 2012 Vegetation Units		Biota (2006) Vegetation Units		Area out side of Study Area (ha)
Vegetation Unit	**NVIS level VI Description**	**Vegetation Unit**	**NVIS level V Description**	
SggAbTp	*Acacia pruinocarpa* and *Eucalyptus leucophloia* subsp. *leucophloia* or *Corymbia hamersleyana* isolated trees over *Senna glutinosa* subsp. *glutinosa, Acacia bivenosa* and *Gossypium robinsonii* open shrubland over *Triodia pungens* hummock grassland	*C1*	*Eucalyptus* spp. scattered low trees over *Acacia maitlandii*, *Gossypium robinsonii*, *Petalostylis labicheoides* shrubland over *Triodia pungens* open hummock grassland and *Eriachne mucronata*, *Themeda triandra* open tussock grassland	15.97
AaTt	*Acacia aptaneura* and *Eucalyptus xerothermica* woodland over *Ptilotus obovatus* isolated shrubs over *Themeda triandra* open tussock grassland	*C2*	*Eucalyptus xerothermica* low open woodland over *Acacia maitlandii*, *Petalostylis labicheoides*, *Rulingia luteiflora* shrubland to tall shrubland over *Triodia pungens* open hummock grassland	14.86
EllAmTssp	*Eucalyptus leucophloia* subsp. *leucophloia* and *E. gamophylla* open woodland over *Acacia maitlandii, A. hamersleyensis, Keraudrenia velutina* and *Senna glutinosa* subsp. *glutinosa* open shrubland over *Triodia wiseana* and/or *T. pungens* and/or *T. basedowii* open hummock grassland.	*H1*	*Eucalyptus leucophloia* low open woodland over *Acacia maitlandii*, A. *hamersleyensis* shrubland over *Triodia pungens* (T. wiseana) mid-dense hummock grassland	210.12
SggTp	*Eucalyptus leucophloia* subsp. *leucophloia* and *Corymbia hamersleyana* isolated trees over *Senna glutinosa* subsp. *glutinosa* and *Acacia maitlandii* sparse shrubland over *Triodia pungens* open hummock grassland.	*H2*	*Acacia catenulata* low woodland over *Triodia pungens* mid-dense hummock grassland	0.00
Tp	*Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia pruinocarpa* isolated trees over *Senna glutinosa* subsp. *glutinosa, A. bivenosa* and *Ptilotus rotundifolius* isolated shrubs over *Triodia pungens* or *T. basedowii* or *T.* sp. Mt Ella hummock grassland.	*H3*	*Corymbia ferriticola*, *Eucalyptus leucophloia* low open woodland over *Triodia* sp. Mt Ella, *T. pungens* hummock grassland and *Eriachne mucronata* open tussock grassland	33.43
EllAmTssp	*Eucalyptus leucophloia* subsp. *leucophloia* and *E. gamophylla* open woodland over *Acacia maitlandii, A. hamersleyensis, Keraudrenia velutina* and *Senna glutinosa* subsp. *glutinosa* open shrubland over *Triodia wiseana* and/or *T. pungens* and/or *T. basedowii* open hummock grassland.	*H4*	*Eucalyptus leucophloia* low open woodland over *Triodia wiseana* midd-dense hummock grassland and *Themeda triandra* tussock grassland	0.00
		H5	*Eucalyptus gamophylla* low woodland over *Triodia* aff. *basedowii* (*T. pungens*) mid-dense hummock grassland	415.33
AaTp	*Acacia pruinocarpa, A. aptaneura* and *A. ayersiana* woodland over *Triodia pungens* open hummock grassland.	*M1*	*Acacia aneura* low open woodland over *Acacia bivenosa*, *Gossypium robinsonii*, *Sida* aff. *cardiophylla*, Scaevola parvifolia shrubland to low open shrubland over *Triodia* pungens, *T. schinzii* mid-dense hummock grassland	98.62

Ecologia 2012 Vegetation Units		Biota (2006) Vegetation Units		Area out side of Study Area (ha)
Vegetation Unit	**NVIS level VI Description**	**Vegetation Unit**	**NVIS level V Description**	
AaTb	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *A. bivenosa* isolated shrubs *Triodia basedowii* and *T. pungens* open hummock grassland.	*M2*	*Acacia aneura* low open woodland over *Triodia* pungens, *T.* aff. *basedowii* mid-dense hummock grassland	23.63
		M5	*Acacia aneura* low closed forest over *Triodia pungens* mid-dense hummock grassland	0.00
PsTp	*Acacia aptaneura* or *A. ayersiana* open woodland over *Pterocaulon sphacelatum* and *Dysphania kalparri* sparse forbland with *Triodia pungens* open hummock grassland	*M3*	*Acacia aneura* woodland over *Maireana* villosa, *Ptilotus obovatus*, *Rhagodia* sp. Hamersley open to low open shrubland over *Triodia* sp. Mt Ella open hummock grassland	32.00
AaAc	*Acacia aptaneura* and *A. pruinocarpa* open woodland over *Aristida contorta* sparse tussock grassland over *Pterocaulon sphacelatum* and *Ptilotus nobilis* subsp. *nobilis* isolated forbs.	*M4*	*Acacia aneura*, *A. pruinocarpa* low closed forest to low woodland over *Eremophila forrestii*, *E. longifolia*, *Ptilotus obovatus*, *Rhagodia* sp. Hamersley low open shrubland to open shrubland over *Triodia pungens* open hummock grassland	223.85

Note: Comparisons are based on aerial imagery and vegetation descriptions. Species by site matrices were not available for data comparison

6.4 LAND DEGREDATION ANANYSIS

6.4.1 Erosion

The seven land systems present within the Study Area as mapped by Payne *et al* (1982) in the Regional Inventory of the Ashburton Rangelands and by Van Vreeswyk *et al*. (2004) in the Regional Inventory of the Pilbara Rangelands are categorised as being quite resistant to the processes of erosion (Van Vreeswyk *et al.* 2004). Van Vreeswyk *et al*. (2004) and Payne *et al* (1982) assessed the percentage of each land system that has been affected by erosion (Table 6.8). Each of the seven land systems have been subject to little or no erosion, the worst affected being the Wannamunna Land System with both minor (3%) and moderate (2%) erosion present in low levels. This data is further supported by observations made in the field where no serious erosion was observed in the Study Area.

Table 6.8 – Erosion as Assessed by Van Vreeswyk *et al*. (2004) and Payne *et al* (1982)

Land System	Description	No Erosion	Minor Erosion	Moderate Erosion
Boolgeeda	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands.	100%	0%	0%
Egerton	Dissected hardpan plains supporting mulga shrublands and hard spinifex hummock grasslands.	100%	0%	0%
Elimunna	Stony plains on basalt supporting Sparse *Acacia* and cassia shrublands and patchy tussock grasslands.	99%	1%	0%
Newman	Rugged jaspilite plateaux, ridges and mountains supporting hard.	99%	0.5%	0.5%
Platform	Dissected slopes and raised plains supporting hard spinifex grasslands.	100%	0%	0%
Rocklea	Basalt hills, plateaux, lowers slopes and minor stony plains supporting hard spinifex (and occasionally soft spinifex) grasslands.	100%	0%	0%
Wannamunna	Hardpan plains and internal drainage tracts supporting mulga shrublands and woodlands (and occasionally eucalypt woodlands).	95%	3%	2%

6.4.2 Spread of Weeds

Vegetation condition ratings within the Study Area were high, with 87% of assessed quadrats being in either excellent or very good condition (Figure 5.1) with the presence of weeds within the Study Area being minimal. This is reflected by the absence of livestock as the Study Area is not located on pastoral land. Figure 4.3 demonstrates that higher densities of weeds were recorded along the rivers and creeks. Drainage lines are a major source of transportation for the most prevalent weed species in the region: *Acetosa vesicaria, Bidens bipinnata, Cenchrus ciliaris* and *Acetosa vesicaria.* These species are likely to continue to spread naturally along the river system, but alterations to flow in both volume and direction will likely facilitate the spread further.

There was also evidence to suggest that *Bidens bipinnata* is also being spread to a small degree by native fauna. *Acetosa vesicaria* was sighted growing within the 3 m buffer of the rail corridor in Deposit G. Track work and other maintenance in these areas could facilitate the spread of this species via vehicles or personnel, as well as soil disturbance. Control methods such as brush-down procedures should be used when working in these areas of the rail.

6.4.3 Previous Disturbance

Previous disturbance within the Study Area was observed to be predominantly from clearing pertaining to previous exploration lines, drill pads, access tracks and associated infrastructure. Deposit G is the most disturbed as part of the rail and the main access road into the West Angelas Mine are within this site. Apart from the primary disturbance from the initial clearing footprint of this infrastructure, dust is also another source of disturbance in the area. West Angeles Mine currently has management plans in place to help control the impact and spread of dust.

6.5 SURVEY LIMITATIONS AND CONSTRAINTS

According to the EPA Guidance Statement 51; *Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessments in Western Australia* (Environmental Protection Authority 2004), vegetation and flora surveys may be limited by several aspects. An assessment of these aspects with regard to this study is detailed in Table 6.9.

Table 6.9– Flora and Vegetation Survey Limitations

Aspect	Constraint	Comment
Sources of information and availability of contextual information (i.e. pre-existing background versus new material)	Minor	Broad scale (1:1,000,000) mapping by Shepherd *et al* (2006) based on the mapping by Beard (1975) is available. More recently the land systems (Van Vreeswyk *et al*. 2004) have been mapped which show also broad scale regional information on vegetation communities based on land systems. Information at a local context was available with the Biota Environmental Sciences surveys in 2006 and 2010 (Biota 2006, Biota 2010), and ME Trudgen & Associates (1998), providing regional data at comparable scale of survey intensity and vegetation mapping. The lack of Species x Site matrices resulted in the need for these surveys to be compared based on their descriptions and spatial position and not on cluster analysis.
The scope (i.e. what life forms were sampled)	Nil	The vascular flora of the Study Area was sampled in accordance with Guidance Statement 51.
Proportion of flora collected and identified (based on sampling, timing and intensity)	Minor	Species accumulation curve analysis suggests that 86-88% of the taxa expected to be present were recorded. Survey timing was considered optimal, with a high proportion of plants flowering and >99% of all collections fully identified. Twenty-four of a total 6,003 specimens were not identified to species level. However, access limitations in some areas may have reduced the total inventory to a minor degree.
Completeness and further work which might be needed *(*e.g. was the relevant area fully surveyed)	Minor	The quadrat density of 1 quadrat per 1.17 km^2 is considered adequate. Quadrats were broadly distributed throughout the Study Area, however the several areas where no vehicular access was possible and distances were too great to be achieved on foot, or where the steepness of escarpments precluded access. All vegetation units were represented with at least two quadrats and in many cases more than 10. Targeted surveys performed during the second were extremely beneficial to the survey with multiple locations of Priority Flora recorded.
Mapping reliability	Minor	For some areas, the aerial imagery as of lo resolution and was therefore blurry in its appearance, making defining vegetation community boundaries difficult at times. The number and distribution of quadrats is considered adequate for definition of vegetation within most areas, however since access to some areas was restricted, it remains possible that additional community types could be defined.
Timing/weather/season/cycle	Minor	The timing of the survey was optimal for most of the flora species with most recorded to be flowering or fruiting. However some of the tussock grasses collected were dry and lacked reproductive material, which resulted in challenges in completing identifications of these taxa. A survey carried out shortly following summer rains did not take place, which may have precluded the collection of some annuals and grasses.
Disturbances (e.g. fire, flood, accidental human intervention)	Nil	There were no natural or man-made interventions that constrained the survey.

Aspect	Constraint	Comment
Intensity (in retrospect, was the intensity adequate?)	Minor	The species accumulation curve suggests that 86-88 % of species present were collected. All vegetation units were mapped were represented by at least two quadrats. Quadrats were distributed across the Study Area at a density of 1 quadrat per 1.17 km^2; however the distribution was limited in some areas due to access constraints.
Resources	Nil	A total of 60 person-days were expended across the survey period. There was sufficient time to access all areas that could be accessed using a vehicle and foot traverses.
Access problems	Moderate	The majority of the survey area was easily accessed. However, the absence and poor condition of some tracks, as well as some vital tracks being recently rehabilitated required an investment of time and effort for accessing some areas on foot. The southeast and northwest areas of the larger study polygon and the centre-southeast area of the smaller study polygon were the least sampled areas due to access difficulties. Aerial imagery and landform mapping for this area indicate that the vegetation communities in the areas where access was restricted have been sampled elsewhere.
Experience levels (e.g. degree of expertise in plant identification to taxon level)	Nil	The Project was overseen by the Biological Sciences Manager who has over 14 years experience in biological assessments within Western Australia, the project manager and field leader have six and two years experience, respectively. Other botanists engaged in survey work have between 1 and 5 years experience in biological surveys. The two taxonomists responsible for identifications both have Doctorates in botanical taxonomy and have completed identifications for multiple, large scale projects within the Pilbara.

7 CONCLUSION

7.1 FLORA

Flora sampling adequacy was estimated using species accumulation curve analysis and extrapolation. Using this analysis it is estimated that between 86% and 88 % of the taxa present were recorded.

Four specimens of the EPBC Act and the WC Act (Declared Rare Flora) listed *Lepidium catapycnon* were collected opportunistically from four locations within Greater West Angelas. A total of 29 individuals were recorded. The presence of preferred habitats beyond the location where the four specimens were collected suggest that it is possible that more individuals could be present given that access to some areas was limited during the survey. Further targeted surveys would be advantageous in defining the population.

Of the thirteen Threatened and Priority Flora taxa, five are not represented within conservation estates (*Aristida jerichoensis* var. *subspinulifera*, *Brachyscome* sp. Wanna Munna Flats (S. van Leeuwen 4662), *Brunonia* sp. long hairs (D.E. Symon 2440), *Indigofera* sp. Gilesii (M.E. Trudgen 15869) and *Triodia* sp. Mt Ella (M.E. Trudgen 12739). These taxa are considered to be of higher conservation significance, irrespective of the fact that *Aristida jerichoensis* var. *subspinulifera* (P1), *Indigofera* sp. Gilesii (M.E. Trudgen 15869) (P3) and *Triodia* sp. Mt Ella (M.E. Trudgen 12739) (P3) are relatively widespread within the Study Area.

Records from the survey include one bioregional extension, *Maireana lanosa*, although only 44 km north of the known population. Records of two taxa represent range extensions; *Corymbia zygophylla* and *Euphorbia schultzii*. These taxa represent the extent of the distribution of their species and are also of conservation significance.

7.2 VEGETATION

One Priority 1 PEC, West Angelas Cracking-Clays, occurs within the Study Area. In this survey it was identified as vegetation unit *AlAp* (*Aristida* and *Astrebla* grassland). The boundaries of the larger area depicted in Figure 6.1 have been ground-truthed in the field.

Vegetation units *SggIrTw* (rocky hilltops) and *AaEcTp* (sandy plains) support five individual threatened and/or priority taxa including *Lepidium catapycnon* (T). Collectively these units account for eight out of the 13 threatened and priority flora recorded. This identifies the significance of unit *SggIrTw* (where *L. catapycnon* occurs), whist also indicating that unit *AaEcTp* is of particular conservation significance.

Vegetation unit *AaPoTt* supports variable densities of *E. victrix* and therefore may be a vadophytic ecosystem (i.e. supporting plants that rely on moisture in the soil surface profile) or occasionally phreatophytic (i.e. supporting plants that rely on groundwater reservoirs), and on this basis has been qualified as a potential GDE. The vegetation unit *AaEcTp* (*Acacia* open woodland over *Eremophila* isolated shrubs over *Triodia* open grassland) supports groved and banded mulga communities and is considered likely to be sheet-flow dependent. Both of these units are sensitive to changes in hydrology.

The least extensive vegetation units locally are *AaEffTp* (141.54 ha) and *AmTw* (108.7 ha), which represent 0.80 % and 0.62% of the Study Area respectively. These units are considered to be of local significance due to their limited representation in the local context.

This page has been left blank intentionally

8 STUDY TEAM

The flora and vegetation assessment in this report was planned, coordinated and executed by:

Project Staff and Qualifications		
Kellie Honczar	BSc	Principal Ecologist
Renee Young	PhD (Botany)	Senior Botanist
Andrew Craigie	PhD (Botany)	Taxonomist and Botanist
Udani Sirisena	PhD (Botany)	Taxonomist
Matthew Macdonald	PhD (Botany)	Senior Botanist
Christopher Parker	BSc	Botanist
Heather Broad	BSc	Botanist

Licences - "Licence to Take Flora for Scientific Purposes"		
The vegetation and flora assessment described in this report was conducted under the authorisation of the following licences issued by the DEC:		
	Permit Number	**Valid Until**
Matthew Macdonald	SL 009996	30/04/2013
Andrew Craigie	SL 009990	30/04/2013
Christopher Parker	SL 009992	30/04/2013
Michelle Holmes	SL009998	30/04/2013
Matthew Macdonald	SL009996	30/04/2013
Heather Broad	SL009976	30/04/2013

This page has been left blank intentionally

9 REFERENCES

2012. Weeds of National Significance Strategies, Resources and Comments. Accessed November 2011. http://www.weeds.org.au/WoNS/.

Australian Government Department of Sustainability, E., Water, Population and Communities,. 2012. Interim Biogeographic Regionalisation for Australia (IBRA), Version 7. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra, ACT.

Beard, J. S. 1975. The vegetation of the Pilbara region. Explanatory notes to map sheet 5 of vegetation survey of Western Australia: Pilbara. University of Western Australia Press, Nedlands.

Beard, J. S. 1976. Vegetation survey of Western Australia - Murchison 1:1 000 000 vegetation series. University of Western Australia Press, Perth.

Biota. 2006. Vegetation and Flora Survey of West Angelas Deposits E and F.

Biota. 2010. A Flora and Vegetation Survey of the Proposed West Angelas Gas-Fired Power Station and Pipeline Corridor.

BOM. 2011. Bureau of Meteorology. Accessed December 2011. http://www.bom.gov.au.

Carolin, R. C. 1992. Goodeniaceae. pp. 149-166 *in* George, A. S., ed. Flora of Australia. Australian Government Publisinh Service, Canberra.

Colwell, R. K. 2009. EstimateS: Statistical estimation of species richness and shared species from samples. Version 8. University of Connecticut, USA, Connecticut.

Department of Agriculture and Food. 1976. Agriculture and Related Resources Protection Act 1976, as at Jan 2011 - Declared Plants. The Agriculture Protection Board, Department of Agriculture and Food, Western Australia.

Department of Conservation and Land Management. 1999. Environmental Weed Strategy for Western Australia. Department of Conservation and Land Management, Government of Western Australia, Western Australia.

Department of Conservation and Land Management, ed. 2003. A Biodiversity Audit of Western Australia's 53 Biogeographic Subregions in 2002. Department of Conservation and Land Management, Perth, Western Australia.

Department of Environment and Conservation. 2008. Native vegetation management plan: Northern Agricultural Region. Department of Environment and Conservation, Perth, Western Australia.

Department of Environment and Conservation. 2012. Priority Ecological communities fr Western Australia. Version 17. Species and Communities Branch, Department of Environment and Conservation, Western Australia.

Department of Environment and Water Resources. 2012. NVIS - National Vegetation Information System. Department of Environment and Water Resources, Canberra.

Department of Sustainability Environment Water Population and Communities. 2009. Biodiversity Assessment - Western Australia. Accessed November 2011. http://www.anra.gov.au/topics/vegetation/assessment/wa/index.html.

Eamus, D. 2009. Identifying groundwater dependent ecosystems: A guide for land and water managers. Land and Water Australia, Canberra, Australia.

Environmental Protection Authority. 2002. Terrestrial Biological Surveys as an element of Biodiversity Protection. Position Statement No. 3. Environmental Protection Authority, Perth, Western Australia.

Environmental Protection Authority. 2004. Terrestrial flora and vegetation surveys for environmental impact assessment in Western Australia. Guidance for the Assessment of Environmental Factors No. 51. Environmental Protection Authority, Western Australia.

Environmental Protection Authority, Government of Western Australia. 2004. Guidance for the Assessment of Environmental Factors No. 51: Terrestrial flora and vegetation surveys for environmental impact assessment in Western Australia.

Hatton, T., Reece, P., Taylor, P., and McEwan, K. 1998. Does leaf water efficiency vary among eucalyptus in water-limited environemnts? Tree Physiology. 18:529-536.

Hickman, A. H. and Kranendonk, M. 2008. Compilers, Geology, in Geological Survey of Western Australia, Pilbara 1:100 000 Geological Information Series, 2008 update: Geological Survey of Western Australia.

Hislop, M. 2012, *pers. comm.*

Hussey, B. M. J., Keighery, G. J., Dodd, J., Lloyd, S. G., and Cousens, R. D. 2007. Western Weeds. Second Edition. The Plant Protection Society of Western Australia and Agriculture Western Australia, Victoria Park.

Johnson, S. L. and Wright, A. H. 2001. Central Pilbara Groundwater Study. pp. 102. Hydrogeological Record Series. Report HG 8. Water and Rivers Commission, Western Australia.

Kendrick, P. 2001. Pilbara 3 (PIL3 - Hamersley subregion). A Biodiversity Audit of Western Australia's 53 Biogeographic Subregions in 2002. Department of Conservation and Land Management, Perth, Western Australia.

Kendrick, P. and McKenzie, N. 2001. Pilbara 1 (PIL1 - Chichester subregion). A Biodiversity Audit of Western Australia's 53 Biogeographic Subregions. Department of Conservation and Land Management, Perth, Western Australia.

Maunsell Australia. 2006. Pit dewatering and vegetation monitoring plan. Iron ore mine and downstream processing, Cape Preston, Western Australia. Unpublished report prepared for Mineralogy Pty Ltd.

ME Trudgen & Associates. 1998. Flora and Vegetation Surveys of Orebody A & B in the West Angelas Hill Area.

Payne, A. L., Mitchell, A. A., and Holman, W. F. 1982. An inventory and condition survey of rangelands in the Ashburton River Catchment, Western Australia. Technical Bulletin No 62. Western Australian Department of Agriculture.

Pilbara Development Commision. 2009. Available at: www.pdc.wa.gov.au.

PlantNET. 2013. New South Wales Flora Online. Accessed January 2013. http://plantnet.rbgsyd.nsw.gov.au/search/simple.htm.

Shepherd, D. P., Beeston, G. R., and Hopkins, A. J. M. 2001. Native vegetation in Western Australia: Extent, type and status. Technical Report 249. Department of Agriculture, South Perth, Western Australia.

Threatened Species Scientific Committee. 2008. Commonwealth Conservation Advice on *Lepidium catapycnon*. Threatened Species Scientific Committee.

Van Vreeswyk, A. M. E., Payne, A. L., Leighton, K. A., and Hennig, P. 2004. An inventory and condition survey of the Pilbara region, Western Australia. Technical Bulletin No. 92. Department of Agriculture, Western Australia.

Western Australian Herbarium. 1998-2012. FloraBase - The Western Australian Flora. Department of Environment and Conservation. Available at: http://florabase.dec.wa.gov.au/.

Western Australian Herbarium. 1998-2013. FloraBase - The Western Australian Flora. Department of Environment and Conservation. Available at: http://florabase.dec.wa.gov.au/.

This page has been left blank intentionally

APPENDIX A EPBC AND DEC CONSERVATION CATEGORIES

This page has been left blank intentionally

Table D.1 – Definition of codes for Threatened Ecological Communities

Code	Definition
PD: Presumed Totally Destroyed	An ecological community that has been adequately searched for but for which no representative occurrences have been located. The community has been found to be totally destroyed or so extensively modified throughout its range that no occurrence of it is likely to recover its species composition and/or structure in the foreseeable future. An ecological community will be listed as presumed totally destroyed if there are no recent records of the community being extant
CR: Critically Endangered	An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or that was originally of limited distribution and is facing severe modification or destruction throughout its range in the immediate future, or is already severely degraded throughout its range but capable of being substantially restored or rehabilitated. An ecological community will be listed as Critically Endangered when it has been adequately surveyed and is found to be facing an extremely high risk of total destruction in the immediate future.
EN: Endangered	An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or was originally of limited distribution and is in danger of significant modification throughout its range or severe modification or destruction over most of its range in the near future. An ecological community will be listed as Endangered when it has been adequately surveyed and is not Critically Endangered but is facing a very high risk of total destruction in the near future.
VU: Vulnerable	An ecological community that has been adequately surveyed and is found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not yet been assured and/or a community that is still widespread but is believed likely to move into a category of higher threat in the near future if threatening processes continue or begin operating throughout its range. An ecological community will be listed as Vulnerable when it has been adequately surveyed and is not Critically Endangered or Endangered but is facing a high risk of total destruction or significant modification in the medium to long-term future.

Table D.2 – Definition of codes for Priority Ecological Communities (DEC)

Code	Definition
P1: Priority One	Ecological communities with apparently few, small occurrences, all or most not actively managed for conservation (e.g. within agricultural or Pastoral lands, urban areas, active mineral leases) and for which current threats exist. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range.
P2: Priority Two	Communities that are known from few small occurrences, all or most of which are actively managed for conservation (e.g. within national parks, conservation parks, nature reserves, State forest, unallocated Crown land, water reserves, etc.) and not under imminent threat of destruction or degradation. Communities may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under threat from known threatening processes.
P3: Priority Three	(i) Communities that are known from several to many occurrences, a significant number or area of which are not under threat of habitat destruction or degradation or: (ii) Communities known from a few widespread occurrences, which are either large or within significant remaining areas of habitat in which other occurrences may occur, much of it not under imminent threat, or; (iii) Communities made up of large, and/or widespread occurrences that may or not be represented in the reserve system, but are under threat of modification across much of their range from processes such as grazing by domestic and/or feral stock, and inappropriate fire regimes. Communities may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and/or are not well defined, and known threatening processes exist that could affect them.
P4: Priority Four	Ecological communities that are adequately known, Rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list. These communities require regular monitoring. (a) Rare. Ecological communities known from few occurrences that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These communities are usually represented on conservation lands. (b) Near Threatened. Ecological communities that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable. (c) Ecological communities that have been removed from the list of threatened communities during the past five years. P5: Priority Five Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.
P5: Priority Five	Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.

Table D.3 – Definition of Threatened Flora Species Categories under the *EPBC Act*

Conservation Code	Definition
Extinct	A species is extinct if there is no reasonable doubt that the last member of the species has died.
Extinct in the wild	A species is categorised as extinct in the wild if it is only known to survive in cultivation, in captivity or as a naturalised population well outside its past range; or if it has not been recorded in its known/expected habitat, at appropriate seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.
Critically Endangered	The species is facing an extremely high risk of extinction in the wild in the immediate future.
Endangered	The species is likely to become extinct unless the circumstances and factors threatening its abundance, survival or evolutionary development cease to operate; or its numbers have been reduced to such a critical level, or its habitats have been so drastically reduced, that it is in immediate danger of extinction.
Vulnerable	Within the next 25 years, the species is likely to become endangered unless the circumstances and factors threatening its abundance, survival or evolutionary development cease to operate.
Conservation Dependent	The species is the focus of a specific conservation program, the cessation of which would result in the species becoming vulnerable, endangered or critically endangered within a period of five years.

Table D.4 – Definition of Declared Rare and Priority Flora Categories under the *WC Act*

Conservation Code	Definition
DRF	Declared Rare Flora-Extant Taxa. Taxa which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such.
P1: Priority One	Poorly Known Taxa. Taxa which are known from one or a few (generally <5) populations which are under threat, either due to small population size, or being on lands under immediate threat, e.g. road verges, urban areas, farmland, active mineral leases, etc., or the plants are under threat, e.g. from disease, grazing by feral animals, etc. May include taxa with threatened populations on protected lands. Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.
P2: Priority Two	Poorly Known Taxa. Taxa which are known from one or a few (generally <5) populations, at least some of which are not believed to be under immediate threat (i.e. not currently endangered). Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.
P3: Priority Three	Poorly Known Taxa. Taxa which are known from several populations, and the taxa are not believed to be under immediate threat (i.e. not currently endangered), either due to the number of known populations (generally >5), or known populations being large, and either widespread or protected. Such taxa are under consideration for declaration as 'rare flora' but are in need of further survey.
P4: Priority Four	Rare Taxa. Taxa which are considered to have been adequately surveyed and which, whilst being rare (in Australia), are not currently threatened by any identifiable factors. These taxa require monitoring every 5-10 years.

This page has been left blank intentionally

APPENDIX B COORDINATES OF FLORA QUADRATS

This page has been left blank intentionally

Quadrat	Botanist	Date	Zone	Easting	Northing
2	Heather Broad	15/07/2012	50	677155	7439160
3	Christopher Parker	11/07/2012	50	664250	7434166
4	Renee Young	23/08/2012	50	676312	7432796
5	Matthew Macdonald	22/08/2012	50	677245	7438185
6	Heather Broad	15/07/2012	50	676964	7439410
7	Andrew Craigie	15/07/2012	50	677143	7440336
8	Renee Young	15/07/2012	50	677224	7439706
9	Renee Young	15/07/2012	50	676777	7439888
10	Andrew Craigie	15/07/2012	50	677202	7440980
11	Renee Young	11/07/2012	50	664936	7432362
12	Heather Broad	12/07/2012	50	669588	7436085
14	Heather Broad	11/07/2012	50	666335	7435014
15	Christopher Parker	11/07/2012	50	666386	7434420
16	Matthew Macdonald	23/08/2012	50	665255	7435767
17	Renee Young	11/07/2012	50	666127	7435443
18	Christopher Parker	13/07/2012	50	670256	7440041
19	Andrew Craigie	13/07/2012	50	670827	7440121
20	Heather Broad	11/07/2012	50	666544	7432889
21	Andrew Craigie	12/07/2012	50	668832	7436351
22	Renee Young	23/08/2012	50	675401	7433583
23	Heather Broad	23/08/2012	50	676745	7433348
24	Andrew Craigie	12/07/2012	50	665179	7437844
25	Heather Broad	11/07/2012	50	666551	7432511
26	Heather Broad	22/08/2012	50	665892	7437188
27	Andrew Craigie	12/07/2012	50	665237	7437562
28	Heather Broad	12/07/2012	50	663809	7437790
29	Christopher Parker	12/07/2012	50	663304	7437192
30	Andrew Craigie	23/08/2012	50	668967	7433839
31	Andrew Craigie	23/08/2012	50	666346	7432772
33	Matthew Macdonald	23/08/2012	50	668560	7433940
34	Heather Broad	23/08/2012	50	676579	7433252
35	Christopher Parker	13/07/2012	50	673632	7438909
36	Renee Young	13/07/2012	50	670777	7438782
37	Heather Broad	14/07/2012	50	687029	7442744
38	Heather Broad	14/07/2012	50	687256	7442411
40	Renee Young	14/07/2012	50	687384	7441660
41	Heather Broad	16/07/2012	50	687019	7440818
42	Matthew Macdonald	22/08/2012	50	676916	7438381
43	Andrew Craigie	13/07/2012	50	669629	7439904
44	Andrew Craigie	13/07/2012	50	672747	7439755
45	Heather Broad	10/07/2012	50	687314	7433554
46	Heather Broad	10/07/2012	50	687705	7433591
47	Andrew Craigie	22/08/2012	50	676625	7435967
48	Heather Broad	23/08/2012	50	673159	7435134
49	Renee Young	22/08/2012	50	670111	7435914
50	Christopher Parker	13/07/2012	50	673669	7437233
51	Christopher Parker	10/07/2012	50	687533	7432652
52	Andrew Craigie	10/07/2012	50	688661	7432669
53	Andrew Craigie and Heather Broad	12/07/2012	50	667899	7436212
54	Christopher Parker	12/07/2012	50	667459	7436044
55	Christopher Parker	15/07/2012	50	693252	7440857
56	Christopher Parker	15/07/2012	50	678032	7441255
57	Renee Young	22/08/2012	50	669044	7438284
58	Heather Broad	22/08/2012	50	666744	7437057
59	Andrew Craigie	22/08/2012	50	677184	7437539

Quadrat	Botanist	Date	Zone	Easting	Northing
60	Matthew Macdonald	22/08/2012	50	676676	7437576
61	Renee Young	13/07/2012	50	673215	7437869
62	Andrew Craigie	21/08/2012	50	675036	7437340
63	Heather Broad	21/08/2012	50	674380	7436772
64	Renee Young	22/08/2012	50	668923	7437248
65	Renee Young	13/07/2012	50	667686	7439468
66	Heather Broad	22/08/2012	50	671181	7437165
67	Andrew Craigie	15/07/2012	50	675707	7438599
68	Christopher Parker	15/07/2012	50	675904	7438645
69	Heather Broad	13/07/2012	50	671233	7439484
70	Christopher Parker	12/07/2012	50	662974	7436737
71	Renee Young	12/07/2012	50	663032	7439901
72	Renee Young	12/07/2012	50	662967	7439466
74	Heather Broad	12/07/2012	50	662935	7437760
75	Andrew Craigie	23/08/2012	50	664518	7436326
76	Heather Broad	15/07/2012	50	674804	7438827
77	Heather Broad	13/07/2012	50	672224	7439689
78	Heather Broad	13/07/2012	50	672023	7439634
79	Andrew Craigie	15/07/2012	50	675187	7438908
80	Matthew Macdonald	23/08/2012	50	664777	7435780
81	Andrew Craigie	23/08/2012	50	664292	7435990
82	Renee Young	15/07/2012	50	673920	7438834
84	Heather Broad	13/07/2012	50	667450	7440007
85	Matthew Macdonald	22/08/2012	50	674706	7436370
86	Christopher Parker	13/07/2012	50	670711	7439869
87	Christopher Parker	13/07/2012	50	673420	7439350
89	Renee Young	13/07/2012	50	672580	7439183
90	Renee Young	13/07/2012	50	672525	7439032
91	Andrew Craigie	22/08/2012	50	677313	7437373
92	Christopher Parker	11/07/2012	50	671795	7434819
93	Andrew Craigie	11/07/2012	50	665188	7433774
94	Christopher Parker	15/07/2012	50	675043	7439279
95	Matthew Macdonald	22/08/2012	50	676930	7437844
96	Heather Broad	15/07/2012	50	674566	7439117
97	Andrew Craigie	13/07/2012	50	672930	7439386
98	Andrew Craigie	10/07/2012	50	690021	7434193
99	Renee Young	10/07/2012	50	692404	7434579
100	Andrew Craigie	11/07/2012	50	665048	7433112
102	Andrew Craigie	11/07/2012	50	673591	7434348
103	Renee Young	11/07/2012	50	665617	7432674
104	Andrew Craigie	22/08/2012	50	676037	7437964
105	Christopher Parker	10/07/2012	50	689329	7433993
106	Andrew Craigie	10/07/2012	50	690813	7434491
107	Renee Young	10/07/2012	50	691959	7434259
108	Andrew Craigie	10/07/2012	50	687622	7432995
109	Renee Young	10/07/2012	50	692133	7434084
110	Renee Young	10/07/2012	50	688061	7433951
111	Andrew Craigie	10/07/2012	50	690781	7434606
112	Christopher Parker	10/07/2012	50	689514	7433871
113	Renee Young	10/07/2012	50	687687	7434485
114	Heather Broad	10/07/2012	50	691391	7433665
115	Heather Broad	10/07/2012	50	691478	7433848
116	Matthew Macdonald	25/08/2012	50	689743	7432298
117	Matthew Macdonald	25/08/2012	50	692296	7432269
118	Matthew Macdonald	25/08/2012	50	691903	7432228
119	Christopher Parker	10/07/2012	50	687390	7432574
120	Renee Young	25/08/2012	50	688668	7435466
121	Heather Broad	25/08/2012	50	690898	7435543

Quadrat	Botanist	Date	Zone	Easting	Northing
122	Heather Broad	25/08/2012	50	690568	7435562
123	Andrew Craigie	18/07/2012	50	691442	7435304
124	Andrew Craigie	18/07/2012	50	690998	7435051
125	Renee Young	25/08/2012	50	689448	7435600
126	Heather Broad	18/07/2012	50	692362	7435225
127	Heather Broad	18/07/2012	50	691897	7435262
128	Renee Young	14/07/2012	50	687617	7441806
129	Andrew Craigie	16/07/2012	50	687534	7441102
130	Andrew Craigie	12/07/2012	50	689733	7439848
131	Christopher Parker	17/07/2012	50	690405	7440055
132	Heather Broad	17/07/2012	50	690710	7440192
133	Heather Broad	17/07/2012	50	690774	7440465
134	Andrew Craigie	17/07/2012	50	689997	7440750
135	Christopher Parker	14/07/2012	50	694775	7442645
136	Andrew Craigie	14/07/2012	50	695085	7442608
137	Christopher Parker	14/07/2012	50	693742	7442990
138	Andrew Craigie	14/07/2012	50	694996	7443069
139	Christopher Parker	17/07/2012	50	691396	7441959
140	Heather Broad	16/07/2012	50	692860	7442223
141	Christopher Parker	16/07/2012	50	677807	7440841
142	Andrew Craigie	17/07/2012	50	691561	7441218
143	Heather Broad	24/08/2012	50	692043	7440355
144	Heather Broad	24/08/2012	50	691601	7440107
145	Christopher Parker	17/07/2012	50	690919	7440001
146	Andrew Craigie; Christopher Parker and Heather Broad	17/07/2012	50	689963	7441587
147	Heather Broad	17/07/2012	50	690015	7442078
148	Andrew Craigie	15/07/2012	50	694100	7441820
149	Andrew Craigie	16/07/2012	50	694618	7441708
151	Christopher Parker	14/07/2012	50	693738	7443431
152	Andrew Craigie	14/07/2012	50	695697	7443107
153	Heather Broad	16/07/2012	50	692827	7441627
154	Christopher Parker	16/07/2012	50	693821	7440864
155	Matthew Macdonald	24/08/2012	50	689478	7442994
156	Matthew Macdonald	24/08/2012	50	688740	7443153
160	Christopher Parker	16/07/2012	50	687010	7441224
200	Renee Young	23/08/2012	50	673438	7437317
201	Renee Young and Heather Broad	23/08/2012	50	677257	7442559

This page has been left blank intentionally

APPENDIX C FLORA SPECIES RECORDED AT WEST ANGELAS

This page has been left blank intentionally

Family	Taxon	Observation
Acanthaceae	*Dicladanthera forrestii*	
	Dipteracanthus australasicus subsp. *australasicus*	
	Harnieria kempeana subsp. *muelleri*	
Aizoaceae	*Trianthema glossostigma*	
Amaranthaceae	*Achyranthes aspera*	
	Alternanthera nana	
	Amaranthus cuspidifolius	
	Amaranthus mitchellii	
	Gomphrena affinis subsp. *pilbarensis*	
	Gomphrena canescens	
	Gomphrena cunninghamii	
	Gomphrena kanisii	
	Ptilotus aervoides	
	Ptilotus astrolasius	
	Ptilotus auriculifolius	
	Ptilotus calostachyus	
	Ptilotus carinatus	
	Ptilotus clementii	
	Ptilotus fusiformis	
	Ptilotus gomphrenoides	
	Ptilotus helipteroides	
	Ptilotus nobilis subsp. *nobilis*	
	Ptilotus obovatus	
	Ptilotus polystachyus	
	Ptilotus roei	
	Ptilotus rotundifolius	
	Ptilotus schwartzii var. *schwartzii*	
Apocynaceae	*Cynanchum floribundum*	
	Marsdenia australis	
	Rhyncharrhena linearis	
	Sarcostemma viminale subsp. *australe*	
Araliaceae	*Astrotricha hamptonii*	
	Trachymene oleracea subsp. *oleracea*	
	Trachymene pilbarensis	
Asteraceae	*Bidens bipinnata*	Invasive
	Brachyscome sp. Wanna Munna Flats (S. van Leeuwen 4662)	P1
	Calocephalus knappii	
	Calotis multicaulis	
	Calotis porphyroglossa	
	Chrysocephalum apiculatum	
	Chrysocephalum eremaeum	
	Chrysocephalum gilesii	
	Chrysocephalum pterochaetum	
	Flaveria trinervia	Invasive
	Peripleura arida	
	Peripleura hispidula var. *setosa*	
	Peripleura obovata	
	Pluchea dentex	
	Pluchea dunlopii	
	Pterocaulon serrulatum	
	Pterocaulon sphacelatum	
	Rhodanthe citrina	
	Rhodanthe floribunda	
	Rhodanthe margarethae	
	Sigesbeckia orientalis	Invasive

Family	Taxon	Observation
Asteraceae	*Streptoglossa bubakii*	
	Streptoglossa decurrens	
	Streptoglossa liatroides	
	Streptoglossa odora	
	Streptoglossa tenuiflora	
	Vittadinia eremaea	
Boraginaceae	*Halgania gustafsenii*	
	Heliotropium chrysocarpum	
	Heliotropium cunninghamii	
	Heliotropium heteranthum	
	Heliotropium inexplicitum	
	Heliotropium pachyphyllum	
	Heliotropium tenuifolium	
	Trichodesma zeylanicum	
	Trichodesma zeylanicum var. *zeylanicum*	
Brassicaceae	*Lepidium catapycnon*	T
	Lepidium pedicellosum	
	Lepidium phlebopetalum	
	Lepidium pholidogynum	
	Lepidium platypetalum	
Campanulaceae	*Isotoma petraea*	
	Lobelia heterophylla	
	Wahlenbergia tumidifructa	
Capparaceae	*Capparis lasiantha*	
	Capparis mitchellii	
	Capparis spinosa var. *nummularia*	
Caryophyllaceae	*Polycarpaea corymbosa*	
	Polycarpaea holtzei	
	Polycarpaea longiflora	
Celastraceae	*Denhamia cunninghamii*	
	Maytenus sp. Mt Windell (S. van Leeuwen 846)	
	Stackhousia intermedia	
Chenopodiaceae	*Dissocarpus paradoxus*	
	Dysphania glomulifera	
	Dysphania glomulifera subsp. *eremaea*	
	Dysphania kalpari	
	Dysphania rhadinostachya subsp. *rhadinostachya*	
	Enchylaena tomentosa var. *tomentosa*	
	Maireana georgei	
	Maireana lanosa	
	Maireana melanocoma	
	Maireana planifolia	
	Maireana tomentosa	
	Maireana triptera	
	Maireana villosa	
	Rhagodia eremaea	
	Rhagodia sp. Hamersley (M. Trudgen 17794) PN	P3
	Salsola australis	
	Sclerolaena convexula	
	Sclerolaena cornishiana	
	Sclerolaena eriacantha	
	Sclerolaena tetragona	
Cleomaceae	*Cleome viscosa*	
Convolvulaceae	*Convolvulus clementii*	
	Duperreya commixta	
	Evolvulus alsinoides	
	Evolvulus alsinoides var. *decumbens*	
	Evolvulus alsinoides var. *villosicalyx*	

Family	Taxon	Observation
	Ipomoea muelleri	
	Ipomoea polymorpha	
	Operculina aequisepala	
	Polymeria ambigua	
Cucurbitaceae	*Cucumis variabilis*	
Cyperaceae	*Bulbostylis barbata*	
	Cyperus cunninghamii subsp. *cunninghamii*	
	Fimbristylis dichotoma	
	Fimbristylis simulans	
Euphorbiaceae	*Adriana tomentosa* var. *tomentosa*	
	Euphorbia alsiniflora	
	Euphorbia australis	
	Euphorbia biconvexa	
	Euphorbia boophthona	
	Euphorbia drummondii	
	Euphorbia schultzii	
Fabaceae	*Acacia adoxa* var. *adoxa*	
	Acacia adsurgens	
	Acacia ancistrocarpa	
	Acacia aptaneura	
	Acacia atkinsiana	
	Acacia ayersiana	
	Acacia bivenosa	
	Acacia catenulata subsp. *occidentalis*	
	Acacia citrinoviridis	
	Acacia colei var. *colei*	
	Acacia cowleana	
	Acacia dictyophleba	
	Acacia eriopoda	
	Acacia hamersleyensis	
	Acacia inaequilatera	
	Acacia incurvaneura	
	Acacia macraneura	
	Acacia maitlandii	
	Acacia marramamba	
	Acacia minyura	
	Acacia monticola	
	Acacia pachyacra	
	Acacia pruinocarpa	
	Acacia pteraneura	
	Acacia pyrifolia	
	Acacia pyrifolia var. *pyrifolia*	
	Acacia rhodophloia	
	Acacia sibirica	
	Acacia aff. *subtiliformis*	P3
	Acacia synchronicia	
	Acacia tenuissima	
	Acacia tetragonophylla	
	Acacia validinervia	
	Crotalaria medicaginea var. *neglecta*	
	Crotalaria novae-hollandiae subsp. *novae-hollandiae*	
	Cullen leucochaites	
	Gastrolobium grandiflorum	
	Glycine canescens	
	Gompholobium oreophilum	
	Indigofera fractiflexa	
	Indigofera georgei	
	Indigofera sp. Gilesii (M.E. Trudgen 15869)	P3

Family	Taxon	Observation
Fabaceae	*Indigofera monophylla*	
	Indigofera rugosa	
	Isotropis forrestii	
	Mirbelia viminalis	
	Petalostylis labicheoides	
	Rhynchosia minima	
	Senna artemisioides subsp. *filifolia*	
	Senna artemisioides subsp. *helMSii*	
	Senna artemisioides subsp. *oligophylla*	
	Senna artemisioides subsp. *x artemisioides*	
	Senna ferraria	
	Senna glutinosa subsp. *glutinosa*	
	Senna glutinosa subsp. *pruinosa*	
	Senna glutinosa subsp. *x luerssenii*	
	Senna hamersleyensis	
	Senna notabilis	
	Senna pleurocarpa var. *angustifolia*	
	Senna sericea	
	Senna sp. Meekatharra (E. Bailey 1-26)	
	Senna stricta	
	Senna symonii	
	Swainsona kingii	
	Swainsona maccullochiana	
	Templetonia egena	
	Tephrosia clementii	
	Tephrosia densa	
	Tephrosia rosea var. *glabrior*	
	Tephrosia supina	
	Vachellia farnesiana	Invasive
	Vigna sp. Hamersley Clay (A.A. Mitchell PRP 113)	
Goodeniaceae	*Brunonia* sp. long hairs (D.E. Symon 2440) PN	P1
	Dampiera candicans	
	Goodenia microptera	
	Goodenia muelleriana	
	Goodenia nuda	P4
	Goodenia scaevolina	
	Goodenia stellata	
	Goodenia stobbsiana	
	Goodenia tenuiloba	
	Goodenia triodiophila	
	Scaevola browniana subsp. *browniana*	
	Scaevola parvifolia	
	Scaevola parvifolia subsp. *pilbarae*	
	Scaevola spinescens	
Gyrostemonaceae	*Codonocarpus cotinifolius*	
Haloragaceae	*Haloragis gossei*	
	Haloragis gossei var. *gossei*	
	Haloragis gossei var. *inflata*	
Hemerocallidaceae	*Corynotheca micrantha*	
Lamiaceae	*Clerodendrum floribundum*	
	Clerodendrum floribundum var. *angustifolium*	
	Newcastelia sp. *Hamersley Range (S. van Leeuwen 4264)*	
	Spartothamnella teucriiflora	
Lauraceae	*Cassytha capillaris*	
Loranthaceae	*Amyema hilliana*	
	Amyema miquelii	
Malvaceae	*Abutilon amplum*	
	Abutilon cryptopetalum	

Family	Taxon	Observation
Malvaceae	*Abutilon cunninghamii*	
	Abutilon dioicum	
	Abutilon fraseri subsp. *fraseri*	
	Abutilon lepidum	
	Abutilon leucopetalum	
	Abutilon macrum	
	Abutilon otocarpum	
	Abutilon oxycarpum	
	Abutilon trudgenii MS	
	Androcalva luteiflora	
	Corchorus crozophorifolius	
	Corchorus lasiocarpus	
	Corchorus lasiocarpus subsp. *parvus*	
	Corchorus sidoides subsp. *sidoides*	
	Corchorus tridens	
	Gossypium australe	
	Gossypium robinsonii	
	Hibiscus burtonii	
	Hibiscus coatesii	
	Hibiscus gardneri	
	Hibiscus sturtii	
	Hibiscus sturtii var. *campylochlamys*	
	Hibiscus sturtii var. *platychlamys*	
	Hibiscus trionum	
	Keraudrenia velutina	
	Malvastrum americanum	Invasive
	Melhania oblongifolia	
	Sida arenicola	
	Sida arsiniata	
	Sida echinocarpa	
	Sida ectogama	
	Sida fibulifera	
	Sida sp. Barlee Range (S. van Leeuwen 1642) PN	P3
	Sida sp. dark green fruit (S. van Leeuwen 2260)	
	Sida sp. Golden calyces glabrous (H.N. Foote 32)	
	Sida sp. Pilbara (A.A. Mitchell PRP 1543)	
	Sida sp. Shovelanna Hill (S. van Leeuwen 3842)	
	Sida sp. spiciform panicles (E. Leyland s.n. 14/8/1990	
	Sida sp. Supplejack Station (T.S. Henshall 2345)	
	Sida sp. verrucose glands (F.H. Mollemans 2423)	
	Sida spinosa	
	Sida trichopoda	
	Triumfetta leptacantha	
	Waltheria indica	
Marsileaceae	*Marsilea hirsuta*	
Moraceae	*Ficus brachypoda*	
Myrtaceae	*Calytrix carinata*	
	Corymbia candida	
	Corymbia deserticola subsp. *deserticola*	
	Corymbia hamersleyana	
	Corymbia zygophylla	
	Eucalyptus gamophylla	
	Eucalyptus leucophloia	
	Eucalyptus leucophloia subsp. *leucophloia*	
	Eucalyptus pilbarensis	
	Eucalyptus socialis subsp. *eucentrica*	
	Eucalyptus trivalva	
	Eucalyptus victrix	

Family	Taxon	Observation
Myrtaceae	*Eucalyptus xerothermica*	
	Melaleuca eleuterostachya	
Nyctaginaceae	*Boerhavia coccinea*	
	Boerhavia paludosa	
Oleaceae	*Jasminum didymum* subsp. *lineare*	
Phyllanthaceae	*Notoleptopus decaisnei*	
	Phyllanthus erwinii	
	Phyllanthus maderaspatensis	
Pittosporaceae	*Pittosporum angustifolium*	
Poaceae	*Acrachne racemosa*	
	Amphipogon sericeus	
	Aristida burbidgeae	
	Aristida contorta	
	Aristida holathera var. *holathera*	
	Aristida ingrata	
	Aristida jerichoensis var. *subspinulifera*	P1
	Aristida latifolia	
	Aristida lazaridis	P2
	Aristida obscura	
	Astrebla pectinata	
	Bothriochloa ewartiana	
	Brachyachne ciliaris	
	Brachyachne convergens	
	Cenchrus ciliaris	Invasive
	Chloris pectinata	
	Chrysopogon fallax	
	Cymbopogon ambiguus	
	Cymbopogon obtectus	
	Cymbopogon procerus	
	Dichanthium sericeum	
	Digitaria brownii	
	Digitaria ctenantha	
	Enneapogon avenaceus	
	Enneapogon caerulescens	
	Enneapogon intermedius	
	Enneapogon lindleyanus	
	Enneapogon pallidus	
	Enneapogon polyphyllus	
	Enneapogon robustissimus	
	Eragrostis cumingii	
	Eragrostis desertorum	
	Eragrostis dielsii	
	Eragrostis eriopoda	
	Eragrostis falcata	
	Eragrostis pergracilis	
	Eragrostis setifolia	
	Eragrostis tenellula	
	Eragrostis xerophila	
	Eriachne helmsii	
	Eriachne lanata	
	Eriachne mucronata	
	Eriachne pulchella subsp. *dominii*	
	Eriachne pulchella subsp. *pulchella*	
	Eulalia aurea	
	Ischaemum albovillosum	
	Iseilema eremaeum	
	Iseilema membranaceum	
	Iseilema vaginiflorum	

Family	Taxon	Observation
Poaceae	*Panicum decompositum*	
	Panicum effusum	
	Panicum laevinode	
	Paraneurachne muelleri	
	Paspalidium basicladum	
	Paspalidium clementii	
	Paspalidium constrictum	
	Paspalidium rarum	
	Perotis rara	
	Setaria dielsii	
	Setaria surgens	
	Sporobolus australasicus	
	Themeda sp. Hamersley Station (M.E. Trudgen 11431) PN	P3
	Themeda triandra	
	Tragus australianus	
	Triodia basedowii	
	Triodia brizoides	
	Triodia longiceps	
	Triodia melvillei	
	Triodia pungens	
	Triodia sp. Mt Ella (M.E. Trudgen 12739)	P3
	Triodia wiseana	
	Tripogon loliiformis	
	Triraphis mollis	
	Urochloa occidentalis var. *occidentalis*	
	Yakirra australiensis	
	Yakirra australiensis var. *australiensis*	
Polygalaceae	*Polygala isingii*	
Portulacaceae	*Calandrinia* sp. The Pink Hills (F. Obbens FO 19/06)	
	Portulaca oleracea	Invasive
Proteaceae	*Grevillea berryana*	
	Grevillea stenobotrya	
	Grevillea wickhamii	
	Grevillea wickhamii subsp. *hispidula*	
	Hakea chordophylla	
	Hakea lorea subsp. *lorea*	
Pteridaceae	*Cheilanthes lasiophylla*	
	Cheilanthes sieberi subsp. *sieberi*	
Rhamnaceae	*Cryptandra monticola*	
	Ventilago viminalis	
Rubiaceae	*Oldenlandia crouchiana*	
	Psydrax latifolia	
	Psydrax suaveolens	
	Spermacoce brachystema	
Santalaceae	*Exocarpos sparteus*	
	Santalum lanceolatum	
	Santalum spicatum	
Sapindaceae	*Dodonaea coriacea*	
	Dodonaea lanceolata var. *lanceolata*	
	Dodonaea pachyneura	
	Dodonaea viscosa subsp. *mucronata*	
	Dodonaea viscosa subsp. *spatulata*	
Scrophulariaceae	*Eremophila caespitosa*	
	Eremophila clarkei	
	Eremophila cuneifolia	
	Eremophila exilifolia	
	Eremophila forrestii subsp. *forrestii*	
	Eremophila forrestii subsp. Pingandy (M.E. Trudgen 2662)	P2

Family	Taxon	Observation
Scrophulariaceae	*Eremophila fraseri* subsp. *fraseri*	
	Eremophila galeata	
	Eremophila jucunda subsp. *pulcherrima*	
	Eremophila lanceolata	
	Eremophila latrobei	
	Eremophila latrobei subsp. *filiformis*	
	Eremophila latrobei subsp. *latrobei*	
	Eremophila longifolia	
	Eremophila phyllopoda subsp. *obliqua*	
	Eremophila platycalyx subsp. *pardalota*	
	Eremophila tietkensii	
Solanaceae	*Nicotiana benthamiana*	
	Nicotiana occidentalis	
	Nicotiana simulans	
	Solanum centrale	
	Solanum horridum	
	Solanum lasiophyllum	
	Solanum phlomoides	
	Solanum sturtianum	
Surianaceae	*Stylobasium spathulatum*	
Violaceae	*Hybanthus aurantiacus*	
Zygophyllaceae	*Tribulus astrocarpus*	
	Tribulus hirsutus	
	Tribulus macrocarpus	
	Tribulus occidentalis	
	Tribulus suberosus	
	Zygophyllum eichleri	
	Zygophyllum iodocarpum	

APPENDIX D COORDINATES OF PRIORITY FLORA AT WEST ANGELAS

This page has been left blank intentionally

Species	Status	Zone	Easting	Northing	Number of plants
Acacia aff. *subtiliformis*	P3	50	668980	7438136	120
		50	668950	7438192	10
		50	668906	7438285	120
Aristida jerichoensis var. *subspinulifera*	P1	50	677203	7440980	10
		50	687314	7433555	30
		50	673160	7435134	5
		50	688661	7432670	10
		50	662974	7436737	5
		50	673920	7438834	5
		50	677314	7437374	10
		50	691479	7433849	10
		50	689743	7432298	10
		50	691904	7432228	10
		50	687390	7432574	5
		50	691443	7435305	10
		50	693821	7440864	5
		50	689229	7432625	20
		50	688666	7443264	1
		50	691399	7432870	10
		50	687804	7432698	6
		50	691532	7432839	5
		50	687467	7432718	100
		50	687911	7433195	50
		50	687463	7433153	20
		50	691430	7432855	20
		50	687528	7433614	50
		50	688590	7432715	50
		50	688445	7432704	30
		50	691194	7432900	1
		50	687468	7433386	100
		50	691475	7432849	5
		50	690693	7432924	1
		50	687835	7433535	1
		50	688387	7432677	50
		50	689426	7432862	6
		50	688612	7433353	20
		50	687809	7432691	100
		50	689375	7432556	1000
		50	688885	7432701	5
		50	688301	7432615	1
		50	689526	7432891	2
		50	687463	7433153	100
		50	691662	7432824	10
		50	690208	7435391	50
		50	689267	7432603	30
		50	687468	7433386	20
		50	688741	7432699	5
Aristida lazaridis	P2	50	694996	7443069	5
		50	689585	7432449	20
		50	688575	7432716	2
Brachyscome sp. Wanna Munna Flats (S. van Leeuwen 4662) PN	P1	50	688703	7432676	1
		50	674380	7436772	2
Brunonia sp. long hairs (D.E. Symon 2440) PN	P1	50	664936	7432362	2
		50	663304	7437192	5
		50	663032	7439901	2
		50	673669	7437233	5
		50	677224	7439706	2

Species	Status	Zone	Easting	Northing	Number of plants
		50	673438	7437317	15
		50	669408	7433885	1
		50	691903	7432228	1
		50	668858	7438440	1
		50	668657	7437327	2
Eremophila forrestii subsp. Pingandy (M.E. Trudgen 2662)	P2	50	676965	7438393	1
Goodenia nuda	P4	50	673438	7437317	5
		50	688964	7435518	2
Indigofera sp. Gilesii (M.E. Trudgen 15869)	P3	50	690781	7434606	15
		50	689514	7433871	2
		50	689653	7433877	3
		50	689632	7433869	10
		50	689310	7433800	16
		50	678032	7441255	15
		50	689963	7441587	16
		50	690998	7441857	1
		50	691049	7441944	1
		50	691203	7441994	10
		50	691229	7441997	4
		50	691240	7441996	1
		50	688927	7443254	100
		50	690382	7441946	12
		50	690401	7441890	10
		50	690408	7441885	10
		50	689919	7441031	1
		50	687791	7434256	2
		50	688725	7433695	5
		50	689007	7435225	1
		50	689050	7434996	15
		50	689055	7434985	14
		50	689065	7434969	15
Lepidium catapycnon	T	50	688710	7443257	20
		50	688715	7443269	1
		50	688716	7443281	1
		50	688685	7443292	7
Rhagodia sp. Hamersley (M. Trudgen 17794) PN	P3	50	691478	7433848	2
		50	671233	7439484	2
		50	672580	7439183	2
		50	676135	7435721	3
		50	676538	7435987	1
		50	677340	7435770	5
		50	676625	7435967	5
		50	674706	7436370	5
		50	676519	7435975	5
		50	688643	7443253	1
		50	688669	7443262	1
		50	688772	7443255	1
		50	688894	7443243	4
		50	688927	7443254	6
		50	688948	7443252	4
		50	688962	7443250	3
		50	689046	7443256	4
		50	691903	7432228	5
		50	687430	7432920	5
		50	687435	7432957	1
		50	687437	7432975	1
		50	687435	7432990	1

Species	Status	Zone	Easting	Northing	Number of plants
		50	687474	7433203	5
		50	687803	7434230	1
		50	687917	7433186	2
		50	688055	7432954	8
		50	688511	7433194	6
		50	690364	7432322	1
		50	691515	7432320	4
		50	691647	7432290	1
		50	691872	7432200	1
Sida sp. Barlee Range (S. van Leeuwen 1642) PN	P3	50	694100	7441820	5
		50	668560	7433940	10
		50	691335	7441998	3
		50	691350	7441983	1
		50	692537	7442144	1
		50	692644	7442173	4
		50	692649	7442186	30
Themeda sp. Hamersley Station (M.E. Trudgen 11431) PN	P3	50	675904	7438645	5
		50	675043	7439279	15
		50	675036	7437340	15
		50	677034	7437867	~500
		50	672958	7437985	1000
		50	674453	7438046	1000
		50	674839	7437923	1000
Triodia sp. Mt Ella (M.E. Trudgen 12739)	P3	50	690781	7434606	30
		50	668560	7433940	5
		50	675528	7433693	50
		50	668709	7434062	100
		50	676312	7432796	32
		50	691966	7442312	50
		50	691899	7442318	20
		50	691875	7442317	50

This page has been left blank intentionally

APPENDIX E RARE AND PRIORITY FLORA REPORT FORMS

(Refer to attached disk)

This page has been left blank intentionally

APPENDIX F WEED CATEGORIES

This page has been left blank intentionally

Table G.1 - Control Codes for Declared Plants in Western Australia

Priority	Requirements
P1 Prohibits movement	The movement of plants or their seeds is prohibited within the State. This prohibits the movement of contaminated machinery and produce including livestock and fodder.
P2 Aim is to eradicate infestation	Treat all plants to destroy and prevent propagation each year until no plants remain. The infested area must be managed in such a way that prevents the spread of seed or plant parts on or in livestock, fodder, grain, vehicles and/or machinery.
P3 Aims to control infestation by reducing area and/or density of infestation	The infested area must be managed in such a way that prevents the spread of seed or plant parts within and from the property on or in livestock, fodder, grain, vehicles and/or machinery. Treat to destroy and prevent seed set for all plants:- - Within 100 metres inside of the boundaries of the infestation. - Within 50 metres of roads and high-water mark on waterways. - Within 50 metres of sheds, stock yards and houses. Treatment must be done prior to seed set each year. Of the remaining infested area:- - Where plant density is 1-10 per hectare treat 100% of infestation. - Where plant density is 11-100 per hectare treat 50% of infestation. - Where plant density is 101-1000 per hectare treat 10% of infestation. Properties with less than 2 hectares of infestation must treat the entire infestation. Additional areas may be ordered to be treated.
P4 Aims to prevent infestation spreading beyond existing boundaries of infestation	The infested area must be managed in such a way that prevents the spread of seed or plant parts within and from the property on or in livestock, fodder, grain, vehicles and/or machinery. Treat to destroy and prevent seed s*et al*. l plants:- - Within 100 metres inside of the boundaries of the infested property - Within 50 metres of roads and high-water mark on waterways - Within 50 metres of sheds, stock yards and houses Treatment must be done prior to seed set each year. Properties with less than 2 hectares of infestation must treat the entire infestation. Additional areas may be ordered to be treated. Special considerations In the case of P4 infestations where they continue across property boundaries there is no requirement to treat the relevant part of the property boundaries as long as the boundaries of the infestation as a whole are treated. There must be agreement between neighbours in relation to the treatment of these areas.
P5	Infestations on public lands must be controlled.

This page has been left blank intentionally

APPENDIX G LOCATION OF WEEDS RECORDED AT WEST ANGELAS

This page has been left blank intentionally

Taxon	Zone	Easting	Northing
Acetosa vesicaria	50	670282	7439512
Bidens bipinnata	50	688661	7432669
	50	692404	7434579
	50	687622	7432995
	50	691478	7433848
	50	666551	7432511
	50	671795	7434819
	50	669588	7436085
	50	662967	7439466
	50	663340	7437261
	50	670256	7440041
	50	670827	7440121
	50	669629	7439904
	50	672747	7439755
	50	673669	7437233
	50	671233	7439484
	50	667450	7440007
	50	673420	7439350
	50	672580	7439183
	50	672525	7439032
	50	672930	7439386
	50	677143	7440336
	50	676777	7439888
	50	693252	7440857
	50	674804	7438827
	50	675187	7438908
	50	675043	7439279
	50	674566	7439117
	50	687534	7441102
	50	677807	7440841
	50	689733	7439848
	50	690405	7440055
	50	690919	7440001
	50	691442	7435304
	50	674380	7436772
	50	665892	7437188
	50	676625	7435967
	50	670111	7435914
	50	677184	7437539
	50	668923	7437248
	50	671181	7437165
	50	676037	7437964
	50	666346	7432772
	50	670282	7439512
	50	676538	7435978
	50	670245	7439842
	50	670290	7439432
	50	694470	7443294
	50	676131	7435725
	50	675457	7438797
	50	677339	7435770
	50	690693	7439991
	50	693338	7440912
	50	663126	7437338
	50	674534	7439138

Taxon	Zone	Easting	Northing
	50	671919	7439437
Bidens bipinnata	50	671996	7439530
	50	672245	7439314
	50	674681	7438937
	50	670797	7438950
	50	685963	7441614
	50	677188	7440257
	50	671144	7436941
	50	672760	7437834
	50	671976	7437503
	50	671876	7437376
	50	671720	7437424
	50	671667	7437390
	50	671508	7437270
	50	671595	7437248
	50	671643	7437271
	50	672628	7437571
	50	672742	7437635
Cenchrus ciliaris	50	676037	7437964
Cenchrus setiger	50	677095	7440194
Flaveria trinervia	50	671233	7439484
	50	677143	7440336
Malvastrum americanum	50	663340	7437261
	50	670827	7440121
	50	669629	7439904
	50	667450	7440007
	50	673420	7439350
	50	672930	7439386
	50	677143	7440336
	50	674804	7438827
	50	674566	7439117
	50	677807	7440841
	50	689733	7439848
	50	690919	7440001
	50	676037	7437964
	50	666346	7432772
	50	689097	7440761
	50	670282	7439512
	50	670290	7439432
	50	663126	7437338
	50	674534	7439138
	50	671919	7439409
	50	674681	7438937
	50	677245	7440321
Portulaca oleracea	50	687622	7432995
	50	668832	7436351
	50	662974	7436737
	50	669629	7439904
	50	673669	7437233
	50	671233	7439484
	50	672580	7439183
	50	694775	7442645
	50	677143	7440336
	50	674804	7438827
	50	675043	7439279
	50	687019	7440818

Taxon	Zone	Easting	Northing
	50	677807	7440841
	50	689733	7439848
	50	675036	7437340
Portulaca oleracea	50	676131	7435725
	50	687031	7441098
Sigesbeckia orientalis	50	665237	7437562
	50	687534	7441102
	50	694100	7441820
	50	691064	7441959
Vachellia farnesiana	50	677203	7437782
	50	674110	7437917

This page has been left blank intentionally

APPENDIX H SITE DESCRIPTIONS

(Refer to attached disc)

This page has been left blank intentionally

APPENDIX I SPECIES X SITE MATRIX

(Refer to attached disc)

This page has been left blank intentionally

West Angelas Deposit C and D

Groundwater Dependent Vegetation Assessment

May 2017

EXECUTIVE SUMMARY

The development of additional deposits at West Angelas is required to sustain production from the existing West Angelas Project. Deposits C and D (the **Proposal**), located to the west of the existing operation, have been identified as the next near-mine resources to be developed, with mining proposed to commence from 2019. With approximately 30% (Deposit C) and 51% (Deposit D) of the resource sitting below the water table (**BWT**), dewatering will be required to provide dry conditions for BWT mining of these deposits.

As part of the Proposal an investigation is required into the potential impacts of the proposed dewatering on the surrounding environmental values, particularly those in Karijini National Park (**KNP**) (approximately 4 km west of the proposed deposits). Of particular importance is an assessment of the structure and composition of local riparian ecosystems to determine whether there are any potentially groundwater dependent species/vegetation (**GDS/GDV**) present and therefore if any potentially sensitive groundwater dependent ecosystems (**GDE**'s) are present in the area.

Based on pre-existing data and desktop investigations, the risk of significant GDE's being present in the study area was deemed to be low, however the proximity of KNP and presence of low to moderate interest riparian vegetation signatures in small areas within the Park boundaries determined that a baseline style assessment was most relevant. Based on the limited hydrogeological information available in KNP and the current state of knowledge in relation to Pilbara Facultative Phreatophytic Species (**FPS**), the level of complexity employed in the current study is considered commensurate with the inherent sensitivity associated of the local riparian communities.

As part of this investigation a field survey was conducted by Jeremy Naaykens (Botanist; Rio Tinto) and Hayden Ajduk (Botanist; 360 environmental) from 12th to 16th April, 2016. The field survey focused on the more substantial riparian vegetation formations within and adjacent to the Proposal and within KNP.

In order to assess the potential significance and likely sensitivity of the relevant riparian ecosystems a baseline riparian assessment of the area was conducted. This assessment included the compilation of species and vegetation data along with the production of vegetation mapping for relevant riparian communities in the area. Of particular focus was the assessment of mesic species composition and structure in all mapped communities. To expand upon traditional qualitative methods purely looking at compositional queues and to enable a more accurate and quantitative risk assessment of the potential for the proposal to indirectly impact potential GDE's; standing riparian biomass per unit area was also considered. This was done through systematic sampling of riparian basal area, as an index for the biomass (and water demands) of potentially GDV.

A follow up visit (to Riparian Zone C; Figure 4-1) on the 12th of October 2016 was undertaken to potentially alleviate concerns that some of the compositional results (i.e. notable mesic species absences) recorded in April may have been significantly influenced by the recent fire of late 2015 which was observed to have affected the area at the time of survey. This follow up visit did not see any regrowth evidence of new mesic indicator species considered important for establishing degrees of water availability.

The results of the baseline study showed that the vast majority of the riparian communities within the study area were dominated by low density *Eucalyptus victrix* communities, the majority of which sit over groundwater too deep to access. Approximately 2 km inside KNP boundary, as **TCEB**

approaches the local topographic constriction, *E. victrix* riparian vegetation density was observed to increase, with density spiking once the creek and its broad floodplain are funnelled into the constricted corridor provided by the local range features. Within Riparian Zone C (see Figure 4-1) a small 4.2 ha patch of riparian vegetation (within the incised channel zone) was found to be co-dominated by *E. victrix* and *E. camaldulensis*. Apart from a couple of *E. camaldulensis* individuals approximately 3.5 km downstream (outside of the potential zone of drawdown influence), this small representation was the only area where this “moderate risk” facultative phreatophyte was detected within the study area.

While focussing on riparian vegetation identified within KNP; this study has used a risk based approach to explore the degree to which the data suggests that riparian vegetation in the study area is dependent on groundwater access and additionally, the degree to which potential groundwater changes might impact riparian vegetation if it is dependent on groundwater access. The risk assessment has combined qualitative and quantitative data to attempt to quantify the risk of impact to vegetation based on the potential groundwater dependence of any identified riparian vegetation (and therefore potential GDEs) in the study area. However it is also acknowledged that the risk to riparian vegetation estimated by this study is also highly dependent upon factors such as: genetic variability within species; the influence of sub-surface factors (which are inherently difficult to understand: e.g. alluvial characteristics and variability; fine scale antecedent groundwater conditions under GDV; and root architecture/distribution of GDS etc.); and the likelihood of groundwater changes being realised in their vicinity (which is also dependent on subsurface factors such as: the interaction of geological and aquifer variability; surface water regimes and groundwater recharge dynamics; and the timing and magnitude of abstraction).

The combined influence of these factors on groundwater dependence, as well as the likelihood that groundwater drawdown will propagate to areas of elevated risk (the last of which is not quantified as part of this study), ultimately determine that the risks presented in this study are relatively conservative. Further, considering the inherent degree of arid adaptation held by local FPS, and the demonstrated ability of established moderate risk FPS (i.e. *E. camaldulensis*) to remain viable in the absence of, or with reduced access to groundwater; the likelihood of significant impacts appears to be Low-Medium and highly spatially restricted.

Based on the following assessment of potential groundwater dependence and associated risk of impact, the vast majority of the study area was considered to be of ‘Negligible’ to ‘Very Low’ risk of impact, with some ‘Low’ risk vegetation identified once inside KNP and approaching or passing through the constriction point provided by the range. Once within the creek constriction provided by the range (riparian Zone C; Figure 4-1), basal area was recorded to peak between 6 and 16 m^2/ha (in North Australian riparian environments basal areas in the order of 50 are not uncommon) and risk of impact was estimated to be ‘Low-Medium’ (22 ha), with a 4.2 ha section of ‘Medium’ risk riparian vegetation positioned in the centre of this Zone (represented by the extent of vegetation unit 2B).

There are however, local observations/characteristics which might support, rather than attenuate, this risk (particularly in Riparian Zone C): characteristics include the shallower trending groundwater height heading into the KNP; topographically confined channel profiles; and certain likely shallow alluvial zones and associated sub-surface lithologies. These characteristics indicate some potential that the risk of groundwater dependence of riparian vegetation is increasing within the KNP and particularly when transitioning from Riparian Zone B into Zone C.

However, it is thought that propagation of groundwater drawdown will likely be limited outside riparian zones A and B (Figure 4-1; beyond which alluvial/colluvial formations are less extensive).

Furthermore given the geological complexity of subsurface lithologies in the section of TCEB which dissects Riparian Zone D (and Zone C; including abundant dolerite dykes which typically form a barrier to groundwater flow, mapped running perpendicular to TCEB in this vicinity) groundwater drawdown downstream of this vicinity is considered increasingly unlikely. This determines that only a 4 km stretch of TCEB (and potentially less; which includes Riparian Zone C and the northern section of Riparian Zone E) has potential to be impacted if the drawdown were to extend into KNP.

Of this 4 km stretch of TCEB only Riparian Zone C (the initial 2 km stretch) possesses vegetation with GDS of sufficient standing biomass to be considered at risk of noticeable impact from drawdown (if drawdown were to be realised). Furthermore, of this 2 km stretch at risk; only a 700 m stretch (Riparian Zone C-1 and the included C2B vegetation unit) possesses GDS (*E. camaldulensis*) of moderate potential groundwater dependence and elevated standing biomass.

Therefore; it is the C-1 stretch which represents the area of greatest risk of groundwater dependence. Conversely Riparian Zone C coincides spatially with that area of diminished potential to propagate potential drawdown. Despite initial hydrogeological investigations indicating that a groundwater divide was potentially located in the vicinity of Riparian Zone C-1; geophysical investigations were unsupportive. Incorporating the results of both investigations, the interpreted likely occurrence within Riparian Zone C of abundant interspersed clay formations, calcrete detrital formations, massive/impervious subsurface materials and potential outcropping of the Wittenoom formation; continue to support a diminished potential for drawdown propagation in this area.

Importantly, disparity exists between the geophysics interpreted depth to groundwater within and downstream of Riparian Zone C (1.5-6.5 m (average 3.5 throughout Zone C (2m within Zone C-1)); GBG MAPS 2017) and the GDS and associated GDV recorded. However; the data on water table heights provided by the geophysics work is at times potentially variable. This is associated with the large proportion of the study area (particularly that area under the C2B community) where water table heights were inferred (rather than interpreted) due to shallow massive/non-permeable subsurface materials. Essentially, based on observations made in other Hamersley creek systems, the floristic composition and GDS present in Riparian Zone C do not generally suggest that groundwater is consistently shallower than 5 m below ground level (**bgl**). Instead they suggest that groundwater heights in Zone C may often be residing at greater depth, and therefore behaving independently of those upstream within the broad alluvial valley. Initially this was thought to indicate that there is potential for a groundwater divide to occur in this area (with early geological observations supporting this theory), however geophysics work did not interpret there to be any relevant shallow basement material formations in the area. Despite this fact some caveats are placed on the accuracy of this interpretation due variable weathering influences (GBS MAPS 2017).

Based on the results of the geophysics work, the distribution of the C2B community somewhat aligns with the gaps in the distribution of shallow relatively impermeable detritals formations (which are unlikely to provide suitable substrate conditions for the proliferation of *E. camaldulensis*) present throughout a significant proportion of riparian zone C. This suggests that potential disparities between likely groundwater proximity and GDS and GDV present could be explained to some degree by constraints on riparian growth provided by poor substrate conditions (regular shallow detritals formations) through large parts of riparian zone C.

As a result, it was concluded that, if modelled groundwater drawdown of approximately 3 m to 8 m were to extend significantly beyond the KNP boundary (i.e. 2-4 km reducing groundwater to approximately 5-10 m bgl under Zone C-1), the overall risk of significant impact would likely be considered “Medium” and restricted to Riparian Zone C, and specifically Riparian Zone C-1.

Downstream and upstream of this zone, the risk of significant impact is considered low. However; hydrogeological modelling of predicted drawdown responses in this area indicates that for the majority of scenarios, groundwater heights would be significantly reduced over a long time frame, but access to groundwater by vegetation would remain. Furthermore; based on various modelled response scenarios, vertical height changes to groundwater potentially experienced within KNP are likely to be in the order of 10-20 cm per year (lowest rate approximately 2 cm/yr; base case rate approximately 10 cm/yr) with a worst case scenario of approximately 40cm/yr. This degree of vertical change to groundwater access is thought to be easily in the order of that which local facultative phreatophytes can successfully adapt to (Kranjcec, Mahoney and Rood 1998; Scott, Shafroth, and Auble 1999; Horton and Clark 2001; Canham 2011). Taking into account substrate complexities in the vicinity of Riparian Zone C; the likely moderation of this slow and adaptable rate of change suggests that the risk of significant impact in this zone is lower than that formally attributed in this study.

Ultimately compositional changes in the dominant species present in Riparian Zone C (within KNP) are considered unlikely, while changes in cover/abundance and health are considered the impact of greatest potential; albeit low-to moderate in significance and extent.

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

1 INTRODUCTION

The development of additional deposits is required to sustain production from the existing West Angelas Project. Deposits C and D (the **Proposal**), located to the west of the existing operation, have been identified as the next near-mine resources to be developed, with mining proposed to commence from 2019.

Approximately 30% of the Deposit C resource and 51% of the Deposit D resource is below the water table (**BWT**) and as such, dewatering will be required to provide dry conditions for BWT mining of these deposits.

An investigation into the potential impacts of the proposed dewatering on the surrounding local groundwater and surface water systems is required. This investigation will include assessment of the structure and composition of local riparian ecosystems to determine whether there are any sensitive groundwater receptors in the area. Of particular importance is determining the presence of any local Groundwater Dependent Species (**GDS**) and Groundwater Dependent Vegetation (**GDV**) likely to represent a local Groundwater Dependent Ecosystem (**GDE**); attributing significance to any potential GDE's within local riparian systems and further, to understand their degree of sensitivity to potential groundwater and surface water changes. An essential part of this investigation will be understanding whether there is potential for dewatering to have an indirect impact on the nearby Karijini National Park (**KNP**) given that the KNP boundary is located approximately 4 kilometres (**km**) to the west of the western end of the proposed deposits.

Protection of GDEs is commonly considered an important criterion in sustainable water resource management, particularly when human water consumption is in competition with environmental water demands.

The following report outlines the resulting assessment of the presence, significance and sensitivity of any potential GDEs (as indicated by the presence of GDV) in the vicinity of the Proposal; particularly local riparian systems occurring in KNP. To expand upon traditional methods and to enable a more accurate and measured risk assessment of the potential for the proposal to indirectly impact GDE's, two key tasks are proposed:

1. Conduct a riparian vegetation mapping exercise and detailed assessment of GDS presence within the study area.
2. Systematic sampling of riparian basal area, as an index for the biomass (and therefore a proxy for water demands) of potentially GDV.

These tasks were undertaken within the area identified as potentially impacted by drawdown (and surface water changes) as a result of the proposed dewatering and are therefore, most relevant to the Proposal (herein referred to as the 'Study Area'). Figure 1-1 shows the location of the Study Area and key riparian corridors in relation to Deposits C and D and KNP, and the main deposits of the existing West Angelas Project.

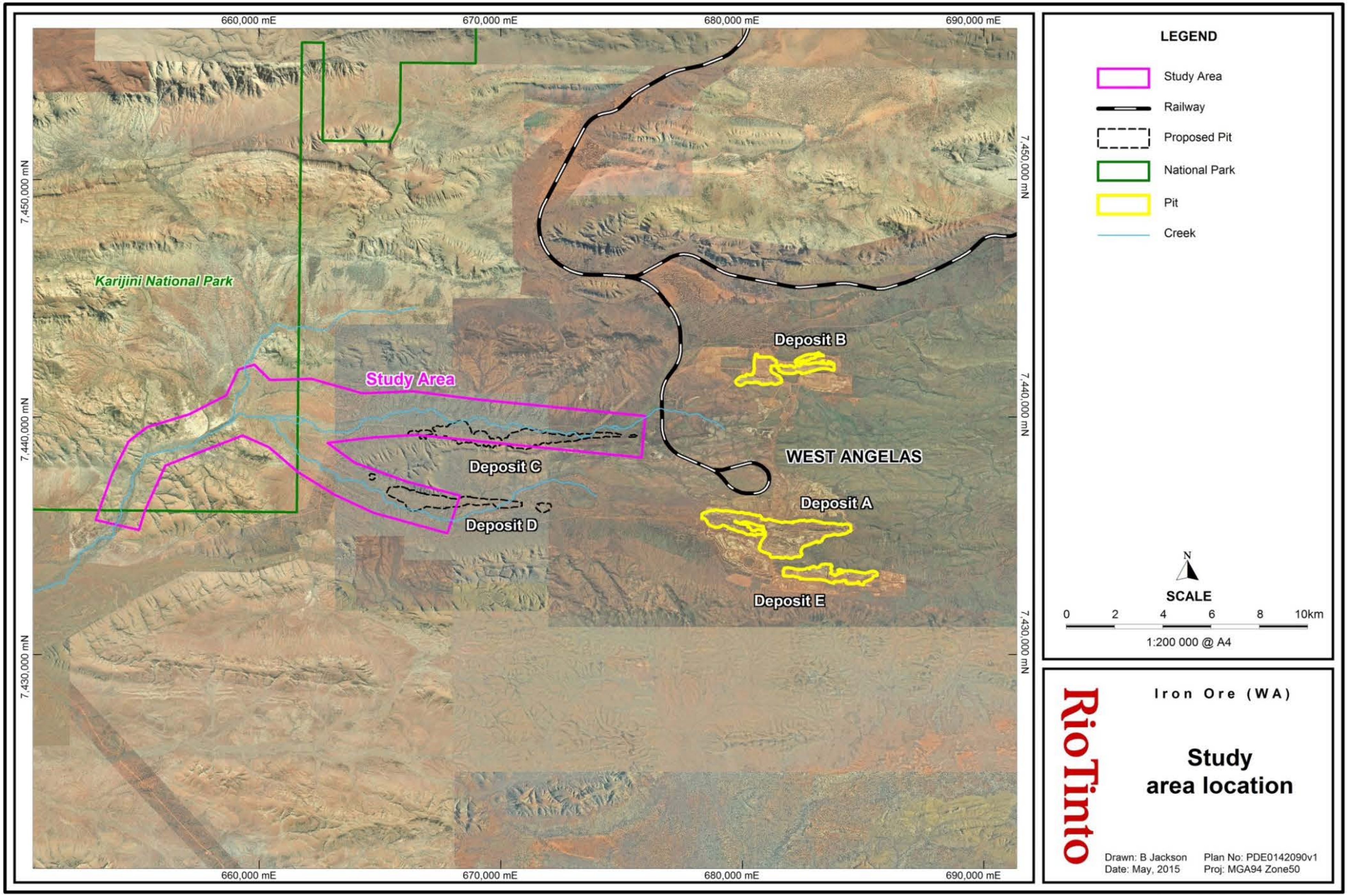


Figure 1-1: Study Area Location

2 BACKGROUND

In general, the structure and composition of creek line vegetation in the Pilbara tends to be driven by the availability of moisture. As such, the structure and composition of vegetation present is often the most reliable indicator of the availability of moisture, providing valuable insight into groundwater proximity, surface water permanence and therefore the potential sensitivity of a riparian ecosystem.

This insight is important as there are often no good alternatives (at a finer scale) for establishing moisture persistence in an area. This is generally due to; historical records not being extensive or detailed enough to determine if a site possesses moisture (groundwater or surface water) permanency, difficulties in accurately interpolating underlying water table heights (often from a limited number and spread of groundwater bores) and the high degree of influence and inherent variability which climatic factors can provide from year to year.

2.1 GROUNDWATER DEPENDENT ECOSYSTEMS

In larger riparian systems of the Pilbara, groundwater can typically be contained within shallow, unconsolidated sedimentary aquifers close to the surface (Landman 2001). These shallow aquifers often support riparian vegetation which can be classified as a GDE. A GDE is an ecosystem (typically identified by the presence of GDS and GDV) that requires the presence or input of groundwater to maintain some or all of its ecological function, composition, or structure (Eamus and Froend 2006; Murray *et al*. 2006).

Such ecosystems are associated with terrestrial vegetation complexes, river base flow systems, wetlands, and caves (Hatton and Evans 1998). GDEs can have various levels of dependency on or utilisation of ground-water, ranging from complete dependence to occasional supplementary use. It is for this reason it is important to define the vegetation present and to estimate the likely dependence of such vegetation on groundwater and surface-water sources so as to contextualise the potential influence of local scale hydrogeological impacts.

Although GDEs only cover a comparatively small proportion of the land surface, they provide specific ecosystem functions supporting unique and important biological diversity at both local and regional scales (Thurgate *et al*. 2001; Boulton and Hancock 2006; Humphreys 2006; Murray *et al*. 2006). In addition to environmental benefits, GDEs often have significant social, economic, and spiritual values (Murray *et al*. 2006). Protection of GDEs is commonly considered an important criterion in sustainable water resource management, particularly when human water management is in competition with environmental water demands.

GDE's and their associated species and landforms represent features of elevated ecological value. In the case of the study area; the tasks of determining presence and attributing significance to any potential GDE's within local riparian systems, as well as considering the significance of potential impacts to such assets, is given an additional degree of complexity as a result of the proximity of the nearby conservation estate. Regardless of their inherent biological values, potential GDE's within the boundary of KNP possess a baseline degree of elevated significance.

2.2 GROUNDWATER DEPENDENT SPECIES

GDEs tend to support relatively dense and diverse vegetation communities. Such vegetation tends to contain an above average proportion of moisture loving or mesic species which often thrive in areas where groundwater proximity significantly increases the availability of moisture. It is these mesic indicating perennial to sub-perennial (and ephemeral) species which are often quite restricted in their distribution and extent and therefore of elevated value.

Species that broadly utilise groundwater are referred to as phreatophytes, and they may be classified as either obligate or facultative phreatophytes depending on their level of dependence on groundwater. Obligate phreatophytes are plants that are completely or highly dependent on groundwater. This dependence can be continual, seasonal or episodic. Obligate phreatophytes tend to be associated with surface expressions of groundwater rather than purely the subsurface presence of groundwater (although not always), and they are highly sensitive to large changes in groundwater regime and respond negatively to rapid groundwater drawdown.

Facultative phreatophytes are plants that can access groundwater but are not totally reliant on groundwater to fulfil their water requirements. Rather, they utilise groundwater opportunistically, particularly during times of drought when moisture reserves in the unsaturated (vadose) zone of the soil profile become depleted. Facultative phreatophytes are generally associated with the subsurface presence of groundwater rather than surface water. Most facultative phreatophytes are large woody trees and shrubs with deep root systems capable of accessing the capillary fringe of the water table which may occur at considerable depth within the soil profile.

Not all phreatophytic species display the same degree of dependency on groundwater and the dependency within species has been shown to vary both spatially and temporally (Eamus and Froend 2006). Obligate phreatophytes are those species for which access to groundwater is critically important to their presence in the landscape. Such species can only inhabit areas where they have access to groundwater in order satisfy at least some proportion of their environmental water requirements (**EWR**) (Eamus *et al.* 2006). Facultative phreatophytes, on the other hand, are plant species for which access to groundwater is not necessarily important to their presence in the landscape. Facultative phreatophytes may utilise groundwater to satisfy a proportion of their EWR but, if required, may also satisfy their total EWR via stored soil water reserves (Eamus *et al.* 2006).

Table 2-1presents the different classes of groundwater dependence (water use strategies) relevant to plant groups in the Pilbara, and the most relevant species considered as being attributable to each.

Table 2-1: Tree species dependence on groundwater

Species dependence on Groundwater	Plant Physiology/water use strategy	Relevant Species in the Pilbara
High	Obligate phreatophyte	*Melaleuca argentea (potentially Melaleuca bracteata)*
Moderate	Facultative phreatophyte (sometimes a vadophyte[1])	*Eucalyptus camaldulensis, Melaleuca glomerata*
Low to Moderate	Vadophyte (in anomalous cases can be a Facultative phreatophyte	*Eucalyptus victrix and Eucalyptus xerothermica*
Low (virtually negligible)	Xerophyte[2]	Examples include *Eucalyptus leucophloia*, *Corymbia hamersleyana*, and Corymbia deserticola

[1] Vadophytes are plants, commonly associated with drainage lines which rely on moisture in the soil surface profile, and are independent of groundwater.

[2] Xerophytes are plants which are adapted to dry environments. Xerophytic adaptations including waxy covering over the stomata, very few stomata, or stomata that only open at night, the development of a dense, hairy leaf covering, the ability to drop leaves during dry periods, the ability to reposition or fold leaves to reduce sunlight absorption all prevent water loss, while fleshy stems or leaves store water.

It is generally recognised that obligate phreatophytes are considered those species with the highest degree of groundwater dependence, and as such are often the best indicator of consistently shallow groundwater tables, or permanent surface water presence. Furthermore; the structure and composition of creekline vegetation is generally considered to be heavily driven by the degree and consistency of moisture availability. As a result the structure and composition of vegetation types present in a riparian system is an important longer term indicator of groundwater proximity and surface water permanence. Furthermore this insight into the degree of moisture permanency also provides insight into the associated values and significance of a riparian ecosystem. It is for these reasons that typically the most reliable and often effective indicator for moisture permanency and therefore inherent hydrological sensitivity is the composition and structure of vegetation present.

To help provide increased resolution and scale to this insight it is important to have an understanding of where different mesic species might sit on the scale of increasing reliance on high levels of water availability. In the Pilbara, a list of sub-perennial to perennial moisture indicating (or mesic) species is likely to contain the species listed below in Table 2-2 (in a conceptual order of importance and therefore increasing reliance on high moisture availability)(adapted from information provided by Western Australian Herbarium 2016, and Pilbara environmental observations).

Table 2-2: Pilbara sub-perennial to perennial moisture indicating (or mesic) species of relevance to GDE's

Species in **bold** identify some of the best upper level indicators of moisture availability / permanence.

• ***Melaleuca argentea***	• *Peplidium sp. E Evol. Fl. Fauna Arid Aust. (A.S. Weston 12768)*
• ***Acacia ampliceps***	• *Samolus spp.*
• ***Eucalyptus camaldulensis***	• *Gossypium sturtianum*
• ***Melaleuca bracteata***	• *Acacia coriacea subsp. pendens*
• ***Muehlenbeckia spp.***	• *Eucalyptus victrix*
• ***Sesbania formosa***	• *Melaleuca linophylla*
• ***Imperata cylindrica***	• *Acacia citrinoviridis*
• *Atalaya hemiglauca*	• *Acacia sclerosperma*
• *Cyperus vaginatus/iria*	• *Acacia coriacea subsp. pendens*
• *Typha domingensis*	• *Lobelia spp.*
• *Marsilea spp.*	• *Stylidium spp.*
• *Potamogeton spp.*	• *Sesbania spp.*
• *Date palm*	• *Stemodia spp.*
• *Various sedge spp.* including *Baumea spp., Fimbristylis spp., etc*	• *Sorghum spp.*
• *Cladium procerum*	• *Eragrostis surreyana*
• *Schoenoplectus spp.*	• *Vallisneria nana*
• *Eleocharis spp.*	• *Senecio hamersleyensis*
• *Fuirena ciliaris (L.) Roxb.*	• *Geijera salicifolia*
• *Pteris vittata*	• *Commelina ensifolia R.Br.*
• *Adiantum capillus-veneris L.*	• *Trigonella suavissima Lindl.*
• *Gossypium sturtianum*	

Consequently, riparian zones or water gaining sites which contain obligate phreatophytes (such as *Melaleuca argentea)* and increasing proportions of the following species are considered to provide good evidence of high moisture availability and its degree of persistence/permanence.

The following key groundwater dependent species are of most relevance to GDE's and GDV in the Pilbara:

2.2.1 *Melaleuca argentea*

In the Pilbara, *Melaleuca argentea* is thought to depend on groundwater almost exclusively and is therefore considered to be an obligate phreatophyte (Lamontagne *et al.* 2005; Graham *et al.* 2003, Landman *et al.* 2003; O'Grady *et al.* 2006).

Due to its dependence on groundwater, *M. argentea* is often the best indicator of consistently shallow groundwater tables or permanent (perennial) surface water presence and subsequently, this species is also widely considered the best available indicator for the presence of GDV and therefore a GDE.

2.2.2 *Eucalyptus victrix*

*Eucalyptus victrix (**E. victrix**)* is a small to medium tree (typically 5 m to 15 m, but can grow to more than 20 m) with smooth white bark (sometimes with a box type stocking to 1 m) and a spreading form that typically occurs on red loamy or sandy soils and clay loams on floodplains, incised channel zones, and in low lying areas across the Pilbara and other areas in the north-west of Western Australia (Western Australian Herbarium 1998-2016).

Mature *E. victrix* trees commonly support a large dimorphic root system, consisting of a prominent tap root and a network of laterally expansive roots near the soil surface and in the top 1 m to 2 m of the soil profile, which can extend to at least 10-20 m away from the main stem (and further). From lateral roots vertical sinker roots can also develop and potentially extend tens of metres to water table depth (Florentine 1999).

E. victrix typically draws the majority of its water requirement from soil pore moisture (the vadose soil resource) however, during extended dry periods *E. victrix* can also use groundwater opportunistically as required and are therefore considered to be facultative phreatophytes.

Previous studies have shown that when provided with access to groundwater, *E. victrix* can maintain high leaf water potentials and high rates of tree water use during times of drought (O'Grady *et al*. 2009; Pfautsch *et al*. 2011; Pfautsch *et al*. 2014). *E. victrix* however, also demonstrates a strong ability to regulate water losses when water supplies are limited via regulation of stomatal conductance (Pfautsch *et al*. 2014) and structural modifications including leaf die-off, crown defoliation and adjustment of leaf area to sapwood area ratio. Such changes enable trees to maintain constant water use despite increasing evaporative demand if sufficient water is available (O'Grady *et al*. 2009). In general, the water use strategy of *E. victrix* appears to be highly plastic and opportunistic, enabling survival in a wide range of ecohydrological settings (Pfautsch *et al*. 2014).

Despite being a relatively plastic species, major adjustments to hydraulic architecture in large trees take time such that *E. victrix* growing over historically shallow groundwater exhibits much greater susceptibility to hydrologic change than trees that have developed over historically deeper groundwater, as highlighted in a recent study by Pfautsch *et al*. (2014).

Work by Loomes (2010), assessing the range of depth to groundwater over which Pilbara riparian species occur, found that in large Pilbara rivers, the mean minimum water level depth occurring under *E. victrix* populations was somewhat greater than that for *E. camaldulensis*, providing some support for the view that *E. victrix* is found in slightly drier areas than *E. camaldulensis* and may not be as responsive to water table fluctuations (Loomes 2010).

Mature *E. victrix* trees display a moderate level of flooding tolerance, and are able to tolerate temporary inundation in the range of weeks to months at most. The presence of adventitious roots and stem hypertrophy (the ability to increase the size of component cells) provides a level of tolerance to waterlogging in seedlings and saplings, allowing them to survive in flood-prone areas (Florentine 1999; Florentine and Fox 2002a). In fact, flooding events are believed to play a major role in the reproductive cycle of *E. victrix*, particularly for seedling establishment (Florentine and Fox 2002b).

2.2.3 *Eucalyptus camaldulensis*

E. camaldulensis is a small to large tree (typically 5 m to 20 m but can grow to more than 30 m) with smooth white bark and a generally spreading form. In general this species displays a great diversity in height, form, trunk and leaf morphology (Western Australian Herbarium 1998-2015).

E. camaldulensis is one of the most iconic and broadly distributed Eucalyptus species in Australia and more is known about this species than nearly all others. Across its broad geographic distribution, *E. camaldulensis* populations display high genetic diversity with regard to hydraulic architecture, water relations and salt tolerance, reflecting how different populations have evolved and adapted to local climates and hydrogeological regimes (Colloff 2014). Furthermore; this diversity is also shown by the various sub-species (there are at least 5 recognised sub-species) known to occur in Australia. In the Pilbara, *E. camaldulensis* is typically represented by *E. camaldulensis* subsp. *Refulgens*, or subsp. *Obtusa*, and commonly occurs along water courses and river banks, growing in deep alluvial sand and sandy loams (Western Australian Herbarium 1998-2016).

Trees in riparian zones exposed to flood events (often in more open areas subject to less competition) tend to have short, thick stems with irregular crowns or multiple stems diverging from a short trunk. Often stems sprout from epicormic buds in living tissue of the bole or root stock, and new stems can arise from horizontal stems fallen by flood, fire or windstorms. In less dynamic environments, fast-growing trees can grow tall and straight with relatively even form similar to that seen in silvicultural plantations. *E. camaldulensis* supports a large root system consisting of vertical tap roots with lateral roots branching off at right angles at several levels, and sinker roots extending downwards from laterals. Mature trees are thought to have a zone of water influence which can extend to more than 40 m around individuals, suggesting the lateral reach of roots is large. This extensive reach would suggest a significant reliance on pore water stored in the vadose soil water resource.

Vertical sinkers provide support for the aboveground part of the tree and deep penetration of soil over a wider area than would be possible via a single taproot. Extension of the root system also allows for access to oxygen from unsaturated portions of the soil profile during periods of inundation; thus enhancing flood tolerance. Mature trees are thought to have roots to depths of at least 9 m to 10 m and possibly as deep as 30 m (Davies 1953, cited in Colloff 2014). Adventitious roots can grow out from boles or branches in response to flooding and as a way of increasing oxygen uptake and also as a form of vegetative propagation. Woody roots of this species are known to have large xylem vessels for fast, efficient rates of water transport and rapid recovery following water stress (Heinrich 1990 cited in Colloff 2014).

Generally, *E. camaldulensis* has the ability to utilise water from a range of different sources including rainfall, floodwater, stored soil water and groundwater and is therefore considered to be a facultative phreatophyte (Mensforth *et al*. 1994). When conditions are favourable, *E. camaldulensis* tends to employ a 'going for growth' strategy that involves vigorous growth rates and high rates of uptake and transpiration from a dependable water source, often provided by groundwater, river base-flow, or floodwaters that sustain groundwater recharge (Gibson, Bachelard, and Hubick 1994; Marshall *et al*. 1997; Morris and Collopy 1999). As a consequence, *E. camaldulensis* is generally regarded as being more reliant on groundwater than *E. victrix*. When stressed, *E. camaldulensis* reduces transpiration and water demand by shedding leaves and sometimes also whole branches (particularly lower limbs).

Where large *E. camaldulensis* trees are present and common, groundwater is generally within the depth of the root zone, and in some environments depth to groundwater is a good predictor of the condition of *E. camaldulensis* stands. Some studies have observed a sharp decline in tree health and stand condition below a threshold depth or around 10 m to 12 m (England *et al* 2009 cited in Colloff 2014). However, some case studies have also shown reasonable resilience in vegetation health when access to groundwater is removed. What is often evident is that not all systems are equal and in certain sized catchments it appears that the frequency of replenishment of the vadose soil resource is great enough to maintain healthy populations of *E. camaldulensis* without access to the water table. Conversely, there are times where drought may determine that the vadose soil resource is inadequate, and in turn fails to sustain local populations. In areas where *E. camaldulensis* has established with groundwater depths at approximately 10 m bgl, susceptibility to impact from hydrological change may be significantly reduced.

2.2.4 Other key potentially GDS

A number of key woody shrub species which are either potentially groundwater dependent or are associated with GDE's and areas possessing shallow groundwater are also commonly recognised to occur in the Pilbara. These include, but are not limited to:

- *Acacia ampliceps;*
- *Melaleuca bracteata;*
- *Melaleuca glomerata;*
- *Melaleuca linophylla;* and
- *Acacia coriacea* subsp. *Pendens.*

Significantly less is known about the groundwater dependence of these species when compared to the key phreatophytic tree species discussed above. A large part of this is likely linked to the shallower roots systems possessed by such species, as well as the degree to which each represents a dominant structural element in Pilbara riparian systems. Whatever the case they consistently appear to indicate increasing water availability, and so are at times linked to the proximity of groundwater resources.

2.3 GROUNDWATER DEPENDENT VEGETATION

As ecosystems are defined by the network of interactions among organisms, and between organisms and their environment, accurately distinguishing a GDE from the broader ecosystem is at times problematic. Given that the presence of GDEs is typically identified by the presence of GDS and therefore GDV, the presence of GDV becomes a reasonably accurate proxy for the presence of a GDE. GDV is defined as terrestrial vegetation that is dependent on the presence of groundwater (which can come in many forms) to meet some or all of their water requirements such that vegetation community structure and function is maintained (Orellana *et al.* 2012). GDV communities are commonly associated with the riparian zones and floodplains of ephemeral creeks and rivers and may be dependent on either the surface expression or subsurface presence of groundwater (Eamus, Hatton *et al*. 2006). To complicate matters, groundwater can come in multiple forms; from the aquifer represented by the broader groundwater table, to smaller localised and often perched aquifers (disconnected from the broader groundwater table), to even smaller localised and topographically confined sub-surface water bodies. Surface expressions of groundwater occur in the form of rivers, streams, creeks, springs and some floodplains where groundwater may soak below the surface and become available to plant roots.

GDV and GDE's generally represent areas with relatively permanent water access (perennial), and as such tend to support relatively dense and diverse vegetation communities (typically in reference to those communities possessing obligate phreatophytic species (**OPS**)). Such vegetation tends to contain an above average proportion of mesic perennial and ephemeral species diversity, and so represents repositories of genetic diversity which are often restricted in their distribution and areal extent. Coupled with the diversity of fauna species (particularly avifauna, and nocturnal invertebrate fauna) which they often support, their value is generally accepted to be high. It is for this reason that those species which are considered obligate phreatophytes, and therefore dependent upon water permanence, are those species which are the best indicators for the presence of these high value communities. The obligate phreatophytic species *M. argentea* is widely considered the best indicator for perennial water availability. Consequently the distribution, abundance and age structure of this species in the environment is often the best available measure for the presence and quality of high value GDV in the Pilbara. However, vegetation communities which occur in ephemeral habitats and instead are only comprised of facultative phreatophytes such as *E. camaldulensis* and *E. victrix* can also be described as GDV (despite the absence of obligate phreatophytic species). Despite the often differing water use strategies of GDV solely dominated by facultative phreatophytes when compared to GDV which includes obligate phreatophytes, these two types of GDV are still both described to fall under of the "umbrella" of groundwater dependence or GDE's. Given the potentially variable water use strategies of phreatophytic species in the Pilbara, it becomes important to distinguish between these lower sensitivity groundwater dependent ecosystems/vegetation, and those which are truly phreatophytic and therefore depend on groundwater almost exclusively to meet their water requirements. To address this disparity, the terms 'Facultative Phreatophytic Vegetation' (**FPV**) and 'Obligate Phreatophytic Vegetation' (**OPV**) are proposed to provide distinction between the facultative, often markedly less significant/sensitive phreatophytic vegetation and those high value communities possessing obligate phreatophytes.

For the purpose of this study, OPV is defined as representing communities which:

> Encompass vegetation associations and sub-associations, whose structure is at least co-dominated by one obligate phreatophyte, namely *M. argentea* (i.e. possesses vegetation described as being dominated by one or more species within the tree or tall shrub stratum and which includes the species *M. argentea* as one of these described dominant species).
>
> Note: this is not a well-recognized term, and has been created for the purpose of this and other related studies from associated, well accepted terms such as obligate phreatophytes and GDV.

Alternatively FPV is defined as representing communities which:

Encompass vegetation associations and sub-associations, whose structure is at least co-dominated by one facultative phreatophyte (typically either *E. camaldulensis* or *E. victrix*) (i.e. possesses vegetation described as being dominated by one or more species within the tree or tall shrub stratum and which includes a FPS as one of these described dominant species), but which is not co-dominated by any obligate phreatophytes and which typically does not possess OPS as an associated species.

Note: this is not a well-recognized term, and has been created for the purpose of this and other related studies from associated, well accepted terms such as facultative phreatophytes and GDV.

Furthermore, these distinctions are important as it allows a distinction between GDV likely to be significantly impacted by changes in the availably of groundwater (OPV) from that which is unlikely to see such impact (FPV). To this effect; dewatering, which causes localised lowering of groundwater levels, may have a significant impact on the health of communities represented by OPV but significantly lesser impacts (at times negligible impact) on communities represented by FPV.

For the purpose of this study and to aid in the process of identifying GDV and the distribution of hydrologically sensitive communities in the study area; this report will consider the presence of FPV and OPV.

2.4 POTENTIAL IMPACTS TO GROUNDWATER DEPENDENT VEGETATION

The response of GDV to changes in the availably of groundwater is predominantly influenced by; the local depth to groundwater (the antecedent conditions), the rate and magnitude of groundwater changes, and the surface water regime in effect at the time (including rainfall, floodwater, stored soil water and the influence climate has on each). Clearly the response of GDV to groundwater drawdown is also dependent on the water use strategy of each of the species comprising the vegetation community.

However it is also influenced by the density and structure of the GDV in question. Vegetation density and structure has a significant influence on the water demand per unit area of a community (Eamus *et al*. 2016), and the likelihood that this demand can be met by available water sources. Importantly it is often the proximity of groundwater that enables a community to establish a higher density and structural complexity to that of the broader riparian environment. Furthermore; it is this increased density and structural complexity (often along with increased diversity) which not only provides many of the associated ecological values of GDE’s but also determines the inherent degree of hydrological sensitivity held by GDV.

The combined influence of local physical, structural and compositional factors determine that under the influence of groundwater changes, the responses and changes experienced by GDV are often incremental and likely punctuated by periods of at least partial restoration. As a result it is critical to emphasise that for FPV, in the majority of cases and particularly those located in arid environments and outside of major river systems; groundwater levels naturally fluctuate such that groundwater access can regularly be very minimal, and at times non-existent. Furthermore, it is well established that one of the biggest hydrological drivers of riparian health is pore-water availability (the vadose soil resource) which is in turn driven by surface water inputs and fluxes associated with vertical infiltration processes. These inputs and fluxes are largely replenished/driven by rainfall events in the catchment, and so the degree to which groundwater changes contribute to plant water stress should not be overstated (although for FPV it can often be overstated). Instead the role and influence of groundwater on potential GDV needs to be well understood and carefully considered in the context of; alternative water source characteristics (e.g. vadose resource size, surface water regime etc.), the biomass driven water demands of the community, the inherent hydrological sensitivity of resident GDS, and the antecedent groundwater conditions.

2.4.1 Potential impacts to GDV as a result of changes to the availability of groundwater

There is general acceptance that reliance of GDV on groundwater decreases with increasing average depth to the water table (DOW 2009). This is based on the fundamental empirical observation of plant growth that root biomass decreases exponentially with increasing depth (Jackson *et al*. 1996) such that most GDS are likely to contain the majority of their root biomass within the top few metres of the soil profile. Obligate phreatophytes that are adapted to shallow water tables and a moderate degree of inundation and waterlogging typically penetrate directly into the saturated zone with a large mass of shallow roots, which enables them to draw a relatively large proportion of their water requirement from groundwater. In contrast, facultative phreatophytes that typically occur in environments with deeper water tables usually only access the saturated zone via a relatively small number of roots, such that groundwater comprises only a relatively small proportion of total plant water use. It follows that GDV established over shallow water tables is likely to be much more sensitive to groundwater fluctuations than GDV established over deep water tables.

For Australian systems, evidence suggests that reliance on groundwater is greatly reduced in areas where the water table exceeds a threshold depth, thought likely to lie between 7 m and 12 m (Benyon, Theiveyanathan and Doody 2006; DOW 2009; O'Grady *et al*. 2010; Zolfaghar *et al*. 2014), with 10 m suggested as a general threshold (Eamus, Froend *et al.* 2006). An assessment of depth to groundwater ranges of dominant riparian eucalypt species across four Pilbara study sites (all major Pilbara Rivers) indicated that this threshold sat at around 9 m (Loomes 2010). However; vegetation may access groundwater when the depth to groundwater is between 10 m and 20 m, but in such cases it is thought to be negligible in terms of the relative contribution to their water requirement (Zencich *et al*. 2002). Beyond 20 m depth, the probability of groundwater as a water source for vegetation is thought to be low. However, evidence suggests that eucalypt species within the Pilbara traditionally considered GDS (although only facultative phreatophytes), namely *E. camaldulensis* and *E. victrix,* are found to occur in areas where the depth to groundwater is between 10 m and 20 m (and deeper). Therefore such species are observed to occur in the range where the contribution of groundwater to water requirements is thought to be negligible.

Based on the above, it reasons that GDV is likely to be significantly impacted by changes in the availably of groundwater where the water table is drawn down below the rooting depth of the GDV. This impact is thought likely to decrease with depth to groundwater (pre-drawdown) given a lower dependence on groundwater. That is, lowering a naturally shallow groundwater table by even a small amount can potentially have significant impacts on obligate phreatophytes with shallow root systems (that depend on groundwater for a large proportion of their water requirement) while lowering a naturally deep groundwater table may not noticeably impact vegetation dominated by deep-rooted facultative phreatophytes (that depend on groundwater for only a small proportion of their water requirement). This potential for impact is also thought likely to decrease with decreasing vegetation density / structural-complexity given a lower pre-existing water demand. Obligate phreatophytes, often associated with increased density and structural-complexity generally have higher water demands while vegetation of lower density and structural complexity dominated by facultative phreatophytes tend to have lower water demands.

Broadly speaking; the ability of GDV to tolerate changes in the availably of groundwater depends on the species present (composition). Available information suggests that changes of less than 2 m can likely be tolerated, but that changes of greater than 2 m are often detrimental to plant health

(Marcam Environmental 1998; Naumburg *et al*. 2005; Braimbridge 2010). However, GDV may be able to tolerate changes of greater than 2 m when groundwater is naturally deep and vegetation density / structural complexity is lower. Alternatively; a more conservative change of 1 m may have a significant impact on GDV when groundwater is naturally shallow (taking into account the vulnerability of OPV that is dependent on groundwater almost exclusively to meet its water requirements).

Consistent with the preceding discussion, understanding the sensitivity of Pilbara GDV to changes in the availably of groundwater is complex. In the case of OPV, drawdown of groundwater below a threshold (approximately 4-5 m bgl) would be expected to result in the potential loss (death) of resident obligate phreatophytes, such that OPV may no longer remain (due to the associated structural and compositional changes). Deaths would not be expected for facultative phreatophytes (*E. camaldulensis and E. victrix*) or FPV growing in areas exposed to drawdown of groundwater below the same threshold given that FPV typically only depend on groundwater for a small proportion of their water requirement. Under this scenario the composition of FPV would likely remain stable and potential impacts are more likely to be encompassed by structural changes such as reductions in canopy cover and reduced stature (via branch drop) in a percentage of individuals. Alternatively, FPV which has established in naturally shallow groundwater and has realised significantly elevated biomass in the form of increased canopy cover and basal area, may experience significant mortality under similar groundwater access changes as the stand competes for shallow and likely inadequate vadose soil resources. As such, studies which attempt to define the sensitivity and likely responses of GDEs to changes in the availably of groundwater should be considered carefully and not literally applied to FPV; often reputed responses are based on more sensitive communities such as OPV, or substantially dense FPV which has established in naturally shallow groundwater (<4 m bgl).

2.4.2 Potential impacts to GDV as a result of rates of groundwater drawdown

The rate at which vegetation is impacted by drawdown is directly proportional to the rate of groundwater drawdown. Gradual drawdown results in a slower progression of reduced water availability and a greater opportunity for plants to adapt to the altered groundwater regime. Rapid drawdown however results in the acceleration of negative impacts, and unlikely potential for adaptation (Froend *et al*. 2004).

In theory, plant roots can maintain a functional connection with groundwater as long as the rate of water table decline does not exceed potential maximum rate of root growth (Naumburg *et al*. 2005). Little is known of the root growth rates of Pilbara GDV species. Evidence from the literature suggests that phreatophytic species would not be expected to maintain contact with groundwater when the rate of drawdown exceeds around 1 cm per day (Kranjcec, Mahoney and Rood 1998; Scott, Shafroth, and Auble 1999; Horton and Clark 2001; and Canham 2011), and once the water table falls below plant rooting depth, root elongation is contingent on there being sufficient water available from other sources to meet plant water requirements (Canham 2011). This suggests that a rapid rate of drawdown in the order of 1 m over several months would likely pose a high risk of impact to GDV (such as OPV), but a more gradual rate in the order of 0.5 m over several years would pose a much lower risk to GDV and particularly FPV.

Within the Pilbara, a section of Weeli Wolli creek directly adjacent to the Hope Downs 1 mine site (which does not receive surplus water discharge), was exposed to vertical drawdown rates under the creek and adjacent floodplain in the order of 2 cm per day until eventual removal of access to groundwater by riparian vegetation resulted (Section 6.3). Based on systematic monitoring of this real world example, the area in question has only experienced mortality rates within local FPS populations in the order of that potentially expected under natural variability levels (2.6%; Rio Tinto

2016b). Another real world example on the Weeli Wolli creek floodplain (directly adjacent to the Yandi JSE operation) saw vertical rates of drawdown in the order of 3 cm per day, and no significant mortality has been noticed in this area based on site inspection and analysis of historical remote sensing (Rio Tinto 2016b). Such examples may not provide direct evidence that roots systems are able to maintain contact with groundwater falling at rates above 1 cm per day, but must be at least equivalent to evidence that through other adaptive processes local FPS are not mortally reliant on low rates of change in groundwater height.

2.4.3 Potential responses of GDV to water stress associated with groundwater drawdown

The response of GDV to groundwater drawdown is typically incremental and highly variable. In the initial stages of drawdown, GDS begin to lose contact with groundwater and become increasingly dependent on soil moisture stored in the unsaturated zone (the vadose soil resource) to meet their water requirements. Contact with groundwater may be completely lost if the water table is lowered beyond the root depth, leading to complete reliance on the vadose soil resource. Further drawdown has little to no additional impact on local plants.

As the store of water in the vadose zone becomes depleted, short-term adaptive physiological responses are initiated (within days to weeks) to conserve water, the most important of which is stomatal closure in leaves restricting water loss (Eamus, Hatton *et al*. 2006). Stomatal closure prevents damage to leaf tissues as a result of dehydration, and prevents failure of the water transport system as a result of cavitation and embolism in xylem vessels. Stomatal closure also reduces the rate of carbon fixation, which in turn leads to a reduction in growth. If water stress is prolonged, adaptive structural responses may be initiated (over weeks and months to years) in an attempt to maintain contact with existing water sources, to explore new sources, or to reduce whole-plant water use in line with reduced water availability. This may include root proliferation and/or the shedding of leaves, branch drop (whereby the plant chooses to lose a particular branch or section of the canopy), and a general process of reducing the stature (or height and spread) of the plant.

Failing at least partial replenishment of moisture in the vadose zone (by vertical infiltration processes following rainfall, or inundation); when faced with severe depletion of water, stomata are kept closed for longer and progressively lower xylem water potentials are experienced (indicative of water stress) that may approach threshold levels beyond which plant tissues may sustain irreversible damage (such as cavitation) and the water transport system may collapse, resulting in plant death. Plants suffering from severe water stress over a prolonged period tend to display symptoms potentially including leaf discolouration (leaf chlorosis), wilting and curling, senescence of fine roots, substantial leaf shedding, branch death, and overall poor canopy condition. At the stand level, severe water stress manifests as increased chlorophyll fluorescence, reduced leaf area index and altered spectral signatures characterised by reduced ‘greenness’.

In addition to these responses prolonged water stress reduces the ability of certain plant species to reproduce, increases the mortality of mature plants, and seedling germination, recruitment and seedling success can also be significantly reduced (Capon and Brock 2006). Eventually, over many years to decades, some of the original species can be replaced, and an altered vegetation composition and structure more suited to the drier hydrological regime will ensue.

The timing and magnitude of the above described responses is highly variable across space and time, and among other factors, these events depend on the timing and magnitude of groundwater drawdown. However, it is also important to emphasise that this sequence of responses represents a relatively severe scenario residing at the more extreme end of the continuum of potential responses. In the case of FPV, it is more likely that groundwater drawdown would only cause structural changes, such as reductions in height, leaf area and possibly stand density, but not permanent compositional change involving an irreversible loss of GDS and replacement by new species.

3 LOCAL ENVIRONMENT

3.1 GEOLOGY

The Pilbara region comprises a large part of the ancient continental shield of Western Australia which is comprised of both Proterozoic and Archaean rocks. The latter constitute a block known as the Pilbara Block which is overlain by the Proterozoics deposited in the Hamersley and Bangernall Basins. The Hamersley Basin which occupies most of the southern part of the Pilbara Block can be divided into three stratigraphic groups; the Fortescue, Hamersley and Turee Creek Groups (Beard 1975).

Of the three stratigraphic groups, the Fortescue Group is the oldest component, resting upon a granite and greenstone basin. It consists mainly of basalt with included beds of siltstone, mudstone, shale, dolomite and jaspilite. This group forms the Chichester Plateaus and underlies the Hamersley Plateau. The Hamersley Group consists predominantly of jaspilite and dolomite, the former giving rise to deposits of haematite and limonite which are now worked as iron ore. These rocks constitute the Hamersley Range and Plateau. The Turee Creek Group is the youngest and is exposed mainly in the Ashburton Valley. It is composed of interbedded mudstone, siltstone, sandstone conglomerate and carbonate (Tyler *et al*. 1990).

Of these three groups, Hamersley is most relevant to the West Angelas area. Generally, 2.5 km thick, it contains both the Brockman Iron Formation and the Marra Mamba Iron Formation which together provide most of the known major iron ore deposits in the Pilbara region (Thorne and Trendall 2001).

In the West Angelas project area, the dominant feature is the Wunna Munna anticline, which plunges to the west, and contains a low-lying plateau of Jeerinah formation in its core. The composition of the member includes mudstones, shales, and ultramafic intrusive dolerite sills. The permeability and groundwater storage is generally low in this formation, except where there are local fracture systems associated with regional lineaments. Areas of low relief have been infilled with Tertiary and Quaternary sediments, up to 70 m thick, and include boulder beds and gravel, calcrete and silcrete, mixed sand and gravel and Channel Iron Deposit (Robe Pisolite) (Thorne and Trendall 2001).

Structurally, the anticline is paralleled both to the north and south by synclines of Brockman Iron Formation overlying lesser outcrop of Mt McRae Shale, Mt Sylvia Formation and Wittenoom Formation.

The Marra Mamba Iron Formation has significant permeability in fractured sections and surrounds the Jeerinah formation. The Marra Mamba Iron Formation is subdivided into three members. The uppermost Mt Newman Member hosts the majority of the mineralisation at West Angelas.

Within the study area the headwaters of Turee Creek East Branch (**TCEB**) and associated tributaries start at the upstream end in and adjacent to an area of the Jeerinah formation of the Fortescue geological group (Thorne and Trendall 2001). Passing through various formations of mafic intrusions (Fortescue group, Achaean age), and strips of Jeerinah formation they eventually travel into the valley floor Alluvium (Holocene age). Continuing west the key creeklines travel through Alluvium and then into the colluvium of the Ranges (Brockman iron formation) to the north (Thorne and Trendall 2001).

3.2 SOILS

Soils of the Pilbara region have been defined and mapped at the 1:2,000,000 scale by Bettenay *et al*. (1967). The dominant soil types covering the West Angelas area are shallow coherent and porous loamy soils with weak pedologic development.

Like most of the area, the dominant soil types covering the eastern half of the catchment are shallow coherent and porous soils with weak pedologic development. In the low rolling hills, which in places represent the surface expression of the Marra Mamba Iron Formation, extensive areas without soil occur. Those 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 (Beard 1975).

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 the low moisture holding capacity and poor nutrient status (Beard 1975).

On the alluvial plains, red alkaline 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.

Given the focus of the study area is on the riparian vegetation of the study area, the soils of interest consist of creek bed, bank, and terrace soils which are much more variable. Typically these soils consisted of Red-Brown Silty loams / Clay loams, in the western half, transitioning to more sandy loams, and sandy clay loams in the upper catchment areas. In general the Basalt parent rock of the Jeerinah formations occurring in the upper catchment areas, determine that the alluvial valleys and riparian zones have received a substantial amount of clay. As a result surface water delivered within such riparian systems tends to have greater residence times and result in increased biomass and ephemeral diversity in creeks and floodplains.

3.3 HYDROGEOLOGY

Groundwater flow is from east to west through the central valley (north of Deposit C), discharging through the calcrete platform and a broad gorge formation in KNP, then into the Turee Creek system. Hydraulic gradients are low and flow rates are thought to be moderate. The water table is generally deep, with some areas presenting shallower water such as the area approximately 1 km inside the KNP boundary where depth to water table seems to be in the realm of 5-6 m below the surface. Water quality in the Jeerinah formations of the area shows some chemical maturity which would indicate low recharge and poor hydraulic connectivity characteristic of an aquifer system comprising discontinuous or local fracture zones in an otherwise low permeability rock formation.

3.3.1 Hydrogeology - Deposit C

Based on information from piezometers installed in 2014, the water table elevation at Deposit C ranges between 635 mRL (approximately 55 m bgl) in the east and 623 mRL (approximately 67 m bgl) in the west. This is comparable with results obtained from recent down hole geophysical surveying (Rio Tinto 2015a).

Based on a groundwater elevation of approximately 630 m RL in nearby Deposit B, and an assumed regional groundwater flow direction to the east, it is apparent that there is a groundwater divide in the central area of Deposit C, in the vicinity of a dyke, possibly forming a barrier to groundwater flow (Rio Tinto 2015a).

3.3.2 Hydrogeology - Deposit D

Based on information from piezometers installed in 2013 and 2014, the water table elevation at Deposit D is nominally 625 mRL (i.e. approximately 58 m bgl). This is comparable with results obtained from recent down hole geophysical surveying, with the exception of a number of elevated groundwater levels, possibly associated with un-mineralised Banded Iron Formation (**BIF**) (Rio Tinto 2015a).

Based on evidence of minimal recharge (hydrographs in the area show no observable response to rainfall), it is anticipated that groundwater will be derived mainly from storage (Rio Tinto 2015a).

3.4 HYDROLOGY AND LOCAL CATCHMENT CHARACTERISTICS

The hydrology of the West Angelas area is dominated by small first-order streams and typically small catchment areas. The only major stream of the area is TCEB. The Turee Creek catchment is a fifth order sub catchment of the Ashburton River System. The Ashburton is a parallel river system with short streams ending on the alluvial plain of the Ashburton River in coalescing outwash fans.

The two main creeklines of Study Area are upper tributaries of TCEB. The confluence of these tributaries (approximately 1 km inside the eastern boundary of KNP) represents the start of the TCEB (the upstream end of Riparian Zone C; Figure 4-1).

Flows in all creek systems in the West Angelas area are ephemeral and there are no permanent surface water resources or springs. However, starting at a distance of approximately 50 km downstream of the study area, surface water remains available all year round in some river pools, waterholes and springs.

Paperbark Spring and Turee Creek Gorge are the nearest permanent surface water expressions, located approximately 28 km west-southwest of Camp Bore (in the Turee Creek Borefield area) and approximately 6 km northwest of Camp Bore respectively.

3.4.1 Hydrology - Deposit C

Deposit C is located on the northern foothills of a steep local ridge characterised by incised gullies. The ridge extends from east to west and at its highest elevation reaches approximately 850 m RL (Figure 3-1).

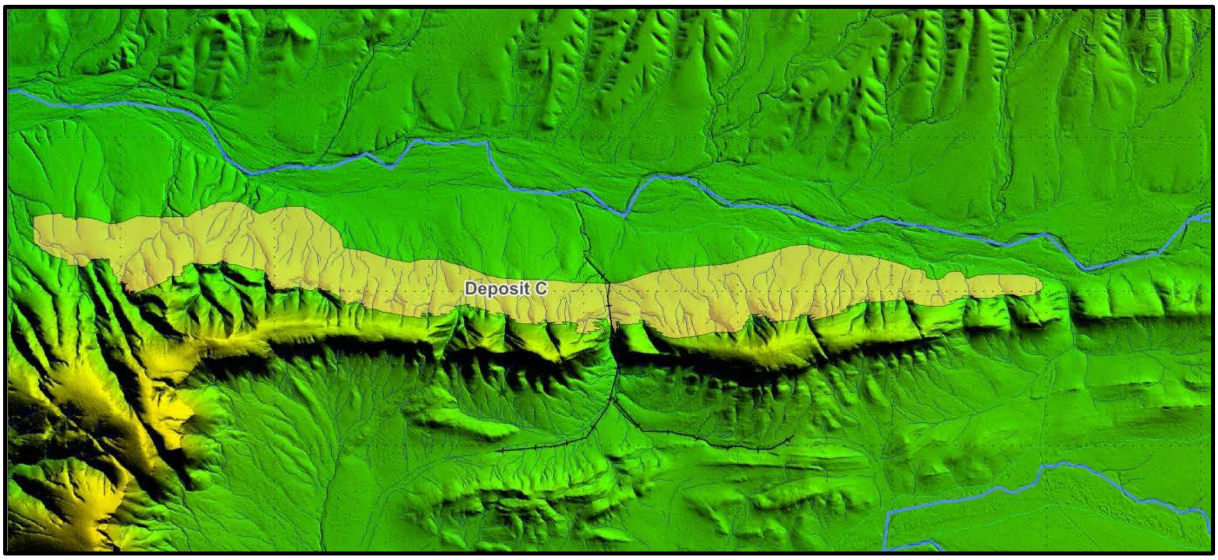


Figure 3-1: Local topography surrounding Deposit C

Deposit C is located immediately south of the headwaters of TCEB. Prior to any development across Greater West Angelas, TCEB at Deposit C had an upstream catchment area of approximately 237 km^2. Mining operations at Deposit A, B and E have removed approximately 85 km^2 (35%) of the contributing surface water catchment and therefore the catchment area contributing surface water to TCEB at Deposit C is now approximately 152 km^2 (Rio Tinto 2015a).

The hydrologic response to large rainfall events upstream of Deposit C may be altered by the presence of a rail line connecting West Angelas to the port. A significant portion (approximately 110 km^2 or 72%) of the contributing catchment flows pass through the culverts beneath the rail prior to reaching TCEB. These culverts have an attenuating effect on flows during large rainfall events.

3.4.2 Hydrology - Deposit D

Deposit D is located approximately 2 km south of Deposit C at the base of a range of steep hills that extend in an east-west direction. At their highest, the hills reach an elevation of approximately 1080 m RL (Figure 3-2).

The hills are characterised by steep, incised drainage channels which drain to the south. However as the drainage channels extend out from the hillside they transform into shallow, poorly defined drainage lines. Overland flow is dominant across the valley floor which has an elevation of approximately 680 mRL. The total catchment contributing to Deposit D is approximately 67 km^2 (Rio Tinto 2015a)

The main creek line in the vicinity of this deposit rises in the hills to the north east of the deposit. It flows south-westerly across the valley floor to the north east of Deposit D before flowing south-westerly across Deposit D. The creek merges with TCEB approximately 6 km north west of the eastern extent of Deposit D.

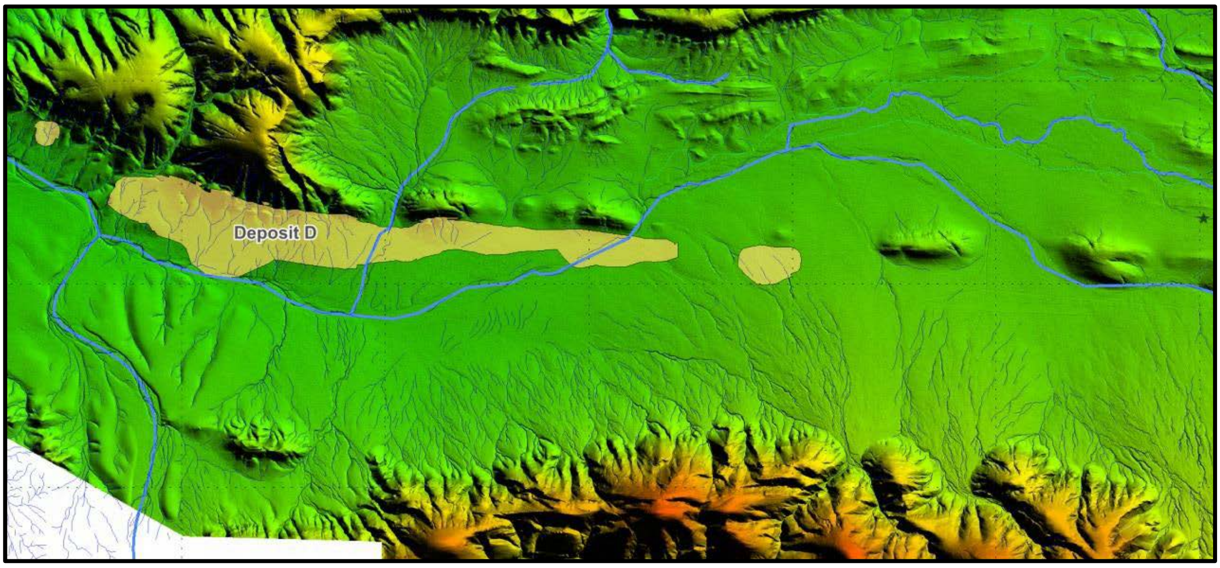


Figure 3-2: Local topography surrounding Deposit D

3.5 PROPOSED CATCHMENT CHANGES

At the eastern KNP boundary within the Study Area, the natural catchment size of TCEB is approximately 340 km^2. Taking into account the north-western tributary which joins TCEB just downstream of the KNP boundary, the total upstream catchment is approximately 570 km^2. At this point on TCEB, the upstream catchment size is at the lower end of the spectrum when compared to the end point catchment size of the majority of named creek systems in the Hamersley Ranges (shown in Table 3-1).

Table 3-1: Major Creeks of the Hamersley Range and their respective catchment sizes

Creek	Approximate Catchment Size (Km^2)
Mindy Mindy Creek	372
Joffre Creek	539
Giles creek	598
Munjina Creek	767
Caliwingina Creek	796
Coondiner Creek	883
Mungarathoona Creek	895
Upper Angelo River	1,225
Weelumurra Creek	1,419
Spearhole Creek	1,431
Fortescue south Creek	1,480
Caves Creek	1,532
Boolgeeda Creek	1,623
Weeli Wolli Creek	1,736
Upper Hardy River	1,844
Upper Beasley River	2,053
Duck Creek	2,149
Upper Robe River (Bungaroo creek)	2,204
Marillana Creek	2,230
Turee Creek East Branch	2,284
Seven Mile Creek	2,585
Turee Creek	6,753

Upstream catchment size typically plays an important role in determining the magnitude and frequency of surface water inputs received by riparian habitats at a particular point in a creek system. The higher the magnitude and frequency of surface water inputs, the more likely a creek system is to support dense and structurally complex riparian vegetation dependent on an elevated degree of moisture availability.

Furthermore, other factors such as the unique characteristics of the local hydrogeology, the distribution of groundwater recharge zones, and the characteristics of local aquifers also have an important influence on the riparian vegetation which develops. As a result, and broadly speaking; the catchment size of the eastern tributary of TCEB (of relevance to the study area; and represented in Figure 3-3 as draining the pink shaded catchment area), is considered unlikely to support dense or structurally complex vegetation dominated by key GDS. Instead it is likely to support riparian species of low groundwater dependence scattered throughout relatively open riparian vegetation. Just inside the National Park boundary, where a local hydrogeological feature (a calcrete or carbonate sheet formation) is present and where the north-western tributary (dissecting the green catchment in Figure 3-3) has a confluence with TCEB, the potential to support dense or structurally complex vegetation and moderately groundwater dependent vegetation becomes elevated. This elevated potential is attributable to the almost doubling of catchment size at this point on TCEB, but also to the calcrete surface deposits indicating the likely presence of a subsurface geological feature (likely the Wittenoom formation running under that vicinity) which may manipulate groundwater flows closer to the surface.

Figure 3-3 shows the two key catchment zones of relevance to the study area. The east catchment (represented by the pink shading), which represents a catchment of approximately 340 km^2, encapsulates the main tributary which drains the study area and associated deposits. This is the catchment area which will be further reduced by approximately 2% (previous catchment changes already realised in the area in the order of 15%) due to proposed mining at Deposits C and D. The north-western catchment (represented by the green shading in Figure 3-3), which represents a catchment of 235 km^2, and which importantly joins in the vicinity of elevated potential for supporting GDV; will remain unaltered by development.

3.6 PREDICTED GROUNDWATER CHANGES

Different modelled predictions for the rates and magnitude of drawdown propagating out from the Proposal area are a product of differing groundwater yields which eventuate in order to achieve the required in pit groundwater changes. For the propose of modelling these are defined as specific yield (Sy) scenarios, and for the Proposal 1% (worst case), 3% (base case), 5% and 10% (best case) specific yields were modelled for.

Of most relevance to this study is that drawdown modelled to propagate towards and into the bounds of KNP. For this reason only the data relevant to predictions at two bores is presented here: one 200 m outside the KNP boundary (MB16WAW0005); and one near the area of most interest approximately 2.5 km inside the KNP boundary (WANG14).

Post mining, at the MB16WAW0005 bore, a maximum drawdown of 4 m and 10 m is observed at the highest (Sy = 10%) and lowest (Sy = 1%) specific yield scenario, respectively. A drawdown of 6 m is predicted for the base case (Sy = 3%). Maximum drawdown at the western end of Deposit C is modelled to occur from the 2040's onwards.

At WANG14 bore modelling results show that during mining the predicted groundwater level declines over time for the scenario (Sy = 1%) and the base case (Sy = 3 %). A maximum reduction of approximately 3 m is predicted at scenario (Sy = 1%) when mining ceases (December 2030). Predicted water levels continue to decline post mining, with a maximum decline of approximately 2 m to 8 m being predicted in scenarios with Sy = 10% and 1%, respectively. For the base case, the maximum decline of 5 m will be reached in 2080. Maximum drawdown in the area around WANG14 is likely to occur from 2040s onwards. Downstream of WANG14 within the riparian zone of key interest; the likely influence of this drawdown is predicted to be even smaller.

Based on the modelled specific yield response scenarios at WANG14; vertical height changes to groundwater potentially experienced within KNP and downstream of WANG14 are likely to be in the order of 10-20 cm per year, with the Lowest rate being approximately 2 cm/yr (Sy = 10%), the base case rate being approximately 10 cm/yr (Sy = 5%), and the worst case scenario of approximately 40cm/yr (Sy = 1%) (Figure 3-4). Table 3-2 shows the actual predicted changes to groundwater height (based on the modelled specific yield scenarios) and the maximum rates of vertical change predicted within the two most relevant riparian zones of TCEB (Figure 4-1).

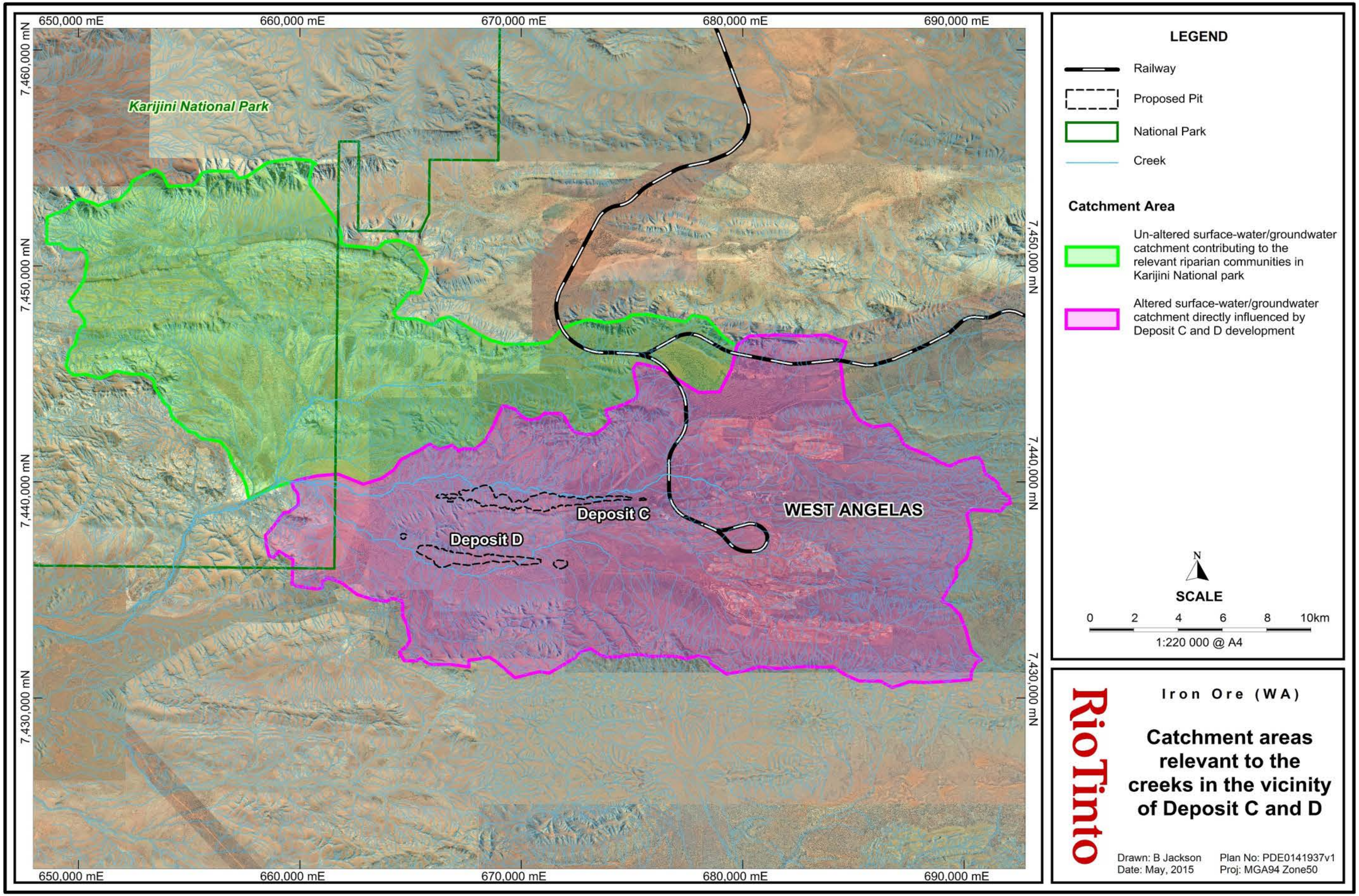


Figure 3-3: Catchment Areas Relevant to the Creeks in the Vicinity of Deposit C and D

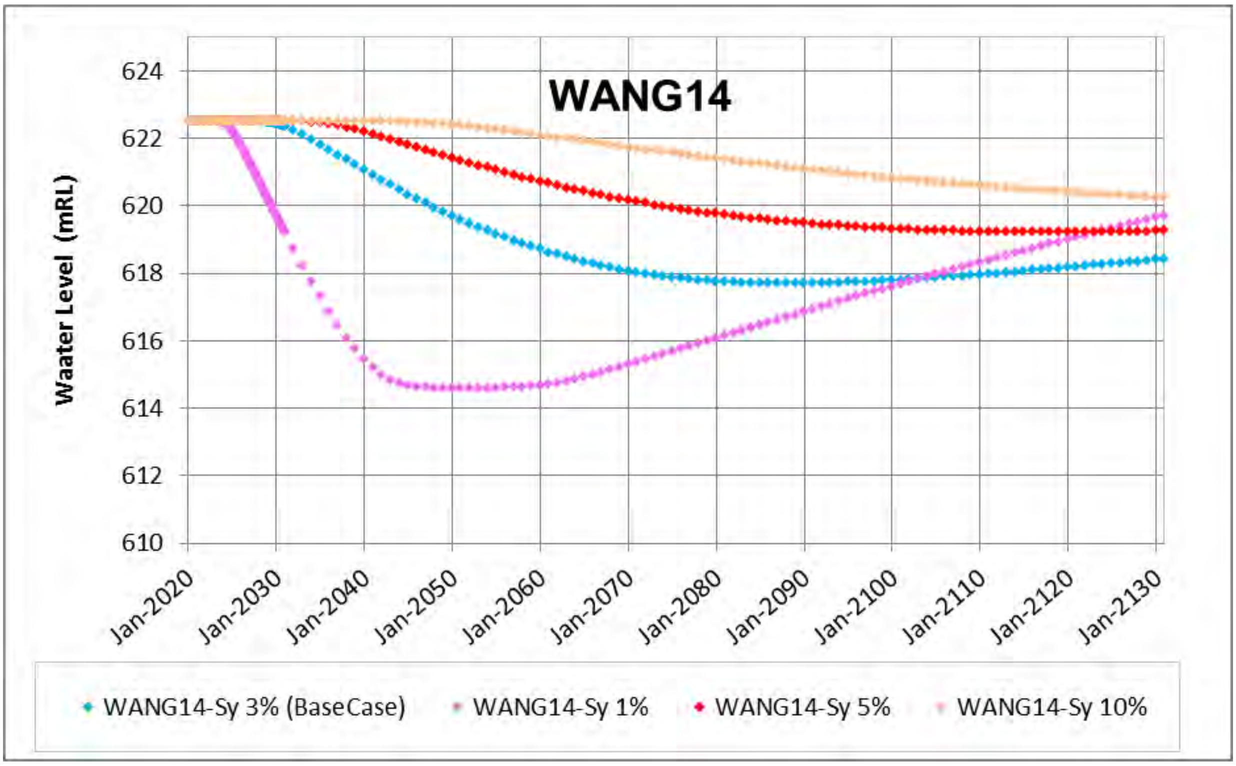


Figure 3-4: Predicted Water Levels and timing at the WANG14 Bore inside KNP

Table 3-2: Actual predicted changes to groundwater height (based on the modelled specific yield scenarios (Rio Tinto 2017)) and the maximum rates of vertical change predicted within the two most relevant riparian zones of TCEB.

Specific Yield (Sy) GW modelling scenarios	Modelled GW drawdown (vertical change) (m)	Fastest rate of vertical GW decline during the modelling period (cm per year)
Sy10% (best case)	2.25	3
	After 110 years	for ~80 years
Sy5%	3.2	6.5
	After 90 years	for ~40 years
Sy3% (base Case)	**4.7**	**10.5cm/year**
	After 60 years	for ~40 years
Sy1% (worst case)	7.96	39.5
	After 25 years	for ~20 years

GW = groundwater

3.7 PREVIOUS VEGETATION MAPPING AND OTHER RELEVENT WORK COMPLETED

Vegetation and flora surveys have been undertaken across the West Angelas region since 1979, covering an area in excess of 61,600ha. A number of these previous surveys are relevant to the current Study Area (Table 3-2). The boundaries of previous surveys relevant to the current study area are shown in Figure 3-5. Despite this, the majority of the riparian system, which is the focus of this study, falls outside of previous mapping. Furthermore; apart from work conducted by the author (Rio Tinto 2009), the vegetation mapping presented as part of previous work has been fairly broad, and has typically not differentiated the vegetation of the main creek bed (the incised channel zone) from that of the floodplain.

Table 3-3: Previous Flora and Vegetation Surveys

Report title	Author	Year
Flora and vegetation surveys of Orebody A and B in the West Angelas Hill area, an area surrounding them, and of rail corridor options considered to link them to the existing rail line	M. Trudgen and Associates	1998
Flora and Vegetation Assessment of the Proposed West Angelas Discharge Creekline Corridor (WADCC)	Rio Tinto Iron Ore	2009
A Flora and Vegetation Survey of the Proposed West Angelas Gas-Fired Power Station and Pipeline Corridor	Biota Environmental Sciences	2010
Flora, Vegetation and Fauna Assessment of the Re-Aligned Gas Pipeline Corridor at West Angelas	ENV Australia	2011
Flora, Vegetation and Fauna Assessment of the West Angelas Gas Pipeline Deviation	ENV Australia	2012
Greater West Angelas Vegetation and Flora Assessment	Ecologia Environment	2012
Statement Addressing the 10 Clearing Principles for West Angelas Deposit C Drill Program	Biota Environmental Sciences	2013

3.8 POTENTIALLY GDS LIKELY TO OCCUR IN THE STUDY AREA

From previous vegetation surveys and anecdotal knowledge of riparian vegetation that occurs along the Turee Creek East branch (**TCEB**) and its tributaries, two key species with potential groundwater dependence are known to be present in the study area: *E. victrix* and *E. camaldulensis.*

The TCEB typically supports populations of medium to large woody species such as *Acacia citrinoviridis* and *Eucalyptus xerothermica,* however the area is not known to support significant populations of other notable medium to large woody species, such as *Melaleuca glomerata, Corymbia candida, Acacia coriacea* subsp. *pendens* or *Atalaya hemiglauca* (often co-occurring with *E. victrix* and *E. camaldulensis)*. Very little is known about the water use, water sources or rooting depths of these species, as well as their potential groundwater dependence.

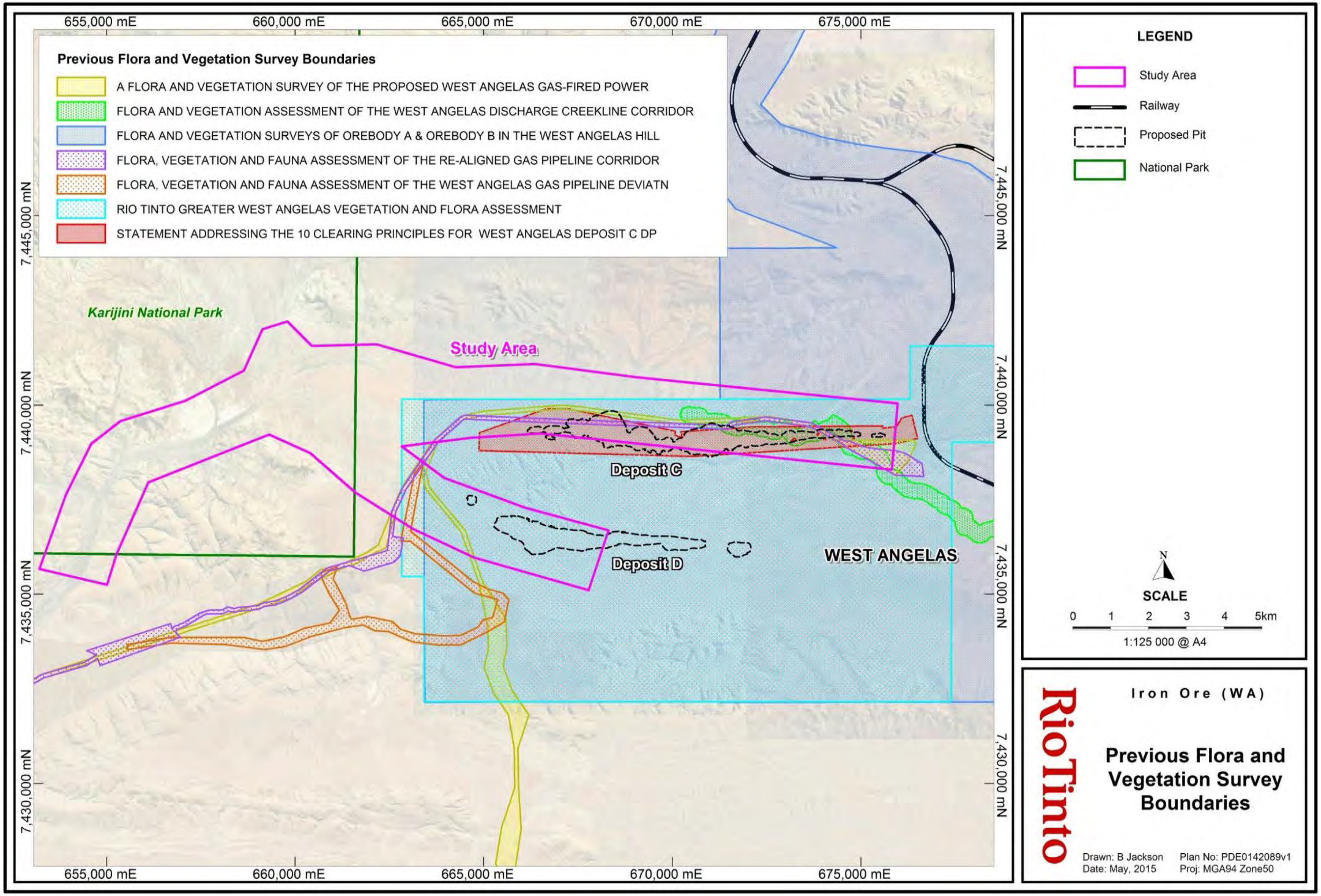


Figure 3-5: Previous Flora and Vegetation Survey Boundaries

4 METHODS

4.1 FIELD SURVEY

A field survey was conducted by Jeremy Naaykens (Botanist, Rio Tinto) and Hayden Ajduk (Botanist, 360 environmental) from 12th to 16th April, 2016. The field survey focused on the more substantial riparian vegetation formations within and adjacent to the proposed development, and within KNP.

Clarification was sought from the Department of Parks and Wildlife (**Parks and Wildlife**) as to whether a Regulation 4 Permit was required for the proposed survey within KNP. Parks and Wildlife advised that a Regulation 4 permit was not required as no physical plant collections were required to be made, and no disturbance activities such as camping, driving on park tracks or setting up of in-situ instrumentation were planned.. The data collected as part of this survey is to be provided along with this report to Parks and Wildlife as part of requirements associated with the collection of data within a conservation estate for commercial purposes.

4.2 GROUNDWATER DEPENDENT SPECIES PRESENCE

In order to determine the structure and composition of local riparian vegetation, produce vegetation mapping for the study area, and conduct basal area assessments of riparian vegetation, traverses of the creek bed and floodplain zones were conducted. Significant focus was placed on determining the suite of potential GDS present. Within the study area traverses were done intermittently, along with the other survey tasks, at various points along the two smaller creeklines which run parallel to Deposits C and D while the entire length of the stretch of TCEB within the KNP was traversed (in most cases twice i.e. down and back) to assess the presence of potential GDS.

Given the nature of the riparian ecosystems in the local area and the smaller size of the upstream catchment in the vicinity of the study area (see section 3.5), two key GDS were predicted to occur; *E. victrix* and *E. camaldulensis*. Furthermore, it was anticipated that *E. camaldulensis* (along with other woody mesic species) would be relatively uncommon, and given the apparent dominance of *E. victrix* within the riparian tree strata (from previous vegetation mapping), particular focus was given to determining the presence of *E. camaldulensis*. As a result, a comprehensive survey of trees within the incised channel zone of TCEB was conducted with a level of scrutiny such that it was unlikely that many, if any *E. camaldulensis* individuals were missed.

Furthermore, all *E. camaldulensis* individuals were identified using floral and vegetative characters in conjunction with the hand lens/leaf morphology method, developed by the author (Rio Tinto Botanist, Jeremy Naaykens). This method involves the use of a hand lens (held behind sunlit leaves) and fresh leaves from target individuals. This identification technique involves an assessment of leaf characters via sunlight illumination at magnification. This technique relies on the fact that *E. camaldulensis* leaves possess true oil glands (while *E. victrix* does not), larger more broadly spaced and erratically shaped lateral veins, darker green reticulum and more brightly coloured veins. *E. victrix* leaves do not possess true oil glands; have closer, relatively uniformly spaced and parallel lateral veins, dull green reticulum and duller coloured lateral veins. All *E. camaldulensis* were also way-pointed so that a local distribution map could be produced for this species. To improve clarity when talking about different sections of riparian vegetation and parts of the creek-system, a series of zones were created across the study area and presented in Figure 4-1.

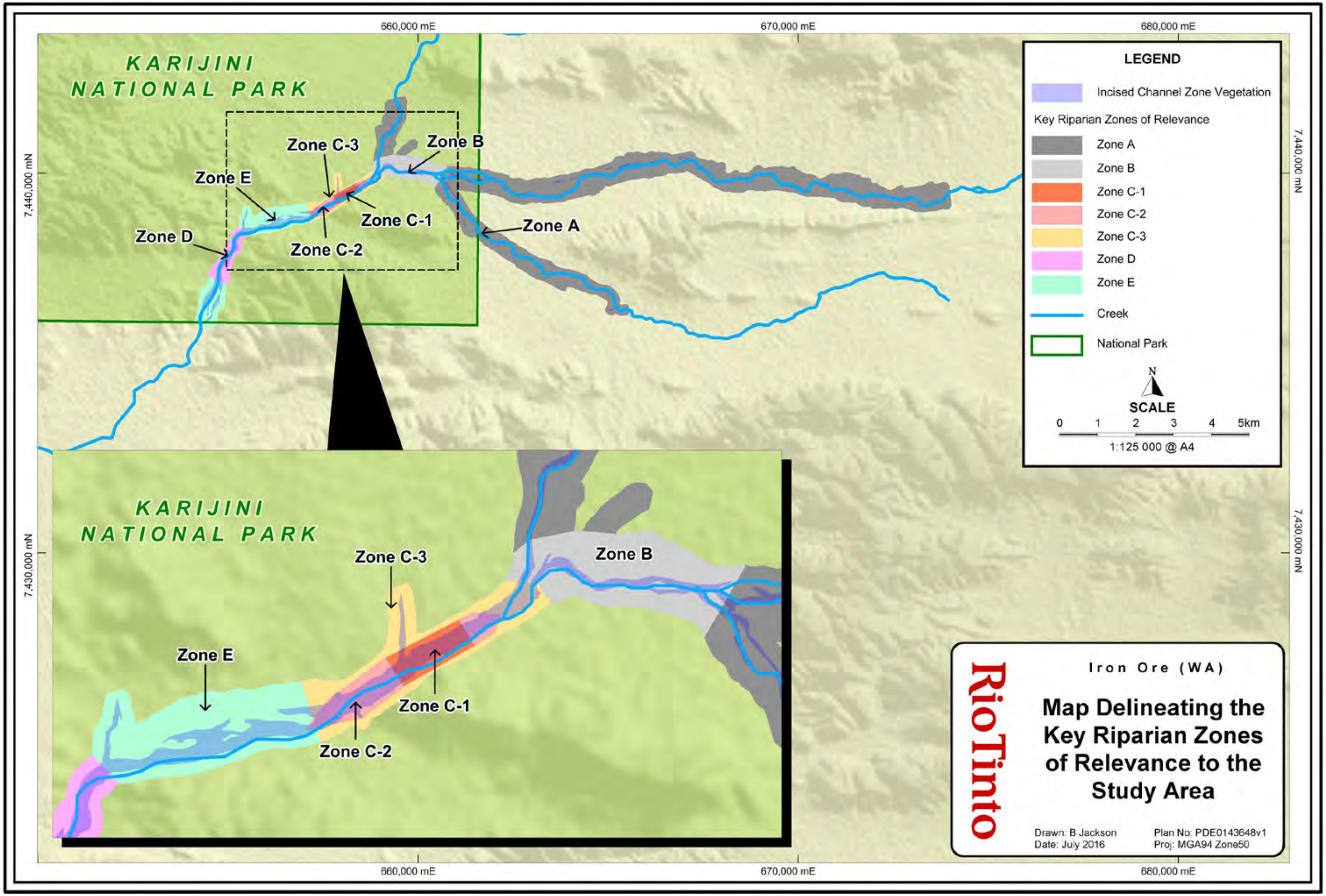


Figure 4-1: **Map delineating the Key Riparian Zones of Relevance to the Study Area**

4.3 VEGETATION MAPPING

The vegetation mapping of the study area expands upon riparian mapping provided as part of previous flora and vegetation surveys conducted in the region, in particular, vegetation mapping by Rio Tinto (2009), as this survey presented a riparian vegetation mapping scale most appropriate to displaying potential groundwater dependence. The vegetation mapping created as a result of this current survey has attempted, wherever appropriate, to perpetuate a vegetation model of similar scale and detail to the mapping units created as part of the 2009 study. The 2009 study focused on the potential impacts of surplus water discharge to one of the key tributaries of relevance to this study (that draining the eastern catchment; Figure 3-3), and so represents a study with similar objectives.

The vegetation mapping was completed after a single phase of sampling work, however it drew upon previous sampling data from 15 quadrats/relevés (from five separate historical surveys) which fell within the riparian zones of the eastern extent of the study area. Nine of the 15 quadrats used in addition to the data acquired in the field component of this study came from the relatively recent 'Greater West Angelas Vegetation and Flora Assessment' conducted in 2012. A list of the name, position and spatial coordinates of each of these quadrats can be found in Appendix 1.

Foot traverses conducted for the purpose of compiling vegetation notes and sampling flora and vegetation at strategic sites, were completed across the study area. As part of this sampling 23 relevés were sampled (not exhaustively as the focus was on vegetation) throughout the study area, generally being conducted in the vicinity of Basal area plots. The location details of these relevés are presented in Appendix 2. This data collection was completed while also collecting other data such as conducting basal area assessments of riparian communities and determining the presence of potential GDS. Boundaries of the vegetation units observed and considered during this survey were partly delineated during these foot traverses, then transferred onto aerial photography and/or location coordinates were recorded. The polygons were subsequently digitised and refined based on sampling data and consideration of the presence of potential GDS as well as the results of the basal area assessments (which provided an indication of vegetation density).

Vegetation descriptions were formulated according to the vegetation classification system developed by Keighery (1994) (see Appendix 3). The riparian vegetation units presented in this study were generally described at the sub-association level (or level VI) as defined under the National Vegetation Information System (DoE 2014).

4.4 BASAL AREA ASSESSMENTS

Basal area is the area of a given section of land that is occupied by the cross-section of tree trunks and stems at their base. The term is typically used in forest management and forest ecology. In most disciplines, this is usually a measurement taken of the diameter at breast height (**DBH**) (1.3 m) of a tree above the ground and includes the complete diameter of every tree in a space, including the bark (Barbour *et al*. 1987). Measurements are typically made for a sampling plot and this is then scaled up for 1 ha of land for comparison purposes to examine the magnitude of the standing biomass, or a forest's productivity and growth rate. For the purpose of this study three types of basal area assessment were made. The location of all basal area assessment plots along with other sampling points and survey effort is presented in Figure 4-2.

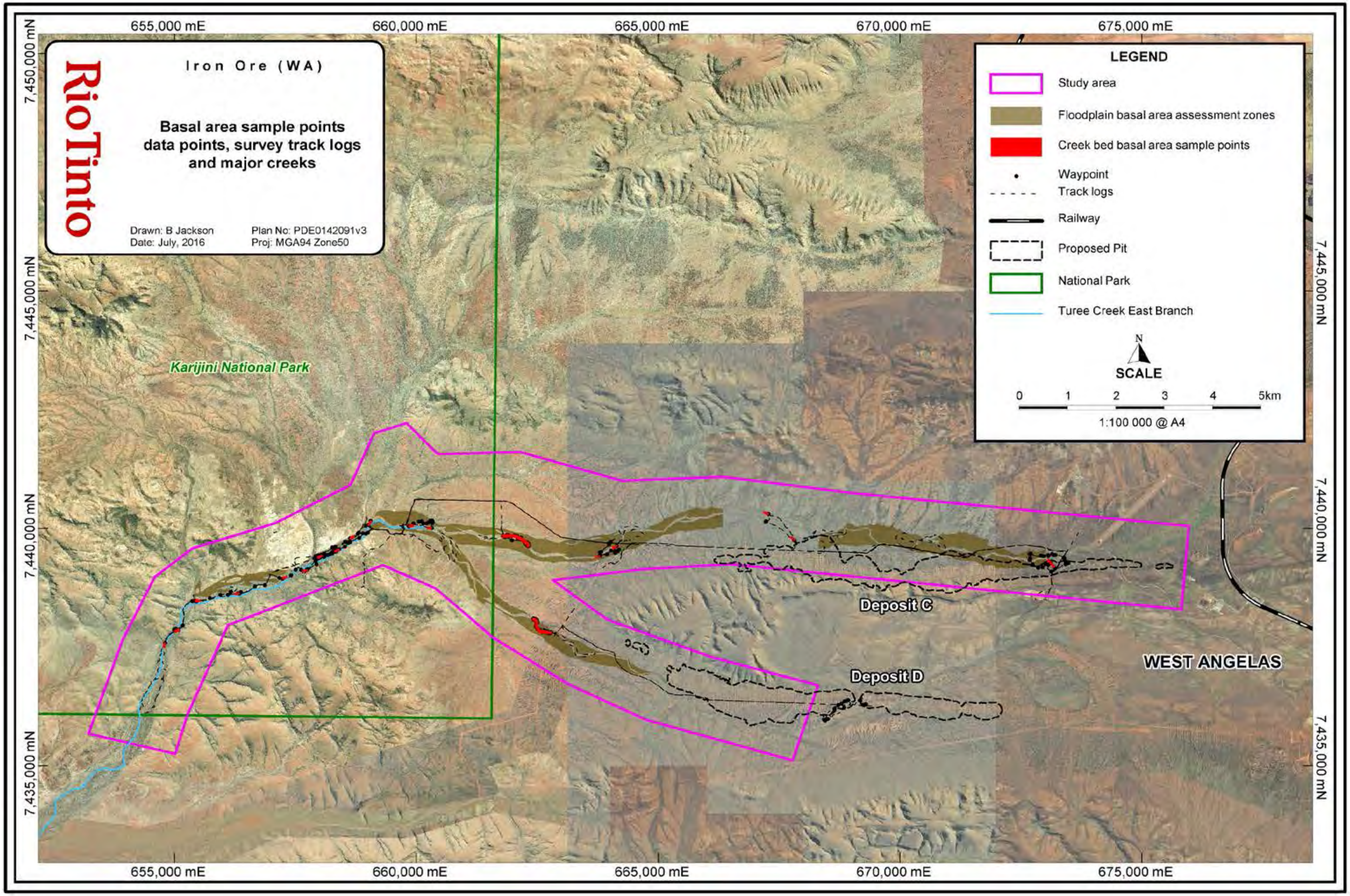


Figure 4-2: Basal Area Sample Points Data points, Survey Track Logs and Major Creeks

Incised Channel Assessment

The first and more traditional basal area plot type was conducted in the incised channel zone of the larger tributaries, and was most often used when the tree density was low to moderate. Plots were 100 m long and were either as wide as the interpreted coverage of vegetation associated with the incised channel zone (in narrower tributaries), or limited to approximately 40 m in the broader incised channel zones. In the narrower incised channels (where the width of the community determined the plot width), the outer bounds of the vegetation which would be included in the plot comprised the main bank feature and a small section of the terrace. In the broader incised channels, the width was often limited to the riparian vegetation interpreted as associated with only one (of potentially multiple) low or secondary flow channel. The corners of these plots were all way-pointed in the field, so that, their bounds and associated spatial area could be easily digitised on GIS software (after field sampling).

Within the designated plots, the DBH of all eucalypt trees and those *Acacia citrinoviridis* individuals which were classified as trees (i.e. no stem branching occurred below breast height) was measured and recorded. The total DBH for the plot was then calculated and divided by the number of hectares the plot covered. The resulting basal area provided an indication of the standing tree biomass of the incised channel zone and associated low flow channel. See Figure 4-3 below for examples of the plots associated with this assessment type.

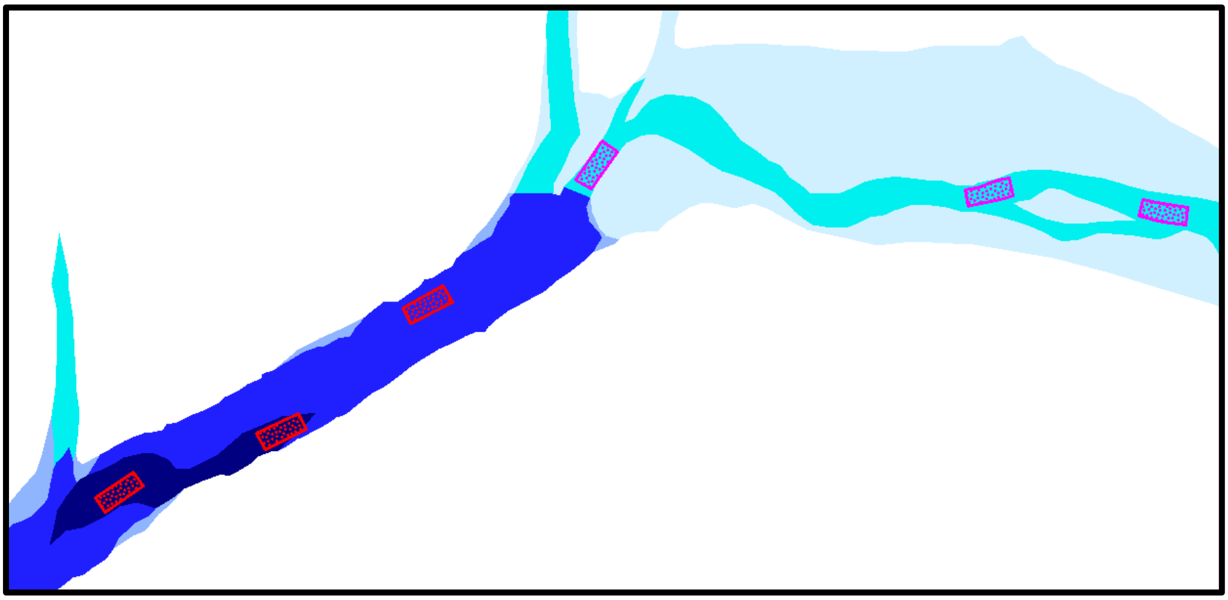


Figure 4-3: Examples of the position and extent of Incised channel Basal area assessment plots

Pink bounded plots represent plots in narrow incised channel zones where the width of the plot is constrained by the width of the vegetation unit, red bounded plots represent plots in broader incised channel zones where the width of the plot is constrained to approximately 40 m.

Low Density Incised Channel Assessment

The second and less traditional basal area plot type was conducted in the incised channel zone of creek sections where the tree and shrub density was relatively low. For this plot type, botanists traversed a much longer representative stretch of the creek channel, measured the DBH and recorded a waypoint for all trees interpreted to fall within the incised channel zone. The start and end points of these plots were also way-pointed in the field so that their bounds and associated spatial area could be interpreted from the aerial photo and associated tree waypoint distribution and thus digitised on GIS software.

This technique allowed much longer sections of creek to be sampled in a similar period of time as the smaller plots (mainly due to them not requiring boundary tapes to be used). However, this technique relies on the extent of the plot being mapped at a desktop level (after field sampling) by interpreting the bounds of the plot from aerial photography, associated vegetation signatures, and the plotted tree waypoints from the field work conducted. Once the plot is digitised at the desktop level, the combined basal areas of all trees within the plot can be compared to the spatial area of the plot in hectares to produce a basal area per hectare.

Within the designated plot, the DBH of all eucalypt trees and those *Acacia citrinoviridis* individuals which were classified as trees (i.e. no stem branching occurred below breast height) was measured and recorded. The total DBH for the plot was then calculated and divided by the number of hectares the plot covered. The resulting basal area provided an indication of the standing tree biomass of the incised channel zone and associated low flow channel. Two plots were assessed using this technique, and both were in the order of 600 m long, and as wide as the interpreted coverage of vegetation associated with the incised channel zone. See Figure 4-4 below for examples of the plots associated with this assessment type.

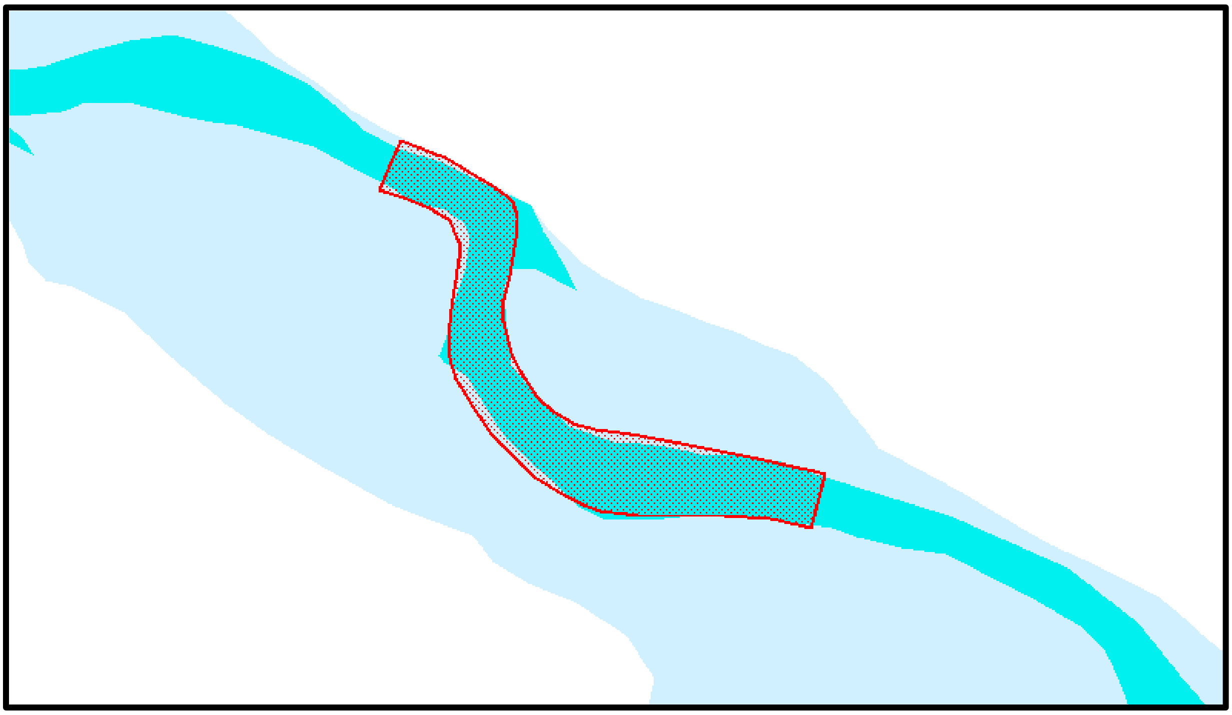


Figure 4-4: Example of the position and extent of low density Incised Channel Basal area assessment plots

Red bounded polygon represents this larger sized plot (in this case it is approximately 600 m long and 30 m wide) along the incised channel zone in an area of low tree and shrub density.

Floodplain Assessment

The third basal area plot type was somewhat experimental, and was conducted on the floodplain zone of the relevant tributaries in the study area. The floodplains covered large areas and the tree density was relatively sparse with only scattered to isolated trees throughout. This significantly increased the potential to miss trees, and as such an alternative method was trialled for basal area assessment in this habitat. For this plot type, botanists would periodically traverse parts of the floodplain adjacent to the incised channel plots to measure the DBH of a sample of trees in the lateral extent of the floodplain. From this periodic sampling, a small database (a total of 85 trees sampled) of floodplain tree DBH was compiled and then a combined basal area for the sampled database of trees was calculated. Mapping of the floodplain vegetation units were then used to provide the spatial boundaries of the floodplain zone for basal area assessments. To determine the bounds of these plots, the floodplain zone of relevant tributaries in the study area were partitioned at a desktop level into separate reaches thought to be representative of areas of increasing catchment size or changing topography. Following this, the aerial photography of each reach was interpreted for the presence of floodplain trees via a visual analysis of canopy and shadow signatures in order to waypoint all visible floodplain trees. Once all trees were way-pointed, the total number of floodplain trees was calculated for each reach and then a basal area for the reach was extrapolated from the total basal area calculated from the field database of floodplain tree DBH. To do this the total number of trees in the reach was divided by the number of trees in the database and then this result was multiplied by the combined basal area for the field database. This number represented the extrapolated total basal area for the floodplain reach, and this number divided by the total area of the reach (in ha) would finally give an indication of the average basal area per hectare for the relevant floodplain reach. This calculation is shown in the following formula which was used to calculate an extrapolated floodplain basal area for each reach:

$$\text{Floodplain Basal Area (Per Hectare)} = \frac{\left[\left(\dfrac{\text{Total \# of trees interpreted in floodplain Reach (e.g. 185)}}{\text{Total \# of trees recorded in field database (floodplain trees – e.g. 95)}} \right) \times \text{Combined Basal area from field database (floodplain trees)} \right]}{\text{Total number of hectares in Floodplain reach}}$$

The floodplain habitats of the Study Area were considered unlikely to contain moderately GDS. Therefore, in combination with very-low tree densities (inherent within floodplain habitats), the low potential for groundwater dependence determined that an extrapolated basal area was adequate for the purpose of giving a broad scale indication of basal areas within floodplain habitats.

Five floodplain plots were assessed using this technique; all were in the order of 2-5 km long and as wide as the interpreted coverage of vegetation associated with the floodplain zone. See Figure 4-5 below for an example of the plots associated with this assessment type.

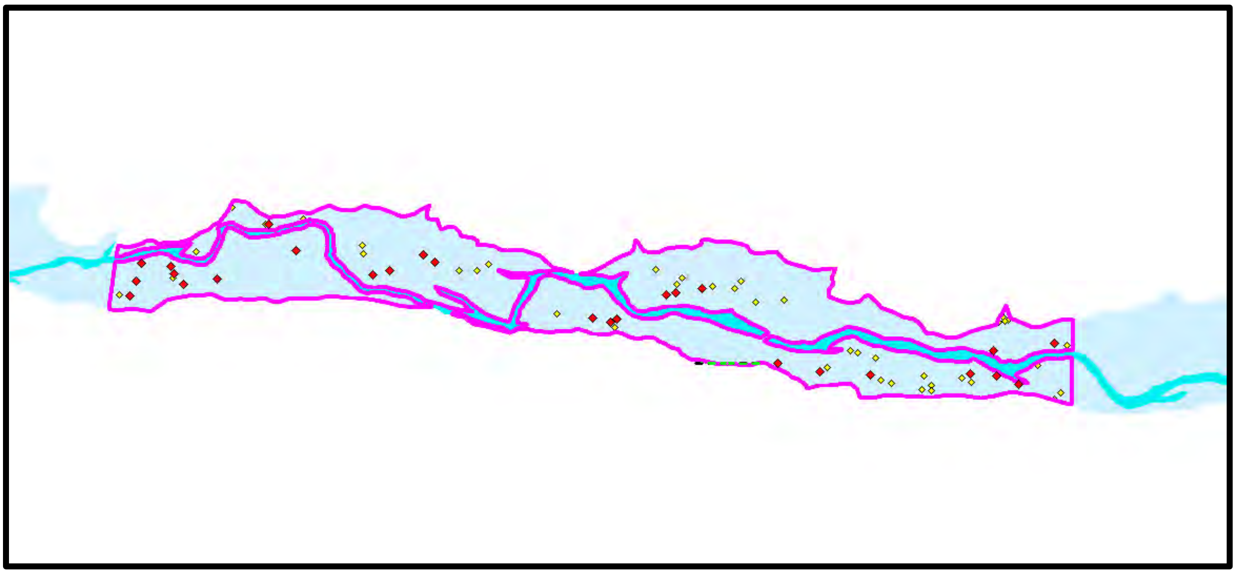


Figure 4-5: Example of the position and extent of the floodplain Basal area assessment plots

Pink bounded plot represents a floodplain plot (in this case, approximately 3.5 km long and 200-300 m wide) assessed via desktop extrapolation (by plotting trees of aerial photos – diamond shaped dots above) throughout the floodplain of a relevant stretch of creek in the study area.

4.5 GROUNDWATER DEPENDENT VEGETATION INTERPRETATION AND RISK MAPPING

Typically for Environmental Impact Assessment (**EIA**) purposes, the initial interpretation of the likelihood that a vegetation community represents GDV has been done purely on the basis of the presence of traditionally accepted groundwater dependent tree species. In the Pilbara, this has generally been limited to the presence/absence of three key species (*M. argentea*, *E. camaldulensis*, and *E. victrix*), but has also at times considered some potentially vadophytic species such as *E. xerothermica*, *Corymbia candida, Acacia coriacea, Atalaya hemiglauca* and certain large shrubby Melaleuca species. Such a method has generally been accepted within the realms of inventory or baseline type studies.

Along with GDS presence and sensitivity; the standing biomass per unit of area established by the riparian community also has a significant influence on the potential groundwater dependency of that community, as it in turn, influences the resultant water demand per unit of area. In fact; models developed for some arid land riparian species (using both hydrological and vegetation datasets) have shown that stand structure is strongly related to water availability (Stromberg *et al*. 1993). This relationship has shown that there are typically thresholds associated with biomass indices such as basal area and stem density below which the presence of groundwater is typically not limiting to survival. In such situations it's apparent that the available vadose soil water resource is more than likely to be adequate enough to sustain minimum water availability for the resident biomass through typical periods of climatic variability. For the floodplain and incised channel zone of the tributaries of TCEB which occur in the study area (but outside of KNP) it is predicted that the basal area (and stem densities) of the resident tree strata is quite low (likely well below the realm of 10 m^2/ha), and is therefore likely to be well below the threshold which would typically indicate reliance on groundwater for survival. For TCEB itself (i.e. the larger riparian system within KNP) the likelihood that basal area is below this threshold is unclear, but apparently reduced.

This relationship is shown in work by Stromberg *et al* (1993) in their paper "Vegetation-Hydrology models: implications for management of *Prosopis velutina* Riparian ecosystems", where the physiology of Mesquite in arid land riparian communities was examined, and relationships established between pre-dawn/midday leaf water potentials, depth to groundwater and various biomass indices such as basal area and Leaf area index. This study showed that a depth to groundwater greater than 20 m (i.e. generally inaccessible by trees) typically resulted in Mesquite leaf water potentials in the realm of -3.5 MPa and lower, which in turn was generally shown to have a relationship with a stand basal area of less than 5-10 m^2/ha. Groundwater depths in the realm of <10 m (i.e. generally accessible by trees) showed much higher leaf water potentials, and basal areas significantly greater than 10 m^2/ha. While these results are not directly applicable to arid Pilbara riparian ecosystems, the relationships and models developed are indirectly applicable and allude to relationships between stand biomass indices and groundwater dependence which can be more broadly applicable throughout the discipline of vegetation ecology.

As a consequence of the relationships descrbed above; this study has attempted to incorporate consideration of community water demand (as a product of standing biomass per unit of area) into an interpretation of groundwater dependence and associated sensitivity. The chosen proxy for water demand used by this study was the biomass index know as basal area. The proposed threshold of elevated tree derived biomass to be used by this study is 9.0 m^2/ha (decided based on the results of Stromberg *et al.* (1993), and discussions with relevant industry specialists). A biomass above the threshold basal area of 9.0 m^2/ha is proposed to indicate that, depending on the GDS species present (the first factor), the vegetation community in question potentially possesses a water demand (per unit area) large enough to determine that a significant component of its water use is potentially required to be provided by the (typically more readily available) groundwater resource.

While it is acknowledged that this threshold is not well accepted and may not be relevant to all situations; in lieu of good groundwater data, and alternative quantitative measures to inform likely groundwater dependence, it was deemed as being a valuable contributor to the process of assessing groundwater dependence.

When using GDS presence for assessing the potential groundwater dependence of a community it is important to consider that, of the three key tree species used as indicators of potential groundwater dependence in the Pilbara (*M. argentea, E. camaldulensis* and *E. victrix*) only the latter two have been detected in the Study Area. As a result the presence/absence of E. victrix and E. camaldulensis will be of most relevance to the species derived interpretations of groundwater dependence undertaken as part of this study. However; it is understood that in natural systems with at least a moderate catchment size (and associated vadose soil water resource); on a scale of groundwater dependence, the observed ecophysiological functioning of *E. victrix* appears to be more accurately characterised as representative of a vadophyte and at times a facultative phreatophyte. Consequently, where access to the groundwater is removed or reduced, this species is unlikely to be mortally reliant on positive antecedent groundwater conditions. Despite this distinction for E. victrix, the Environmental Water Strategy (**EWS**) of GDS is not always clear, and is importantly related to the water demands associated with resident tree densities, the increased size of the vadose soil resource typically associated with moderate to larger catchments and the inherent frequency of surface water inputs which they typically provide. As a result, the most relevant approach for conducting groundwater risk assessments for Pilbara riparian vegetation is to focus on identifying the two primary GDS; *M. argentea* and *E. camaldulensis*, and show minimal reliance on the presence of *E. victrix*.

Therefore, the methodology proposed to interpret the relative groundwater dependence of communities within the riparian zone of the Study Area (groundwater dependence interpretation

methodology) involves a four step process to produce greater resolution, and a more measured interpretation of risk to GDV due to changes in groundwater availability.

1. Step 1 - consider the GDS present. Based on phreatophytic structural and compositional evidence (briefly outlined within the matrix associated with the risk scale presented in Table 4-1), provide an interpretation of whether a community is representative of potentially GDV, and the relative inherent sensitivity of the species which it is comprised of.
2. Step 2 - calculate the relevant basal area for an area of riparian vegetation and consider the results of 'Step 1' in light of how far below or above the proposed basal area threshold the relevant vegetation sits.
3. Step 3 - determine the resultant combined potential for groundwater dependence expressed as an attained risk of significant-impact* to potentially GDV due to groundwater changes, guided by the baseline risk scale presented in Table 4-1 (and applied within the working matrix in Table 4-1). The matrix requires consideration of the 'phreatophytic structural and compositional evidence' (step 1) as well as the recorded basal area (step 2).
4. Step 4 - following the determination of risk based on an interpretation of each particular case through the working matrix (Table 4-1), there is an opportunity to modify/moderate the result (to only a minor degree) based on other factors or further structural/compositional detail deemed relevant. This could include consideration of the influence of; distance from the potential impact source, the proximity of additional tributaries (surface water input), topographical characteristics (i.e. channel width/confinement), geological characteristics (alluvium depth, bedrock proximity, sub-surface permeability). Where the result is modified via this step, notes detailing the additional factors involved in the modification will be provided as justification for the modifications.

Table 4-1: Interpretive baseline risk scale for estimating groundwater dependence as a measure of risk of significant-impact* from groundwater changes

Phreatophytic Structural and Compositional evidence (plus mesic indicators)	Basal area range (m^2/ha)	Risk
Isolated to scattered Low risk Facultative phreatophytes present	0.01-0.15	Negligible
Isolated to scattered Low risk Facultative phreatophytes present	0.15-1	Very Low
Scattered to low open woodland Low risk Facultative phreatophytes present and at times dominant	1-6	Very Low+
low open woodland Low risk Facultative phreatophytes present and at times dominant	2-9	**Very Low-Low**
Low open Woodland to Woodland Low risk Facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes	5-9	**Low**
Woodland Low risk Facultative phreatophytes dominant, isolated medium risk facultative phreatophytes	**9-13**	**Low+**

Phreatophytic Structural and Compositional evidence (plus mesic indicators)	Basal area range (m^2/ha)	Risk
Woodland Low risk Facultative phreatophytes dominant, medium risk facultative phreatophytes associated - No specific Mesic woody species detected	**9-18**	**Low-Medium**
Woodland to open forest Low and moderate risk Facultative phreatophytes dominant - No to minimal specific Mesic woody species detected	**9-18**	**Medium**
Woodland to open forest Low and moderate risk Facultative phreatophytes dominant - Multiple woody Mesic species detected	**10-20**	**Medium+**
Woodland to open forest Low and Moderate risk Facultative phreatophytes dominant - Obligate phreatophytes associated - Multiple woody and herbaceous Mesic species detected	**10-20**	**Medium-High**
Woodland to open forest Moderate risk Facultative phreatophytes co-dominant - Obligate phreatophytes co-dominant - Multiple woody and herbaceous Mesic species detected	**10-25**	**High**
Open forest Obligate phreatophytes dominant - Moderate risk Facultative phreatophytes co-dominant - Multiple woody and herbaceous Mesic species detected, high sedge diversity present	**15-30**	**Very High**

* 'Significant Impact' is defined as detectable (beyond natural variability) changes to the health, composition and structure of riparian communities, brought about by changes to groundwater access. Natural impacts to vegetation as a result of changing water availability are common in arid riparian habitats of the Pilbara region, and so significant impacts are those changes which are able to be distinguished from the background variability in effect at the locality. For this reason it is important to be able to distinguish impacts likely to be a result of the proposal from the inherent degree of baseline variation and associated riparian change. This baseline (or natural) riparian change is generally restricted to changes in health and at times structure, but less often leading to compositional changes. It is for this reason that potential 'significant impact' from the proposal and associated groundwater change is restricted to that level of riparian change which includes both health changes as well as at least one of either compositional or structural change in resident vegetation.

4.6 LIMITATIONS

Some significant recent fires had burnt a large proportion of the study area (estimated to have burnt more than 5 months prior to the current study). Based on the opinions of the field team, these fires did not inhibit the ability to determine the presence of potentially groundwater dependent tree species. However, the level of certainty surrounding the presence/absence of other woody mesic species, as well as those more herbaceous common mesic indicator species was reduced. Such indicator species are commonly relied upon to give some additional insight into water availability, and so the ability to determine their presence absence can provide important additional detail relevant to interpretations of GDE presence and shallow groundwater.

To combat this, the survey employed techniques which, if present, would have allowed for the identification of the remains of woody and herbaceous mesic indicator species which would be expected in a riparian system with above average water availability. However; no evidence of common mesic indicator species was found, despite searches in small unburnt areas and good regrowth of other non-mesic indicator species. For this reason there is still a fairly high degree of confidence that the general absence of mesic indicator species within key parts of the study area (such as riparian Zone C; Figure 4-1) is a sound conclusion. The majority of the confidence in this conclusion is based on the lack of any evidence (not even a small amount) for the presence of common species like *Melaleuca glomerata*; even within those small areas found to have escaped fire, rather than a small amount of evidence of this species being found. It is acknowledged that evidence of mesic indicator species may have been disguised by the effects of a hot fire, but the lack of even a small amount of regrowth of such species is important. If a small amount of evidence (such as the start of regrowth from burnt stumps) for mesic indicator species was found, then interpreting the degree to which those species previously occupied the study area would likely be dependent on the preceding fire conditions, and subject to significant interpretive error. However, the absence of any evidence of common mesic indicator species, despite good regrowth in populations of other non-mesic indicator species, suggests with a relatively high degree of confidence, that the potential for such species being present in the study area is very low. Furthermore, given that these species were either absent or uncommon, the potential for mesic conditions being present is also very low.

While it is acknowledged that small populations of some of these mesic indicator species may have been disguised by the effects of the fire, the minimal likely size of such populations would determine that the evidence they provided would suggest that pre-fire water availability was also quite minimal.

A second visit to the study area focusing on riparian Zone C was proposed to be conducted early in quarter 3 of 2016 to confirm the absence of mesic indicator species within key parts of the Study Area. This visit focused on searching for new regrowth evidence of any mesic indicator species which may have been absent at the time of the current survey. The results of this visit were that no new evidence for the presence of key mesic indicator species was found.

The recent fires may have also potentially had some influence on the basal area results. Removal of mature trees by fire would reduce the basal area recorded and as such, could influence the combined interpretation of groundwater dependence associated with local potentially GDV. The DBH of trees observed as obviously having been burnt in the recent fire was recorded (estimated at the time of observation), however the DBH of trees which were not obviously burnt may not have been recorded and it is therefore possible that some basal area was not included in the assessment. Fire is, however, a natural part of arid riparian ecosystems and as such, some reduction in basal area following fire could be considered natural attrition and is therefore not a significant source of error in such assessments.

5 RESULTS

5.1 GROUNDWATER DEPENDENT SPECIES PRESENT

Only two out of the three key groundwater dependent tree species were present in the Study Area:

1. *Eucalyptus victrix* – Common in their distribution within the incised channel zone of the creek bed, and scattered to isolated in their distribution on the floodplain.
2. *Eucalyptus camaldulensis* – essentially isolated in their distribution on the creek bed (apart from one small area), and absent from the floodplain.

None of the key potentially groundwater dependent shrub species were detected in the study area. Semi-mesic species like *Acacia pyrifolia*, and *Androcalva luteiflora* were detected along the creek beds but these species are essentially common in all small to medium sized creeks in the Pilbara, and are not generally recognised to display any dependence on or association with shallow groundwater.

The riparian zone at the beginning of the TCEB which displayed the most substantial of the riparian vegetation signatures present within the study area on aerial photography (100k orthophoto from August 2004) can be seen in Figure 5-1, occurring in the vicinity of the only local calcrete formation. Given this aerial signature, as well as the structure and density of riparian vegetation present within this calcrete zone it might typically be expected that a moderately mesic shrub species like *M. glomerata* would be present. *M. glomerata* is typically one of the initial larger woody shrub species to colonise the understorey of creek bed habitats which possess facultative phreatophyte trees species and which are tending towards representing a slightly more mesic creek system. At the time of survey, this section of creekline had been recently burnt, however it was concluded that these fires did not inhibit the ability to determine the presence of this species. Burnt or semi-burnt remains of other non-mesic indicator shrub species (such as *Petalostylis labicheoides, Acacia pyrifolia, Androcalva luteiflora*, and *Acacia citrinoviridis*) were identifiable throughout this section of creek so it is assumed that the absence of similar remains of *M. glomerata* indicates that this species was either absent or uncommon in this section of creek. Generally creeks which possess only one such woody mesic shrub indicator species with low to moderately groundwater dependent facultative phreatophytes (i.e. *E. victrix* and *E. camaldulensis*), are typically not considered to be any more than moderately groundwater dependent. The absence of such riparian species in the most significant of the riparian zones within the study area generally indicates that vegetation access to groundwater is relatively low.

Some common sedge species were detected within the creek beds and terraces of the study area, these included, *Cyperus vaginatus* and to a lesser extent *Cyperus iria*. While sedge species can generally be a good indicator of increasingly mesic conditions their abundance will typically be substantial in creeks possessing ample water availability. Furthermore; these species are relatively common and are widespread within small to large sized creek systems within the Hamersley Ranges. The presence of these species at a number of locations within the study area in relatively low densities does not contribute evidence to suggest vegetation of potential groundwater dependence occurs in the study area. Some very young populations of *Baumea sp*. (all essentially juvenile and sterile) and *Typha domingensis* were noted growing in some of the small clayey pools in the creek bed (standing water as a result of recent rains rather than semi-permanent pools) prior to the TCEB confluence. This was thought to be unusual, given the lack of other mesic species within the creek channel. These very localised occurrences are thought to be driven by availability of surface water rather than groundwater given the small size (1-3 m in length) and general rarity of the patches, the absence of larger sized mature patches of these species, the clay substrates in the locality and the recent good rains/growth-conditions.

5.2 REFINED VEGETATION MAPPING

Five key riparian vegetation communities were mapped throughout the study area for the purpose of providing baseline information about the riparian vegetation and most importantly for assessing the potential groundwater dependence of the vegetation. While other smaller scale tributaries and associated riparian vegetation systems were present within the study area, riparian vegetation mapping focussed on the more substantial (and therefore potentially groundwater dependent) riparian ecosystem's present within the study area including KNP.

Figure 5-2 and Figure 5-3 show the resulting riparian vegetation mapping. Table 5-1 presents both broad and detailed descriptions of the key riparian vegetation communities occurring throughout the study area.

The key results of relevance to the study area are:

- The dominance of the riparian tree strata by the low risk phreatophyte *E. victrix* was recorded to continue throughout the study area (in the vicinity of the Proposal), including riparian zones within KNP.
- Two small patches of *E. victrix* and *E. camaldulensis* co-dominated vegetation were detected within KNP (amounting to 4.8ha) in topographically confined reaches of TCEB.
- The presence of potentially GDS and GDV or species commonly associated with GDE's or shallow groundwater, therefore indicating mesic conditions, is relatively lacking in the area, even in the vicinity of the local calcrete formation, and despite the evidence of lacustrine or palustrine paleoenvironments which such formations indicate.

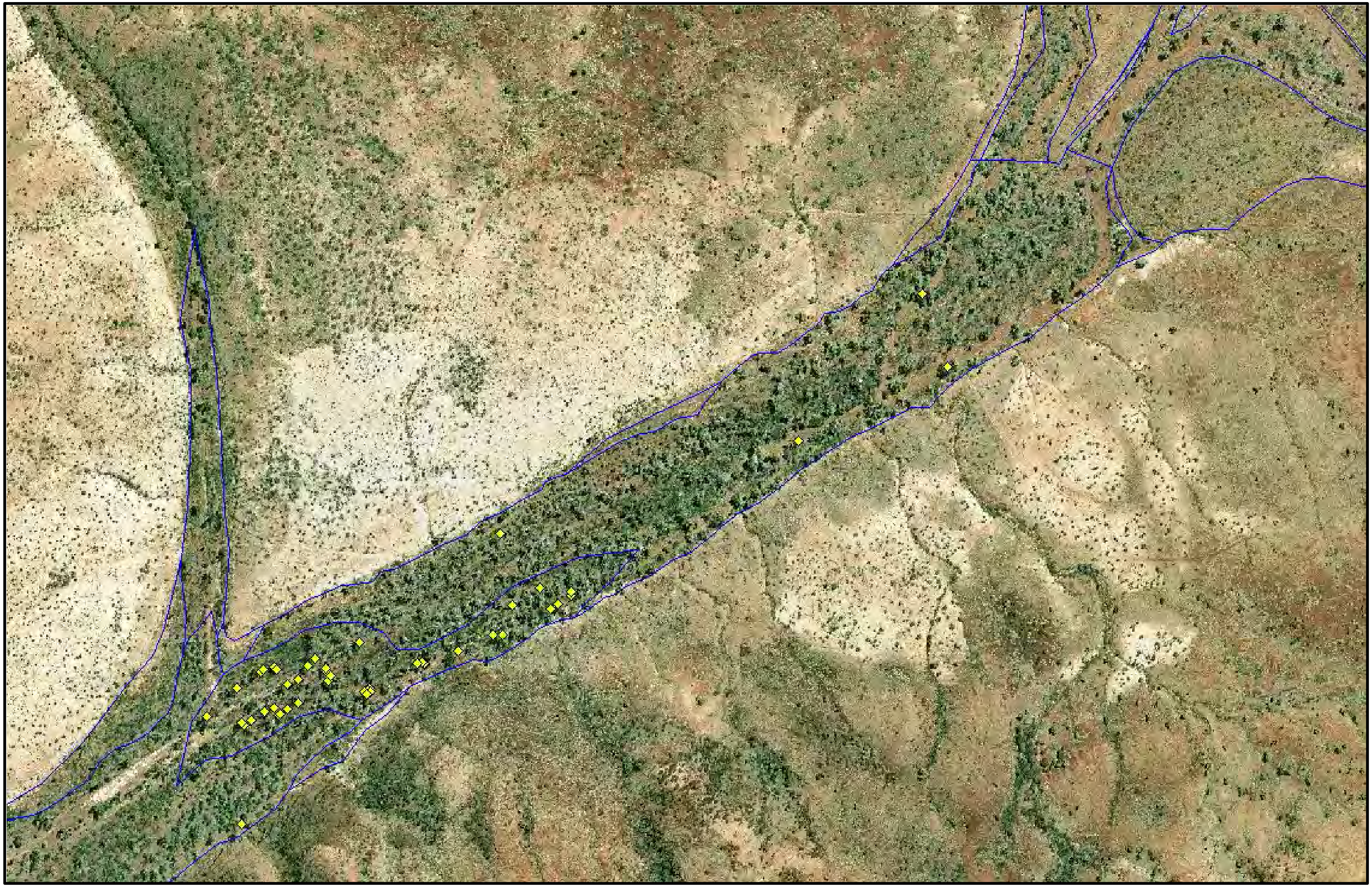


Figure 5-1: Aerial photo map showing the most substantial of the riparian vegetation signatures present on TCEB within the Study Area, with vegetation mapping boundaries (blue boundaries), and individual mature *Eucalyptus camaldule*nsis locations (Yellow diamonds)

Table 5-1: List of the riparian vegetation mapping units, landscape position, associated vegetation descriptions, and a list of the associated species recorded for the riparian communites recorded within the Study Area

Vegetation Code	Landscape position	Broad Vegetation Description	Detailed Vegetation Description
C2B	**Incised Channel Zone** - straddling multiple channels including the low flow channel	**E. victrix and *E. camaldulensis* woodland over *Acacia citrinoviridis* tall open shrubland** over mixed open-shrubland/low-open-shrubland over mixed open tussock grassland	*Eucalyptus victrix* and *E. camaldulensis* woodland (to open forest in places), over *Acacia citrinoviridis* tall open shrubland (to tall shrubland in places), over *Acacia pyrifolia, Petalostylis labicheoides* and *Androcalva luteiflora* open shrubland, over *Corchorus crozophorifolius* and *Tephrosia rosea* var. Fortescue creeks low open shrubland, over mixed open tussock grassland typically dominated by *Eulalia aurea, Themeda triandra, Cenchrus ciliaris, Eriachne tenuiculmis*.
	List of associated species recorded		
	Abutilon amplum; Abutilon cunninghamii; Abutilon fraseri; Abutilon lepidum; Abutilon macrum; Acacia aptaneura; Acacia aptaneura; Acacia bivenosa; Acacia citrinoviridis; Acacia pruinocarpa; Acacia pyrifolia var. pyrifolia; Acacia pyrifolia; Adriana tomentosa var. tomentosa; Alternanthera nana; Alternanthera nodiflora; Amaranthus cuspidifolius; Androcalva luteiflora; Aristida contorta; Bidens bipinnata; Boerhavia coccinea; Cenchrus ciliaris; Centipeda minima subsp. Minima; Chrysocephalum eremaeum; Cleome viscosa; Convolvulus clementii; Corchorus crozophorifolius; Corymbia hamersleyana; Crotalaria medicaginea var. neglecta; Cucumis variabilis; Cymbopogon obtectus; Cymbopogon procerus; Cyperus vaginatus; Dichanthium fecundum; Dicladanthera forrestii; Digitaria brownii; Dipteracanthus australasicus subsp. australasicus; Duperreya commixta; Dysphania kalpari; Dysphania rhadinostachya subsp. rhadinostachya; Enneapogon lindleyanus; Enneapogon polyphyllus; Eremophila longifolia; Eremophila phyllopoda subsp. obliqua; Eriachne helmsii; Eriachne mucronata; Eriachne pulchella subsp. dominii; Eriachne tenuiculmis; Eucalyptus camaldulensis subsp. Obtusa; Eucalyptus victrix; Eucalyptus xerothermica; Eulalia aurea; Euphorbia australis; Euphorbia biconvexa; Euphorbia boophthona; Evolvulus alsinoides var. villosicalyx; Gomphrena canescens; Gomphrena cunninghamii; Goodenia stellata; Gossypium robinsonii; Heliotropium tenuifolium; Hibiscus gardneri; Hybanthus aurantiacus; Indigofera colutea; Indigofera georgei; Iseilema eremaeum; Isotropis forrestii; Jasminum didymum subsp. Lineare; Malvastrum americanum; Melhania oblongifolia; Paraneurachne muelleri ; Paspalidium clementii; Peripleura hispidula var. setosa; Petalostylis labicheoides; Phyllanthus maderaspatensis; Pluchea dentex; Pluchea dunlopii; Polycarpaea longiflora; Portulaca oleracea; Pterocaulon sphacelatum; Ptilotus helipteroides; Ptilotus nobilis subsp. nobilis; Ptilotus obovatus var. obovatus Ptilotus obovatus; Ptilotus polystachyus; Rhynchosia minima; Salsola australis; Senna artemisioides subsp. Oligophylla; Senna glutinosa subsp. glutinosa; Senna notabilis; Setaria dielsii; Setaria verticillata ; Sida sp. spiciform panicles (E. Leyland s.n. 14/8/1990); Sida sp. verrucose glands (F.H. Mollemans 2423); Sporobolus australasicus; Stemodia grossa; Streptoglossa decurrens; Swainsona decurrens; Swainsona maccullochiana; Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186); Themeda triandra; Trachymene oleracea subsp. Oleracea; Tragus australianus; Trichodesma zeylanicum var. zeylanicum; Triodia epactia; Wahlenbergia tumidifructa; and Waltheria indica.		

<table>
<tr><th>Vegetation Code</th><th>Landscape position</th><th>Broad Vegetation Description</th><th>Detailed Vegetation Description</th></tr>
<tr><td rowspan="3">C3B</td><td>Incised Channel Zone - straddling multiple channels including the low flow channel, but also some creek terrace habitats</td><td>E. victrix woodland over Acacia citrinoviridis tall open shrubland over mixed open-shrubland/low-open-shrubland over mixed open tussock grassland</td><td>Eucalyptus victrix woodland, over E. victrix scattered low trees, over Acacia citrinoviridis tall open shrubland (to tall shrubland in places), over Acacia pyrifolia, Petalostylis labicheoides and Androcalva luteiflora open shrubland, over Corchorus crozophorifolius and Tephrosia rosea var. Fortescue creeks low open shrubland, over mixed open tussock grassland typically dominated by Eulalia aurea, Themeda triandra, Cenchrus ciliaris, Eriachne tenuiculmis.</td></tr>
<tr><td colspan="3">List of associated species recorded</td></tr>
<tr><td colspan="3">Abutilon amplum; Abutilon cunninghamii; Abutilon fraseri; Abutilon lepidum; Abutilon macrum; Acacia aptaneura; Acacia citrinoviridis; Acacia aptaneura; Acacia pruinocarpa; Acacia pyrifolia var. pyrifolia; Acacia pyrifolia; Alternanthera nana; Amaranthus cuspidifolius; Androcalva luteiflora; Aristida contorta; Astrebla pectinata; Bidens bipinnata; Boerhavia coccinea; Cenchrus ciliaris; Chloris pectinata; Chrysocephalum eremaeum; Cleome viscosa; Convolvulus clementii; Corchorus crozophorifolius; Cucumis maderaspatanus; Cucumis variabilis; Cymbopogon ambiguus; Cymbopogon obtectus; Dichanthium fecundum; Dicladanthera forrestii; Digitaria brownii; Digitaria ctenantha; Dipteracanthus australasicus subsp. australasicus; Duperreya commixta; Dysphania rhadinostachya subsp. rhadinostachya; Dysphania saxatilis; Enneapogon lindleyanus; Enneapogon polyphyllus; Enneapogon robustissimus; Eremophila forrestii subsp. Forrestii; Eremophila longifolia; Eremophila phyllopoda subsp. obliqua; Eriachne helmsii; Eriachne mucronata; Eriachne pulchella subsp. dominii; Eriachne tenuiculmis ; Eucalyptus camaldulensis ; Eucalyptus victrix; Eucalyptus xerothermica; Eulalia aurea; Euphorbia australis; Euphorbia biconvexa; Euphorbia boophthona; Euphorbia tannensis subsp. Eremophila; Evolvulus alsinoides var. villosicalyx; Gomphrena canescens; Gomphrena cunninghamii; Goodenia stellata; Heliotropium tenuifolium; Hibiscus gardneri; Hybanthus aurantiacus; Indigofera georgei; Iseilema eremaeum; Isotropis forrestii; Malvastrum americanum; Melhania oblongifolia; Paraneurachne muelleri; Paspalidium clementii; Peripleura hispidula var. setosa; Petalostylis labicheoides; Phyllanthus maderaspatensis; Pluchea dentex; Pluchea dunlopii; Polycarpaea longiflora; Portulaca oleracea; Pterocaulon sphacelatum; Ptilotus nobilis subsp. nobilis; Ptilotus helipteroides; Ptilotus obovatus; Ptilotus polystachyus; Rhynchosia minima; Androcalva luteiflora; Salsola australis; Senna artemisioides subsp. Oligophylla; Senna artemisioides subsp. Helmsii; Senna glutinosa subsp. glutinosa; Senna notabilis; Senna stricta; Setaria dielsii; Setaria verticillata; Sida fibulifera; Sida sp. spiciform panicles (E. Leyland s.n. 14/8/1990; Sida sp. verrucose glands (F.H. Mollemans 2423); Solanum lasiophyllum; Sporobolus australasicus; Streptoglossa decurrens; Swainsona decurrens; Swainsona maccullochiana; Tephrosia rosea var. Fortescue creeks; Tephrosia rosea var. glabrior; Themeda triandra; Trachymene oleracea subsp. Oleracea; Tragus australianus; Tribulus suberosus; Trichodesma zeylanicum var. zeylanicum; Triodia epactia; Triodia longiceps; Triodia pungens; and Waltheria indica.</td></tr>
</table>

Vegetation Code	Landscape position	Broad Vegetation Description	Detailed Vegetation Description
C3C	**Incised channel zone** - generally representing the main low flow channel, banks and initial terrace habitat	***E. Victrix* low open woodland over *Acacia citrinoviridis* tall open shrubland** over mixed scattered-shrubs/low-open-shrubland over mixed open tussock grassland	Scattered *Eucalyptus victrix* trees, over *E. victrix* low open woodland (to scattered low trees), over *Acacia citrinoviridis* tall open shrubland (with scattered *Acacia aptaneura* in places), over scattered to open shrubland of *Acacia pyrifolia* and *Petalostylis labicheoides* (*Acacia citrinoviridis, Acacia aptaneura*), over *Corchorus crozophorifolius* and *Tephrosia rosea* var. Fortescue creeks (*Dipteracanthus australasicus*) low open shrubland, over mixed open tussock grassland of *Eulalia aurea, Eriachne tenuiculmis, Themeda triandra, Chrysopogon fallax*, (*Cymbopogon ambiguous, Eulalia* sp. Three Rivers, *Setaria dielsii*).
	List of associated species recorded		
	Abutilon amplum; Abutilon cunninghamii; Abutilon fraseri; Abutilon lepidum; Abutilon macrum; Acacia aptaneura ; Acacia aptaneura; Acacia citrinoviridis ; Acacia citrinoviridis; Acacia incurvaneura; Acacia macraneura ; Acacia pruinocarpa; Acacia pyrifolia var. pyrifolia ; Acacia pyrifolia; Alternanthera nana; Amaranthus cuspidifolius; Androcalva luteiflora ; Aristida contorta; Astrebla pectinata; Bidens bipinnata ; Boerhavia coccinea ; Chloris pectinata; Chrysocephalum eremaeum; Chrysopogon fallax ; Cleome viscosa; Codonocarpus cotinifolius; Convolvulus clementii; Corchorus crozophorifolius; Cucumis maderaspatanus; Cucumis variabilis; Cymbopogon ambiguus; Dactyloctenium radulans; Dicladanthera forrestii; Digitaria brownii; Dipteracanthus australasicus subsp. Australasicus ; Duperreya commixta; Dysphania rhadinostachya subsp. rhadinostachya; Dysphania saxatilis; Enchylaena tomentosa var. tomentosa; Enneapogon caerulescens ; Enneapogon lindleyanus; Enneapogon polyphyllus; Enneapogon robustissimus; Eremophila fraseri subsp. Fraseri; Eremophila galeata; Eremophila longifolia; Eremophila phyllopoda subsp. obliqua; Eriachne helmsii; Eriachne mucronata; Eriachne pulchella subsp. Dominii; Eriachne tenuiculmis ; Eucalyptus victrix ; Eucalyptus xerothermica; Eulalia aurea; Euphorbia australis; Euphorbia biconvexa; Euphorbia boophthona; Euphorbia tannensis subsp. Eremophila; Evolvulus alsinoides var. decumbens; Evolvulus alsinoides var. villosicalyx; Glycine canescens; Gomphrena affinis subsp. pilbarensis; Gomphrena canescens; Gomphrena cunninghamii; Goodenia lamprosperma; Goodenia stellata; Grevillea wickhamii subsp. Hispidula; Heliotropium cunninghamii; Heliotropium tenuifolium; Hibiscus gardneri; Hybanthus aurantiacus; Indigofera georgei; Iseilema eremaeum; Isotropis forrestii; Jasminum didymum subsp. Lineare ; Maireana villosa; Malvastrum americanum; Marsilea hirsuta; Melhania oblongifolia; Notoleptopus decaisnei ; Paraneurachne muelleri ; Paspalidium clementii; Peripleura hispidula var. setosa; Peripleura sp.; Petalostylis labicheoides ; Phyllanthus maderaspatensis; Pluchea dentex; Pluchea dunlopii; Polycarpaea longiflora; Portulaca oleracea; Pterocaulon sphacelatum; Ptilotus exaltatus var. exaltatus; Ptilotus helipteroides; Ptilotus nobilis subsp. nobilis; Ptilotus obovatus; Ptilotus polystachyus; Rhagodia eremaea; Rhynchosia australis; Rhynchosia minima; Rulingia luteiflora; Salsola australis; Salsola tragus subsp. grandiflora; Senna ferraria; Senna glaucifolia; Senna glutinosa subsp. x luerssenii ; Senna notabilis; Senna stricta; Setaria dielsii; Sida sp. spiciform panicles (E. Leyland s.n. 14/8/1990); Sida sp. verrucose glands (F.H. Mollemans 2423); Solanum lasiophyllum; Sporobolus australasicus; Sporobolus australis ; Streptoglossa decurrens; Swainsona decurrens; Swainsona maccullochiana; Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186); Tephrosia rosea var. glabrior; Themeda triandra ; Trachymene oleracea subsp. Oleracea; Tragus australianus; Tribulus suberosus; Trichodesma zeylanicum var. zeylanicum; Trichodesma zeylanicum; Triodia epactia; Triodia longiceps; Triodia pungens; Wahlenbergia tumidifructa; and Waltheria indica		

Vegetation Code	Landscape position	Broad Vegetation Description	Detailed Vegetation Description
F3	**Floodplain zone** and associated habitats - including more minor high flow channels	**Scattered to isolated *E. victrix* low trees** over mixed scattered tall-shrubs/shrubs, over very open tussock/hummock grassland	Scattered to isolated *Eucalyptus victrix* and *Eucalyptus xerothermica* low trees, over *Acacia citrinoviridis*, and *Acacia aptaneura* (*Acacia ayersiana*) scattered to tall open shrubland (to shrubland in places), over scattered mixed shrubs (typically dominated by of *Petalostylis labicheoides, Acacia pruinocarpa, Acacia pyrifolia, Acacia ayersiana, Eremophila longifolia, Eremophila forrestii, Eremophila latrobei* subsp. *latrobei*, *Rhagodia eremaea*), over mixed scattered to low open shrubland (typically dominated by mixes of *Indigofera georgei, Ptilotus obovatus, Senna artemisioides* subsp. *oligophylla, Dipteracanthus australasicus*, and *Corchorus crozophorifolius*), over mixed very open tussock grassland (typically dominated by mixes of *Chrysopogon fallax, Eulalia* sp. Three rivers, *Themeda triandra*, *Eriachne mucronata, Eriachne tenuiculmis, Enneapogon lindleyanus*) over *Triodia epactia/pungens* very open hummock grassland.
	List of associated species recorded		
	Abutilon fraseri subsp. fraseri; Abutilon macrum; Abutilon otocarpum; Abutilon sp.; Acacia ayersiana; Acacia bivenosa; Acacia citrinoviridis; Acacia incurvaneura; Acacia macraneura; Acacia pruinocarpa; Acacia pyrifolia var. pyrifolia; Acacia tetragonophylla; Acrachne racemosa; Amaranthus cuspidifolius; Amaranthus mitchellii; Aristida contorta; Bidens bipinnata; Boerhavia coccinea; Boerhavia paludosa; Cheilanthes sieberi subsp. Sieberi; Chrysocephalum gilesii; Chrysopogon fallax; Cleome viscosa; Convolvulus clementii; Corchorus tridens; Cucumis variabilis; Cymbopogon ambiguus; Dicladanthera forrestii; Digitaria brownii; Dipteracanthus australasicus subsp. Australasicus; Duperreya commixta; Dysphania kalpari; Dysphania rhadinostachya subsp. Rhadinostachya ; Enchylaena tomentosa var. tomentosa; Enneapogon lindleyanus; Enneapogon polyphyllus; Enneapogon robustissimus; Eremophila forrestii subsp. forrestii; Eremophila longifolia; Eriachne pulchella subsp. Dominii; Eucalyptus victrix; Eucalyptus xerothermica; Euphorbia australis; Euphorbia biconvexa; Euphorbia boophthona; Evolvulus alsinoides var. villosicalyx; Flaveria trinervia; Goodenia muelleriana; Hibiscus burtonii; Hibiscus sturtii var. campylochlamys; Hummock Grasses; Indigofera georgei; Ischaemum albovillosum; Iseilema eremaeum; Maireana planifolia; Maireana villosa; Malvastrum americanum; Marsdenia australis; Panicum effusum; Paspalidium rarum; Peripleura hispidula var. setosa; Petalostylis labicheoides; Polycarpaea corymbosa; Portulaca oleracea; Pterocaulon sphacelatum; Ptilotus helipteroides; Ptilotus nobilis subsp. Nobilis; Ptilotus obovatus; Ptilotus polystachyus; Rhagodia eremaea; Rhagodia sp. Hamersley (M. Trudgen 17794); Rhynchosia minima; Salsola australis; Sclerolaena convexula; Sclerolaena cornishiana; Senna artemisioides subsp. Helmsii; Senna artemisioides subsp. oligophylla; Senna artemisioides subsp. x artemisioides; Senna notabilis; Setaria surgens; Sida fibulifera; Sida sp. Shovelanna Hill (S. van Leeuwen 3842); Sida sp. verrucose glands (F.H. Mollemans 2423); Solanum lasiophyllum; Sporobolus australasicus; Swainsona maccullochiana; Themeda triandra; Trichodesma zeylanicum var. zeylanicum; Triodia longiceps; Triodia pungens; and Triraphis mollis.		

Vegetation Code	Landscape position	Broad Vegetation Description	Detailed Vegetation Description
F2	**Floodplain zone** and associated habitats - including more minor high flow channels	**Scattered *E. victrix* and *Eucalyptus xerothermica* low trees** over mixed tall-open-shrubland/open-shrubland, over mixed very open tussock/hummock grassland	Scattered Eucalyptus victrix and *Eucalyptus xerothermica* low trees, over *Acacia citrinoviridis* tall open shrubland (to shrubland in places), over mixed open shrubland (typically dominated by mixes of *Petalostylis labicheoides, Acacia pruinocarpa, Acacia pyrifolia, Acacia ayersiana, Acacia aptaneura, Eremophila longifolia, Eremophila forrestii, Eremophila latrobei* subsp. *latrobei*, *Rhagodia eremaea*), over mixed low open shrubland (typically dominated by mixes of *Indigofera georgei, Ptilotus obovatus, Senna artemisioides* subsp. *oligophylla, Dipteracanthus australasicus*, and *Corchorus crozophorifolius*), over mixed very open tussock grassland (typically dominated by mixes of *Chrysopogon fallax, Eulalia aurea, Eulalia* sp. Three rivers, *Themeda triandra, Eriachne mucronata, Eriachne tenuiculmis, Enneapogon lindleyanus*) over *Triodia epactia/pungens* very open hummock grassland.
	List of associated species recorded		
	Acacia citrinoviridis; Acacia incurvaneura; Acacia macraneura; Acacia pruinocarpa; Acacia pyrifolia var. pyrifolia; Acacia tetragonophylla; Acrachne racemosa; Amaranthus cuspidifolius; Amaranthus mitchellii; Aristida contorta; Bidens bipinnata; Boerhavia coccinea; Boerhavia paludosa; Cheilanthes sieberi subsp. Sieberi; Chrysocephalum gilesii; Chrysopogon fallax; Cleome viscosa; Convolvulus clementii; Corchorus tridens; Corymbia hamersleyana; Cucumis variabilis; Cymbopogon ambiguus; Cymbopogon obtectus; Dicladanthera forrestii; Digitaria brownii; Dipteracanthus australasicus subsp. Australasicus; Duperreya commixta ; Dysphania kalpari ; Dysphania rhadinostachya subsp. Rhadinostachya; Enneapogon lindleyanus; Enneapogon polyphyllus; Eremophila forrestii subsp. forrestii; Eremophila longifolia; Eriachne pulchella subsp. Dominii; Eucalyptus victrix; Eucalyptus xerothermica; Euphorbia australis; Euphorbia biconvexa; Euphorbia boophthona; Eulalia aurea; Evolvulus alsinoides var. villosicalyx; Flaveria trinervia; Goodenia muelleriana; Hibiscus burtonii; Hibiscus sturtii var. campylochlamys; Hummock Grasses; Indigofera georgei; Ischaemum albovillosum; Iseilema eremaeum; Maireana planifolia; Maireana villosa; Malvastrum americanum; Marsdenia australis; Panicum effusum; Paspalidium rarum; Peripleura hispidula var. setosa; Petalostylis labicheoides; Polycarpaea corymbosa; Portulaca oleracea ; Pterocaulon sphacelatum; Ptilotus helipteroides ; Ptilotus obovatus; Ptilotus polystachyus; Rhagodia eremaea; Rhynchosia minima; Salsola australis; Sclerolaena convexula; Sclerolaena cornishiana; Senna artemisioides subsp. Helmsii; Senna artemisioides subsp. oligophylla; Senna artemisioides subsp. x artemisioides; Senna notabilis ; Setaria surgens ; Sida fibulifera ; Sida sp. Shovelanna Hill (S. van Leeuwen 3842); Sida sp. verrucose glands (F.H. Mollemans 2423); Solanum lasiophyllum; Sporobolus australasicus; Swainsona maccullochiana; Themeda triandra ; Trichodesma zeylanicum var. zeylanicum; Triodia longiceps ; Triodia pungens; and Triraphis mollis.		

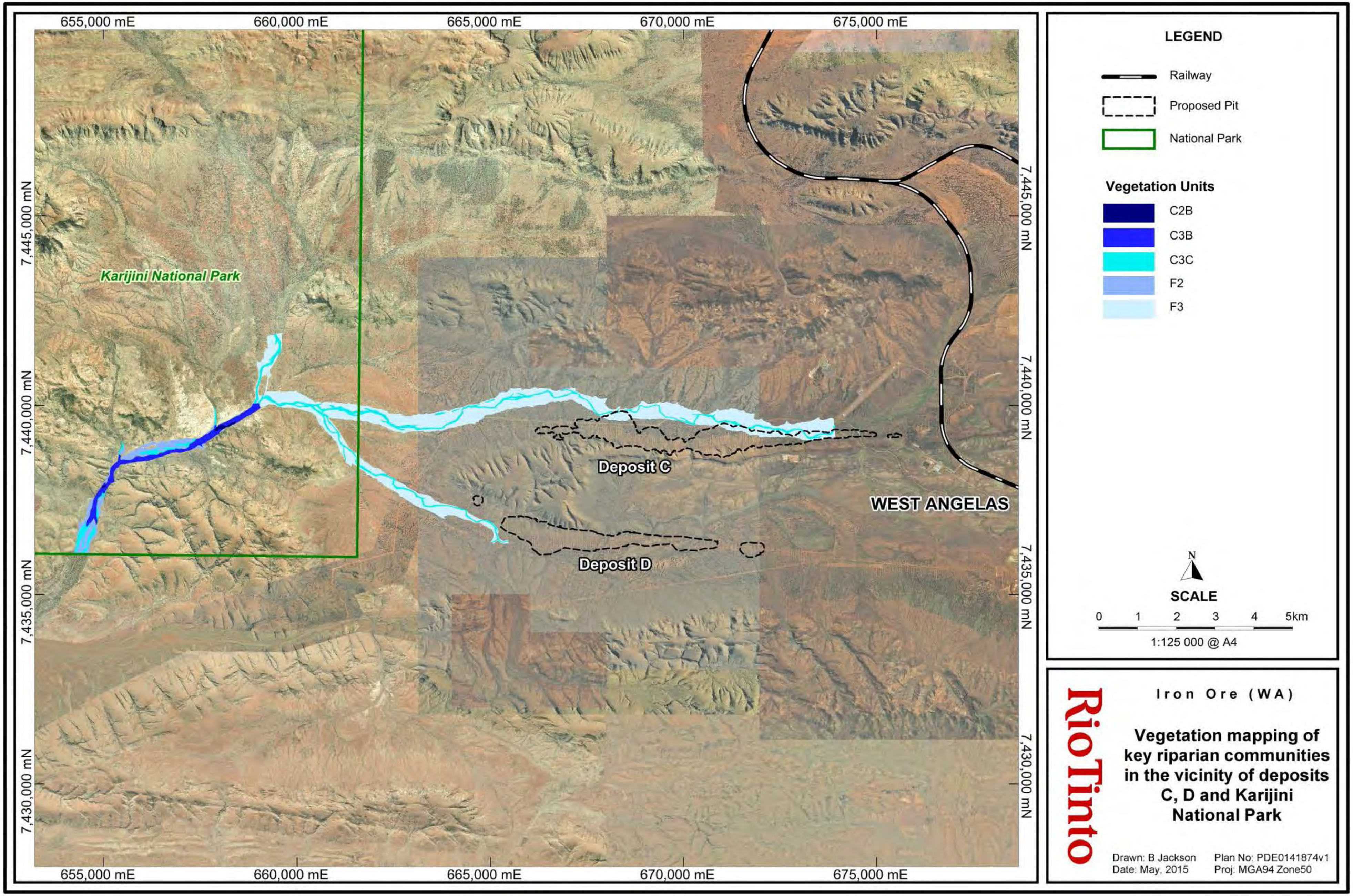


Figure 5-2: Vegetation Mapping of Key Riparian Communities in the Vicinity of Deposits C, D and Karijini National Park

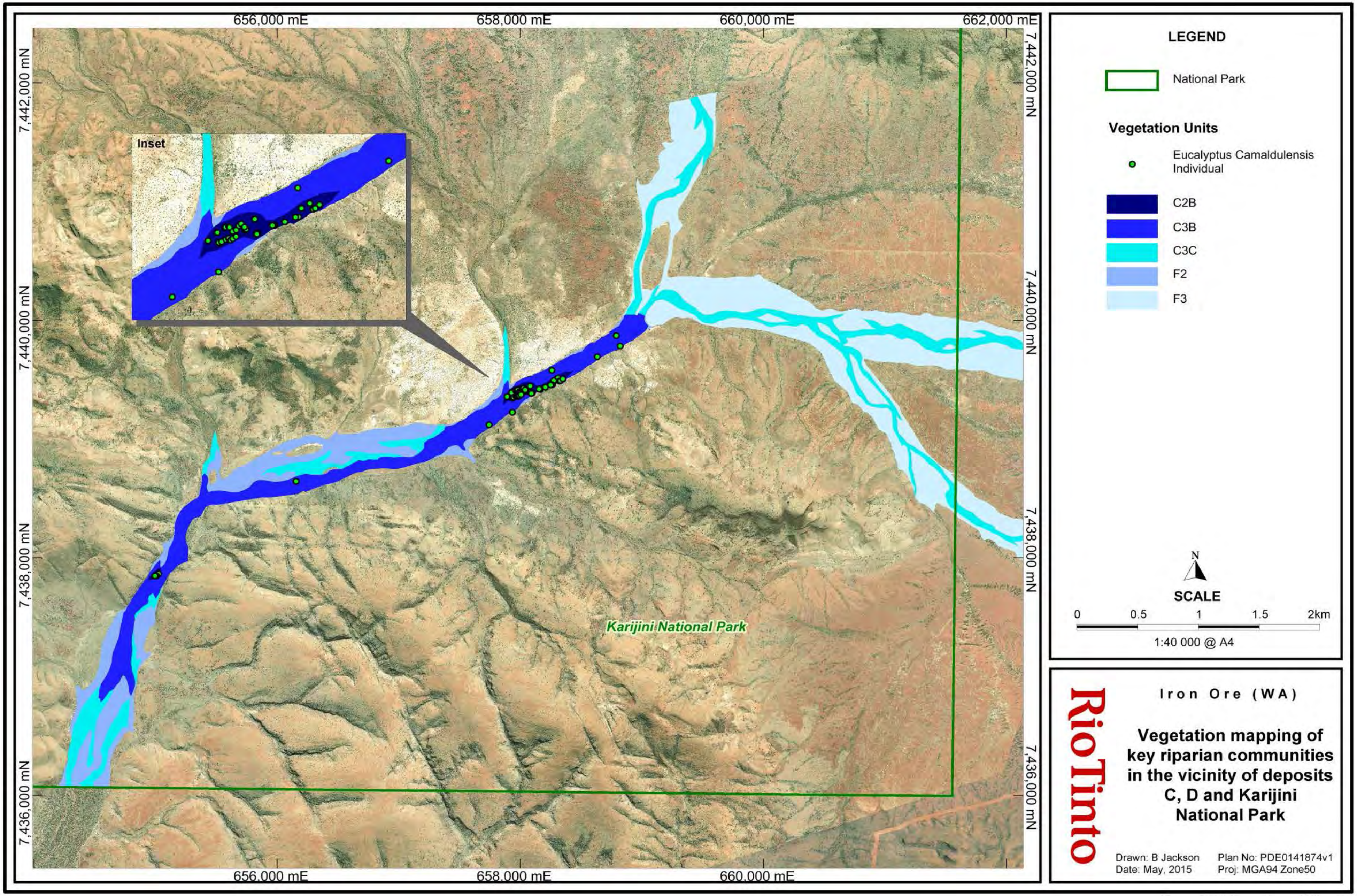


Figure 5-3: Vegetation Mapping of Key Riparian Communities in the Vicinity of Deposits C, D and Karijini National Park

5.3 POTENTIAL GROUNDWATER DEPENDENT VEGETATION PRESENCE

In general, the vegetation recorded within the Study Area and most importantly within KNP suggests that while potentially GDV communities occur, the inherent groundwater dependence of the majority of vegetation is 'low'. The structure and composition of riparian vegetation throughout the Study Area, predominantly in the form of phreatophytic structural and compositional evidence in relation to groundwater dependence, is integrated into the working risk matrix (step 1 & 3 in the described groundwater dependence and 'impact risk' interpretation methodology; Section 4.5) and presented in Table 5-3.

One community, represented by the C2B vegetation mapping unit (approximately 4.8ha) does possess relatively small co-dominant populations of the potentially low to moderately groundwater dependent species *E. camaldulensis*. The co-dominant presence of this species in the tree strata of the C2B community infers an increased potential for this vegetation to be groundwater dependent. As such, the potential groundwater dependence of this community is considered to be 'low to moderate' in scale. However, when further compositional indicators (such as those discussed in section 5.1) are considered, the potential groundwater dependence of this community is considered to lie towards to the lower end of the 'low to moderate' rating. The small scale of this community combined with some characteristics of the underlying geology and the topographic confinement of surface water flows its vicinity, further support this interpretation. Despite such supporting characters other geophysical characteristics of the locality also suggest the opposite, thus determining that the interpreted potential groundwater dependence of low-moderate is likely an appropriate estimate for this community.

The C3B vegetation community, which is also generally restricted to the more topographically confined stretch of TCEB within KNP (Riparian zones C, D and E; Figure 4-1), but which is only dominated by the tree species *E. victrix*, is considered to possess a low (to slightly higher in the denser portions) potential for groundwater dependence.

Based on the structure and composition of the C3C community, such vegetation is generally considered to be classed as possessing very low potential for groundwater dependence. While very compositionally similar to the C3B community, its comparatively reduced potential for groundwater dependence is primarily based on structural differences when compared to the C3B community.

Based on the structure and composition of the remainder of the communities in the study area, their associated potential groundwater dependence is generally considered negligible, and supported by the depth to groundwater observed below the vast majority of these communities.

Given that the inherent groundwater dependence of the majority of vegetation within the Study Area is considered 'low', the risk to riparian vegetation communities as a result of groundwater drawdown is also considered relatively low. However, this is only part of the assessment, and the finer scale contextualisation of risk which follows supports this general conclusion while also identifying areas with elevated risk.

The structure and composition of riparian vegetation throughout the study area has been considered in terms of the basic phreatophytic structural and compositional evidence they provide which is of relevance to groundwater dependence. As part of the process of determining the presence of potential GDV, this evidence has been integrated into the risk matrix as part of step 1 & 3 in the groundwater dependence and impact risk interpretation methodology used in this study.

5.4 BASAL AREA ASSESSMENTS

A total of 25 basal area assessments were conducted. The distribution of basal area sampling sites was biased towards the riparian vegetation communities associated with Zones C, D and E of TCEB given the concentration of vegetation communities possessing a higher potential for groundwater dependence within KNP. Figure 5-4 shows the location of all the basal area assessment plots and the basal area attained from calculations at each of the plots. Table 5-2 lists these results in order of basal area magnitude.

Table 5-2: Basal area assessment results

Plot	Site/WPT	Plot dimensions/length	Basal area (per ha)
FL4	Flood 4	4.7 km long reach	0.045
FL3	Flood 3	4.9 km long reach	0.082
FL1	Flood 1	3.3 km long reach	0.132
FL2	Flood 2	4.2 km long reach	0.236
FL5	Flood 5	2.2 km long reach	0.498
LD-IC2	J267 to J304	620 m length of creek	**1.162**
IC5	J134	(u) 36x100x46	**1.811**
LD-IC1	J208 to J251	580 m length of creek	**1.925**
IC7	J149(d)	(u) 39x100x36	**2.047**
IC18	J400	(u) 27x100x26	**2.298**
IC1	H1340	(u) 37x100x33	**2.640**
IC6	j137	(u) 30x100x36	**2.844**
IC2	H1341	(u) 37x100x33	**3.421**
IC4	H1343	(u) 40x100x40	**3.468**
IC3	H1342	(u) 35x100x30	**3.534**
IC12	J177	(d) 40x100x40	**4.444**
IC8	J163	(u) 39x100x37	**5.367**
IC16	J192	(d) 37x100x40	**6.681**
IC11	j176	(d) 42x100x44	**7.984**
IC15	J185	(u) 37x100x37	**9.593**
IC10	J175	(u) 40x100x39	**13.093**
IC9	J174	(u) 50x100x50	**13.361**
IC14	J183	(d) 40x100x40	**13.431**
IC13	J179	(d) 42x100x42	**14.945**
IC17	J195	(u) 40x100x40	**16.481**

FL indicates Floodplain Zone, IC indicates Incised Channel Zone

As predicted the basal area values recorded on the floodplain are very low, and in all cases was below 0.5 m^2/ha. In terms of areal extent, the floodplain represents 75% of the riparian habitat extent mapped within the study area.

The basal area values recorded in the incised channel zone of the tributaries of TCEB (Riparian Zone A and B; Figure 4-1) ranged from 1 m^2/ha to 5 m^2/ha. This zone represented approximately 15% of the total riparian habitat extent mapped within the study area.

The remainder of the basal area sites were restricted to TCEB (Riparian Zones C, D and E; Figure 4-1) and values ranged from 6 m^2/ha to 16 m^2/ha. This area represented approximately 10% of the riparian habitat extent mapped within the study area.

From the suite of 25 basal area plots assessed, 6 plots of note (IC09, IC10, IC13, IC14, IC15 and IC17) were identified as possessing a standing biomass above the proposed basal area threshold. All 6 plots were located in the two stretches of TCEB which were in topographic 'constriction points' and incised gorge like features where floodplain habitats were incapable of forming. Basal area values in these sites ranged from 9.5 m^2/ha to 16.5 m^2/ha, with basal areas in the vicinity of 15 m^2/ha representing an above average standing biomass for a creek of this size. From this data biomass change gradients were also considered. A change in basal area from approximately 2 m^2/ha to 15 m^2/ha over a relatively short distance (approximately 1-2 km) appears to be a significant change. This change is likely a least partly attributable to the 100-200 (depending on position) square kilometres of catchment which are added via confluences in the vicinity. Additionally this change may provide evidence (along with bore data) for decreasing depth of groundwater from east to west within the study area. However, for the most part it likely demonstrates that topographical (and geological) constriction and the termination of the floodplain (and its integration into the incised channel zone) is significantly increasing vadose water availability. Whatever the reason, the data importantly provides an indication of biomass change which is typically only interpreted (fairly inaccurately) from aerial photo signatures. To contextualise the range of basal area recorded within the study area, it should be noted that within North Australian riparian environments basal areas in the order of 50+ m^2/ha are not uncommon (Lamontagne *et al.* 2005). While Basal area data in the Pilbara in higher biomass riparian areas is low, and providing a potential upper zone is problematic, it is likely that basal areas in the order of 20-40 m^2/ha are likely in Pilbara creeks and rivers.

To demonstrate the potential inaccuracies of interpreting biomass from aerial photo signatures, Figure 5-55 shows how the basal area values can vary significantly between basal area assessment plots while the aerial photo signature does not appear to vary to the same degree. Often this is an artefact of interference from the understorey vegetation highlighting the constraints of aerial photo interpretation for groundwater dependence. When considering potential groundwater dependence, the standing biomass represented by trees is more important than understorey vegetation since this is the component of the vegetation most likely to be accessing groundwater. As such, improvements in the measurement of biomass represented by trees, such as the use of basal area assessments, are of high value.

5.5 BASAL AREA/BIOMASS MAPPING

From relatively point based (as well as some area based plots) basal area results, patterns of variability within basal area results throughout the study area and gradients of interpreted groundwater availability; basal area results were extrapolated to provide the basal area range likely to be present in separate reaches of the creek system. These ranges are only a guide, and essentially represent the characterisation of basal area for each portion (split by reach and zone within the creek profile) of riparian vegetation deemed relevant. It is therefore noted that higher and lower basal areas could exist over small scales within the vegetation of each mapped reach.

Figure 5-6 shows the distribution and variability of extrapolated riparian vegetation basal area ranges within separate reaches of the floodplain and incised channel zones of the Study Area. Integration of the basal area ranges characterised for each relevant reach into the working risk matrix (step 2 & 3 in the groundwater dependence and impact risk interpretation methodology used in this study) is presented in Table 5-3.

5.6 INTERPRETING RISK FROM POTENTIAL GROUNDWATER DEPENDENCE AS A PRODUCT OF VEGETATION STRUCTURE/COMPOSITION, STANDING BIOMASS AND OTHER FACTORS

The risk to potentially GDV in the study area from changes to groundwater availability is interpreted from the integration of all available information into the working GDE Risk Matrix (step 3 & 4 in the groundwater dependence and risk impact interpretation methodology used in this study), presented in Table 5-3. The information considered as part of this integration comprises:

1. the vegetation mapping (represented primarily by the embedded phreatophytic compositional and structural information);
2. the basal area mapping (and associated plot results); and
3. and “other” spatial risk factors likely to contribute to either potential groundwater dependence, or local characteristics which might increase the risk of groundwater changes.

The first two categories of information above essentially form the determination of likely groundwater dependence, however within the matrix this is instead described on a scale of risk. The GDE Risk Matrix also allows for consideration of “other” modifying or supporting factors which might be of relevance to each of the reaches. It is this consideration of the initial determination of groundwater dependence together with point three (“other”), which contextualises the potential dependence and initial risk to determine an ’interpreted residual risk’.

Notes created following the consideration of the “other” modifying or supporting factors deemed relevant to each spatial vegetation partition are provided in the “modifying or supporting factors” column of Table 5-33. Following this column in Table 5-3, the “interpreted residual risk” column provides the final risk which has been interpreted as being relevant to each spatial vegetation partition. The ultimate suite of vegetation partitions considered as part of the risk matrix are a product of the spatial cookie-cutting interaction of the vegetation mapping, the basal area mapping, and “other” spatial risk factors which combine to produce a different residual magnitude of risk for different spatial areas.

Based on the residual risk results provided in the GDE Risk Matrix, approximately 93% of the study area is represented by riparian vegetation interpreted to possess a ‘Very Low to Low’ residual risk of groundwater dependence, and therefore, a commensurate ‘Very Low to Low’ risk of significant impact as a result of groundwater drawdown from the proposed dewatering for the Proposal. The remaining riparian vegetation (6.6% of the study area) has been interpreted to possess either ‘Low’ (4% or 42ha), ‘Low-Medium’ (2% or 22 ha), or ‘Medium’ (0.4% or 4.2 ha) residual risk (of the same definition).

Areas interpreted to be representing ‘Low-Medium’ or ‘Medium’ residual risk have generally been attributed this rating due to the presence of *E. camaldulensis* (at varying densities)(a moderate risk facultative phreatophyte), and a basal area recorded to be at times significantly above the proposed basal area threshold of 9 m^2/ha. Despite the small areal extent of these 'Low-Medium' or 'Medium' risk communities, both predominantly reside 6-7 km from the potential impact source in Riparian Zone C, which is the apparent terminus of groundwater levels in the area, so clearly represent the zone of most significant potential risk if groundwater impacts were to propagate within their vicinity.

It should be noted that the risk of significant (noticeable) impact to the health composition and/or structure of potentially GDV from groundwater drawdown associated with the proposed dewatering of Deposits C and D is only relevant if significant changes to groundwater extends to each of the reaches delineated as part of this study. In areas where potentially GDV communities exist over a groundwater table which is approximately 5-10 m bgl, relatively slow groundwater drawdown in the order of 2-5 m (negative and on average) are likely to determine that the risks attributed to each potentially GDV community may be realised; however for drawdown in the order of only 1-2 m the risks attributed are unlikely to be realised (i.e. significant impact is unlikely). Alternatively, in areas where potentially GDV communities exist over a groundwater table which is approximately 10-15 m bgl; groundwater drawdown in the order of 2-5 m (negative and on average) is likely to determine that the risks attributed to each community are unlikely to be realised.

5.7 GDE RISK MAPPING

The GDE Risk Matrix (presented in Table 5-3) provides a relatively transparent and robust framework for working through the groundwater dependence interpretation methodology used in this study to determine the risk of 'significant impact' to potentially GDV from changes to groundwater availability. However the task of displaying the spatial distribution of risk present in the riparian environment is best done via mapping.

GDE Risk Mapping represents the spatial distribution of risk (of 'significant impact') to potentially GDV in the study area from changes to groundwater availability after integration of the vegetation mapping, the basal area mapping, and consideration of "other" modifying or supporting spatial risk factors in the GDE Risk Matrix.

Figure 5-7 and 5-8 represents the GDE Risk Mapping associated with the proposed dewatering of Deposits C and D. The GDE risk polygons (and associated risk scale (Table 4-1)) presented in this mapping are defined as representing the spatial distribution of varying risk that drawdown from the proposal will 'significantly impact' (i.e. noticeable impact) the health composition and structure of riparian communities in the local area. It is important to emphasise the distinction which is made with regard to impacts associated with this risk rating. Natural impacts to vegetation as a result of changing water availability are common in arid riparian habitats of the Pilbara region. For this reason it is important to be able to distinguish impacts likely to be a result of the proposal from the inherent degree of baseline variation and associated riparian change. This baseline riparian change is generally restricted to changes in health and at times structure, but less often leading to compositional changes. It is for this reason that potential impact from the proposal and associated groundwater change is restricted to that level of riparian change which includes both health changes as well as at least one of either compositional (of dominant species) or structural change in resident vegetation.

In addition to the definition of significant riparian impacts to which the interpreted risk relates, it is important to emphasise the fact that the interpreted risk is only relevant if significant changes to groundwater access are realised in the vicinity of riparian vegetation delineated as part of this study.