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 50% (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 likely 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; basement rock (beneath the alluvial’s) characteristics; 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 mitigate, 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 Riparian Zone C.

However, with the broader valley aquifer thinning to a terminus at the western end, the Wittenoom formation outcropping in parts of Riparian Zone C and thick calcrete formations present in the same zone it is thought that propagation of groundwater drawdown will likely be limited beyond Riparian Zones A and B (Figure 4-1). Furthermore given the Mount McRae Shale layer (known aquitard) at the end of Riparian Zone E and the geological complexity of subsurface lithologies surrounding Riparian Zone D (and Riparian 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 highly 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, 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 (Mount McRae Shale) 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 Riparian Zone C (2m within Riparian 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 unreliable. This is associated with the large proportion of the study area (particularly that area under Riparian Zone C-1) where water table heights were inferred 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 Riparian 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 impervious detrital 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 1 m to 6 m were to extend significantly beyond the KNP boundary (i.e. 2-4 km reducing groundwater to approximately 5-10 m bgl under Riparian 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.

However, with numerical modelling not considering typical surface water inputs (cyclonic recharge is considered), positive recharge complexities at the western end of the model, and the influence of thick calcrete formations, all modelling based groundwater predictions should be considered as conservative and unlikely to be realised. Furthermore Mount McRae Shale outcropping on the south bank of Riparian Zone C-1 correlating spatially with the restricted distribution of key phreatophytes in this zone suggests that primarily surface water driven recharge and groundwater ponding behind at least partial barriers to flow at the end of Riparian Zone C-1 may best explain the distribution of GDV in Riparian Zone C. This explanation is also strengthened by the observation that vegetation at the downstream end of Riparian Zone E doesn’t support uninterrupted groundwater connection through to the known aquitard in that location. Importantly, if such an explanation is true then the evidence suggests that communities in Riparian Zone C are likely to be more reliant on surface water inputs in this area than the behaviour of the broader aquifer of the Project area. Despite this, groundwater from the broader aquifer should continue to be considered as potentially providing a supporting role to vegetation in at least Riparian Zones C and E.

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 overstorey vegetation should 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 and the enhanced recharge and ponding associated with thick calcrete and other lithologies in the vicinity of Riparian Zone C, the likely mitigation 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 thus potentially structural changes) and health are considered the impact of greatest potential, albeit low-to moderate in significance and extent.

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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 50% 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.

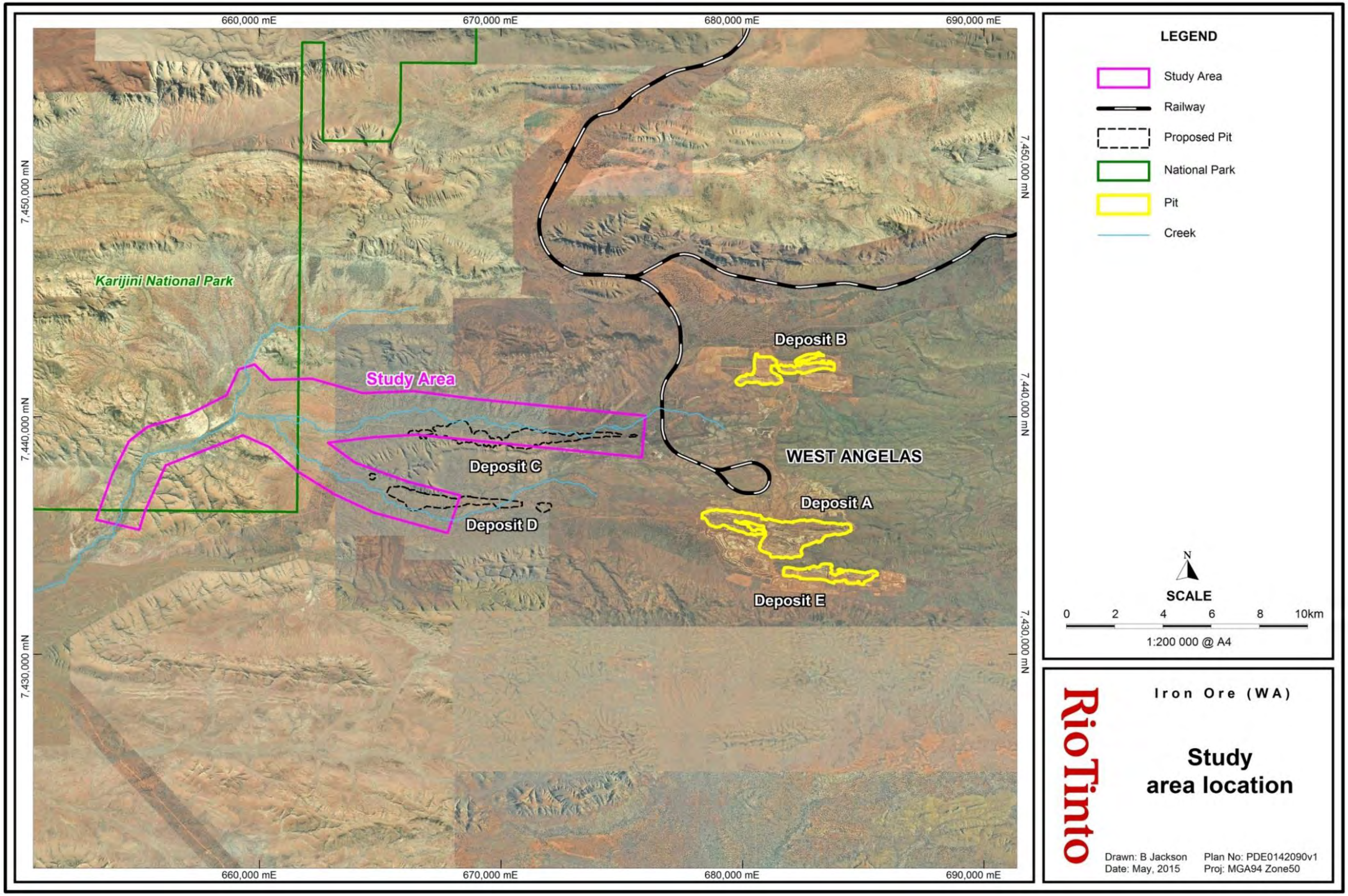

Figure 1-1: Study area Location

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 2-1 presents 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***	• *Samolus spp.*
• ***Acacia ampliceps***	• *Cullen leucanthum*
• ***Eucalyptus camaldulensis***	• *Acacia coriacea subsp. pendens*
• ***Melaleuca bracteata***	• *Eucalyptus victrix*
• ***Muehlenbeckia spp.***	• *Melaleuca linophylla*
• ***Sesbania formosa***	• *Acacia citrinoviridis*
• ***Imperata cylindrica***	• *Acacia sclerosperma*
• *Atalaya hemiglauca*	• *Acacia coriacea subsp. pendens*
• *Cyperus iria*	• *Lobelia spp.*
• *Marsilea spp.*	• *Stylidium spp.*
• *Potamogeton spp.*	• *Typha domingensis*
• *Date palm*	• *Cyperus vaginatus*
• *Various sedge spp.* including *Schoenus spp. , Baumea spp., Fimbristylis spp., etc.*	• *Sesbania spp.*
• *Cladium procerum*	• *Stemodia spp.*
• *Schoenoplectiellia spp.*	• *Sorghum spp.*
• *Eleocharis spp.*	• *Eragrostis surreyana*
• *Fuirena ciliaris (L.) Roxb.*	• *Vallisneria nana*
• *Pteris vittata*	• *Senecio hamersleyensis*
• *Adiantum capillus-veneris L.*	• *Geijera salicifolia*
• *Gossypium sturtianum*	• *Commelina ensifolia R.Br.*
• *Peplidium sp. E Evol. Fl. Fauna Arid Aust. (A.S. Weston 12768)*	• *Trigonella suavissima Lindl.*

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* (***M. 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. 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 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 1 m change 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 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 636 m RL (approximately 55 m bgl) in the east and 623 m RL (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 m RL (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).

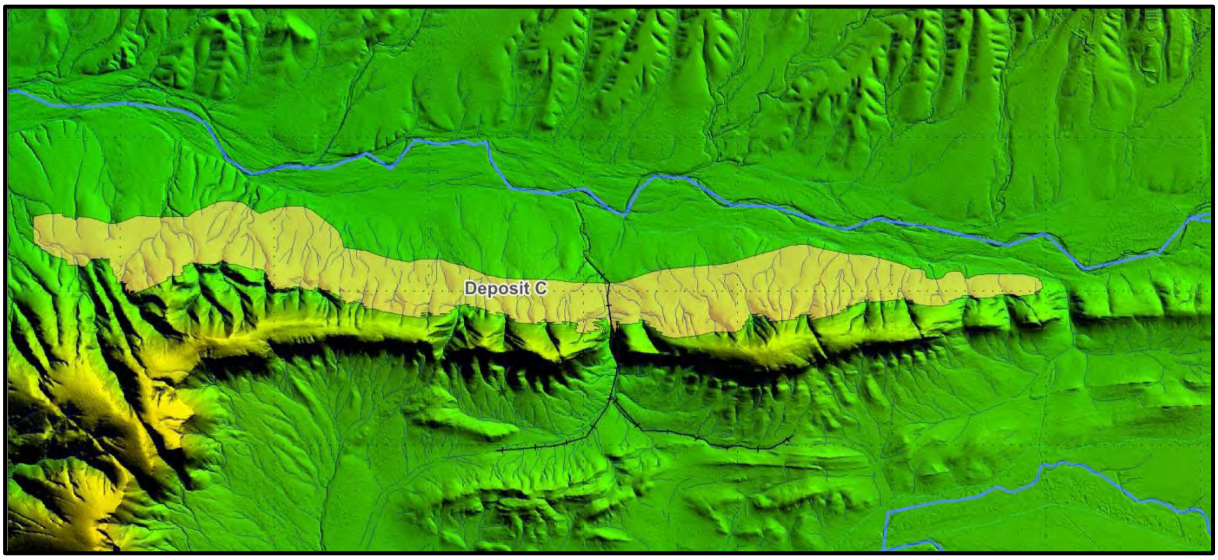

Figure 3-1: Local topography surrounding Deposit C

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 m RL. 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.

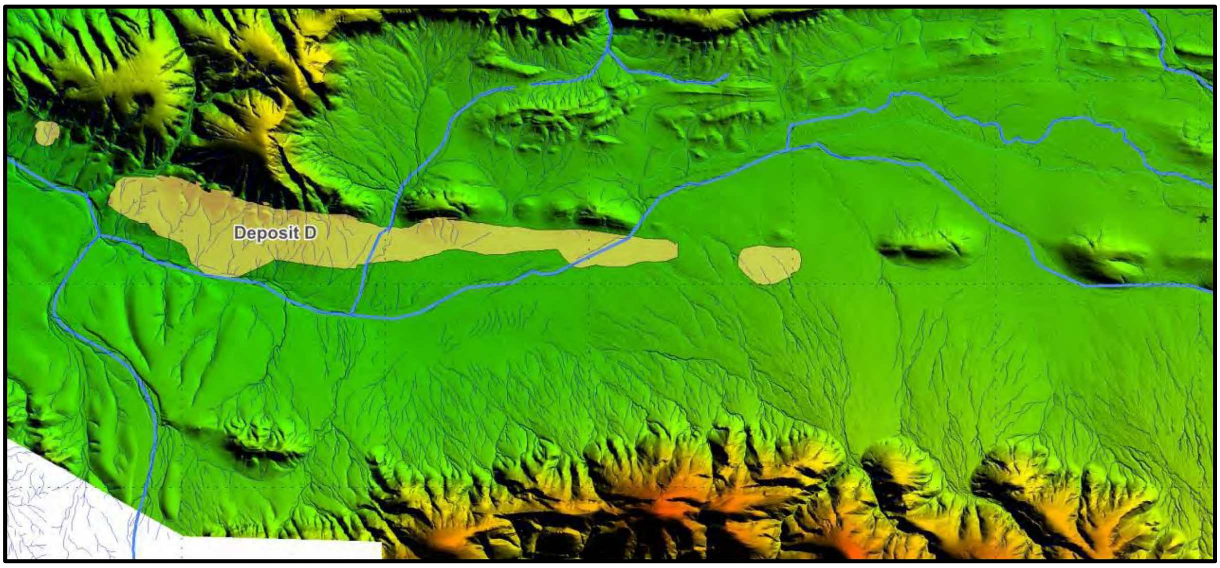

Figure 3-2: Local topography surrounding Deposit D

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 approximately 2 m and 8 m is observed at the highest (Sy = 10%) and lowest (Sy = 1%) specific yield scenario, respectively. A drawdown of 4 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 4.5 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 1 m to 6 m being predicted in scenarios with Sy = 10% and 1%, respectively. For the base case, the maximum decline of 3 m will be reached in 2050. 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 30-40cm/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).

However, while cyclonic recharge events have been considered, there are a number of hydrological factors which are not included in or taken into account within the numerical modelling. These include:

- Typical ephemeral surface water flows along Turee Creek East;
- Additional complexity to the west of the deposits and beneath Karijini National Park due to the presence of substantial calcrete formations;
- The potential presence of additional at least partial aquitards on TCEB upstream of that included in the model.

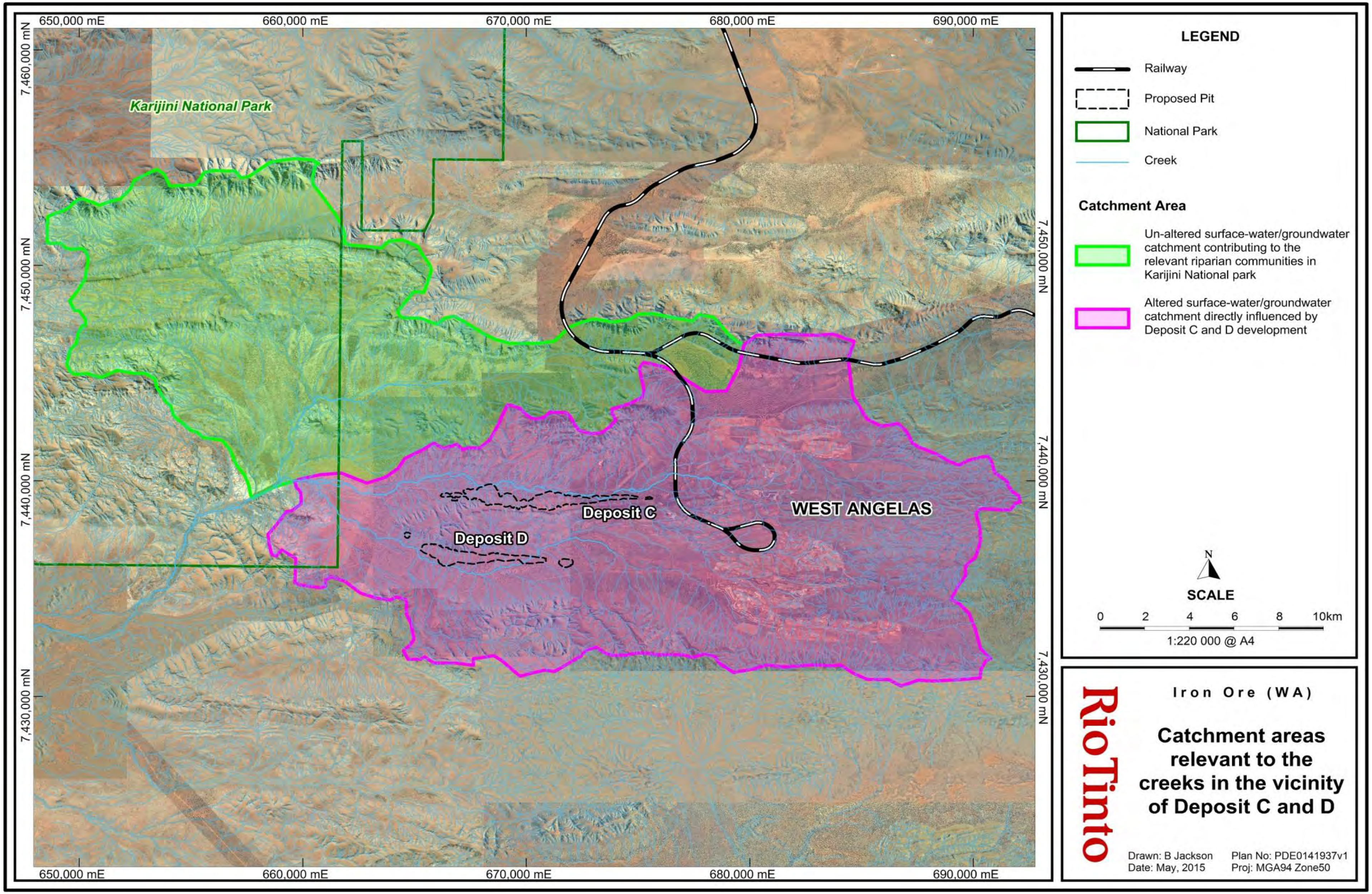

Figure 3-3: Catchment Areas Relevant to the Creeks in the Vicinity of Deposit C and D

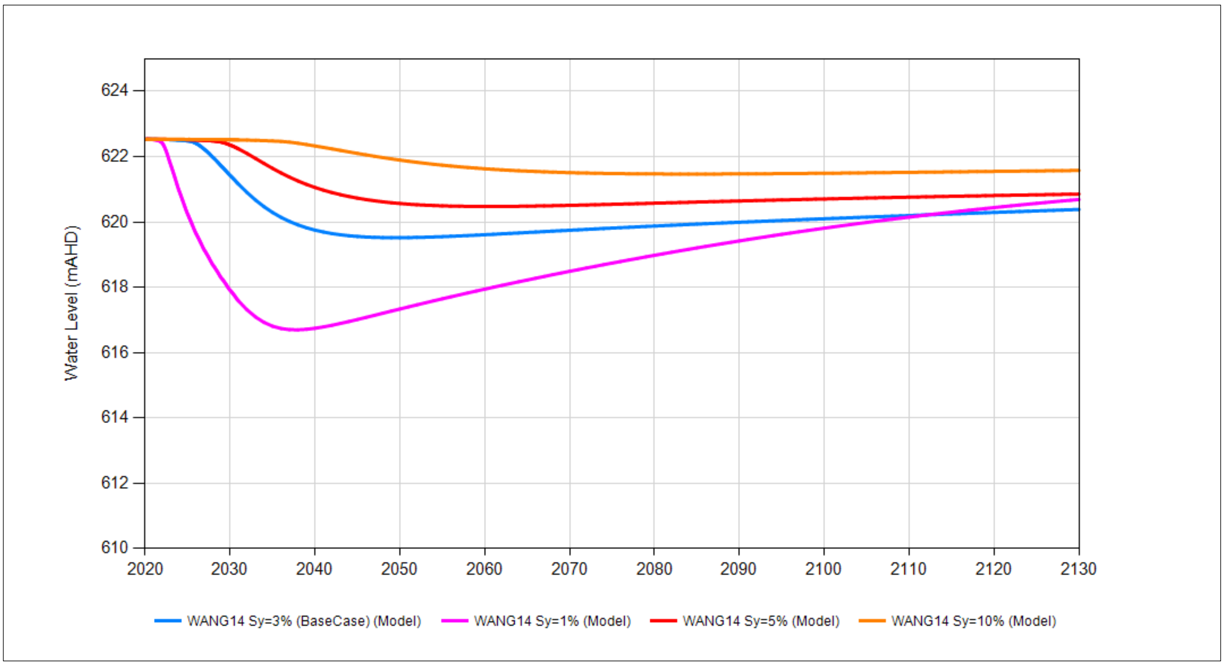

Figure 3-4: Predicted Water Levels and timing at the WANG14 Bore inside KNP

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)	1.1	4-2.5 **cm/year**
	After 65 years	for ~10-32 years
Sy5%	1.9	16-10 **cm/year**
	After 40 years	for ~8-20 years
Sy3% (base Case)	**3.0**	**26-16cm/year**
	After 30 years	for ~8-19 years
Sy1% (worst case)	5.9	75-35 **cm/year**
	After 18 years	for ~3-17 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 3-3). 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.

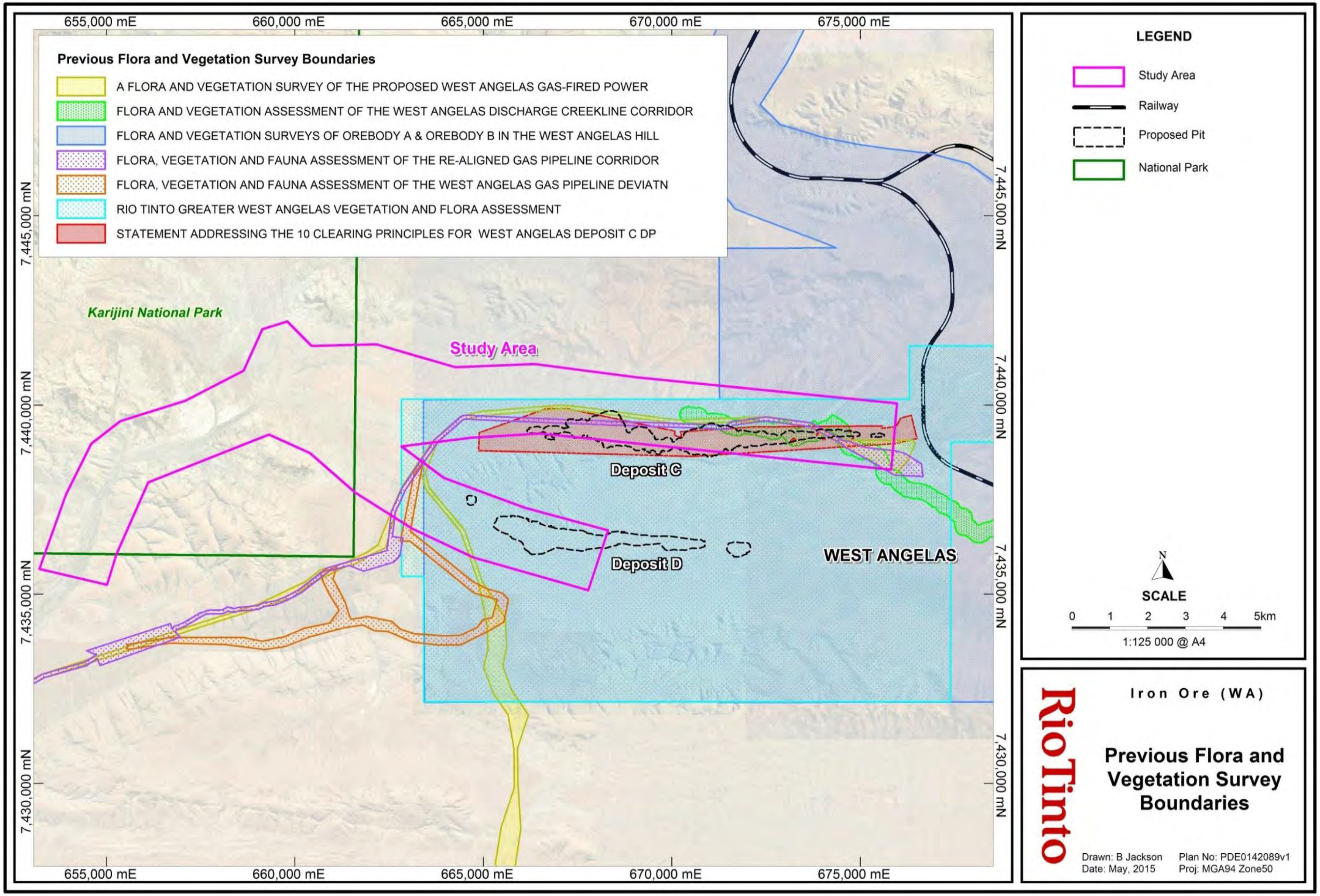

Figure 3-5: **Previous Flora and Vegetation Survey Boundaries**

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.

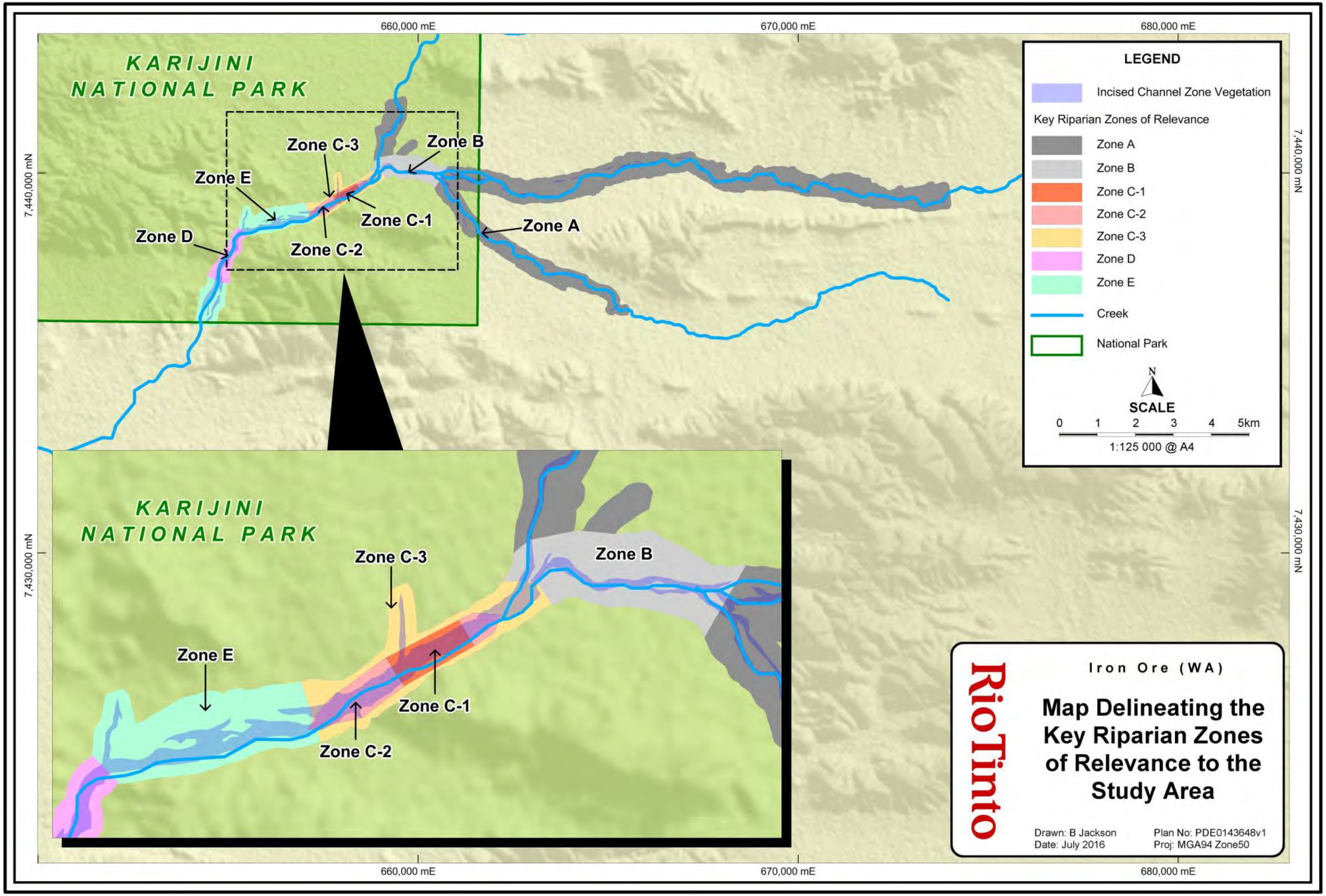

Figure 4-1: Map delineating the Key Riparian Zones of Relevance to the Study area

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.

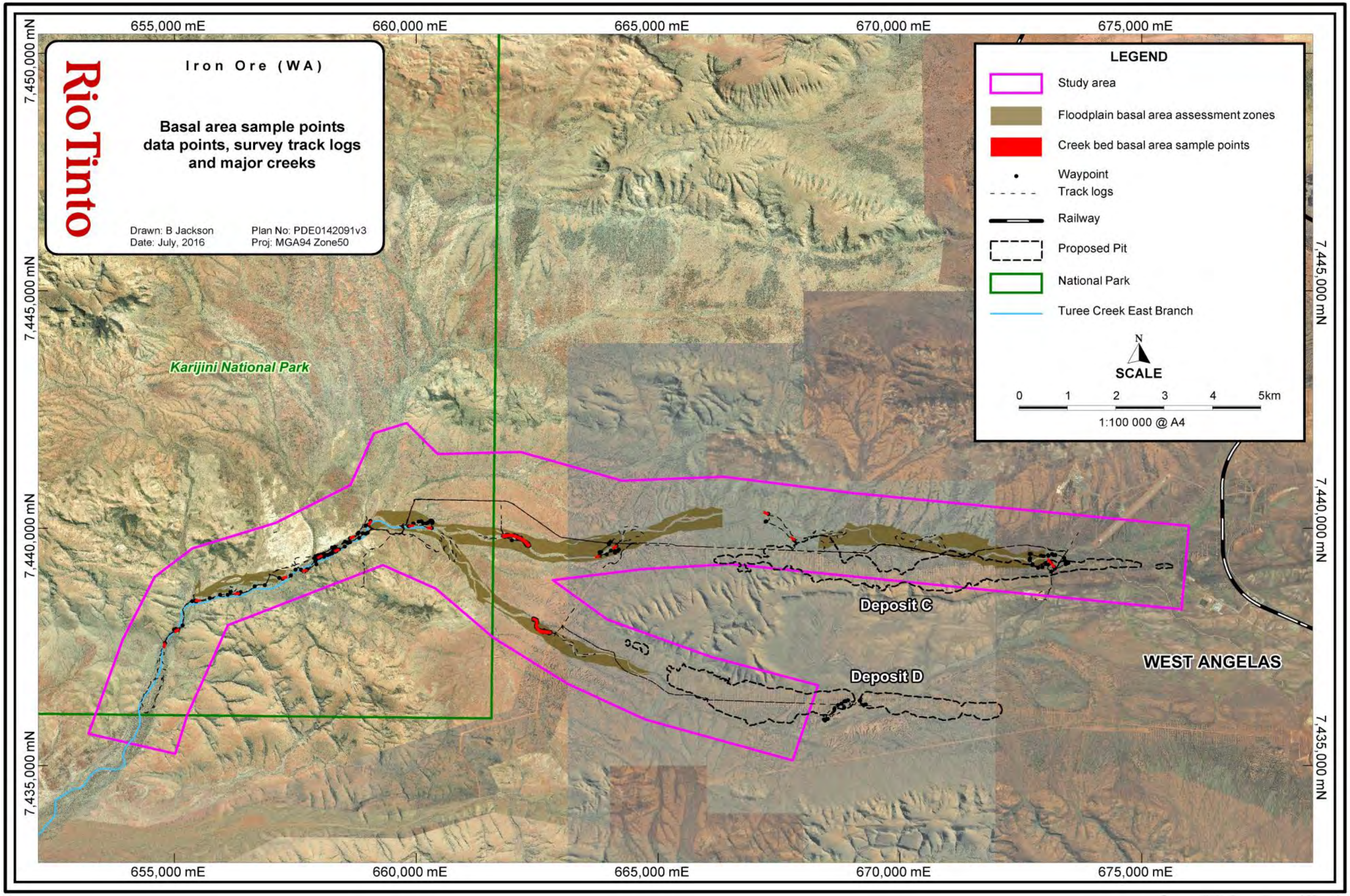

Figure 4-2: **Basal Area Sample Points Data points, Survey Track Logs and Major Creeks**

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.

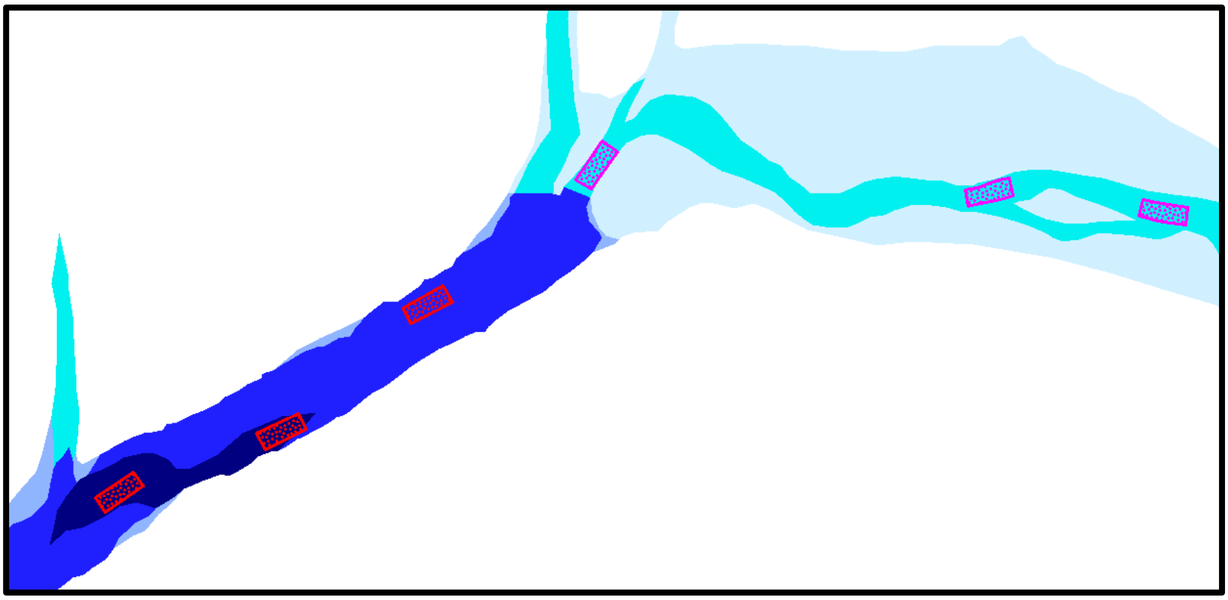

Figure 4-3: Examples of the position and extent of incised channel Basal area assessment plots

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.

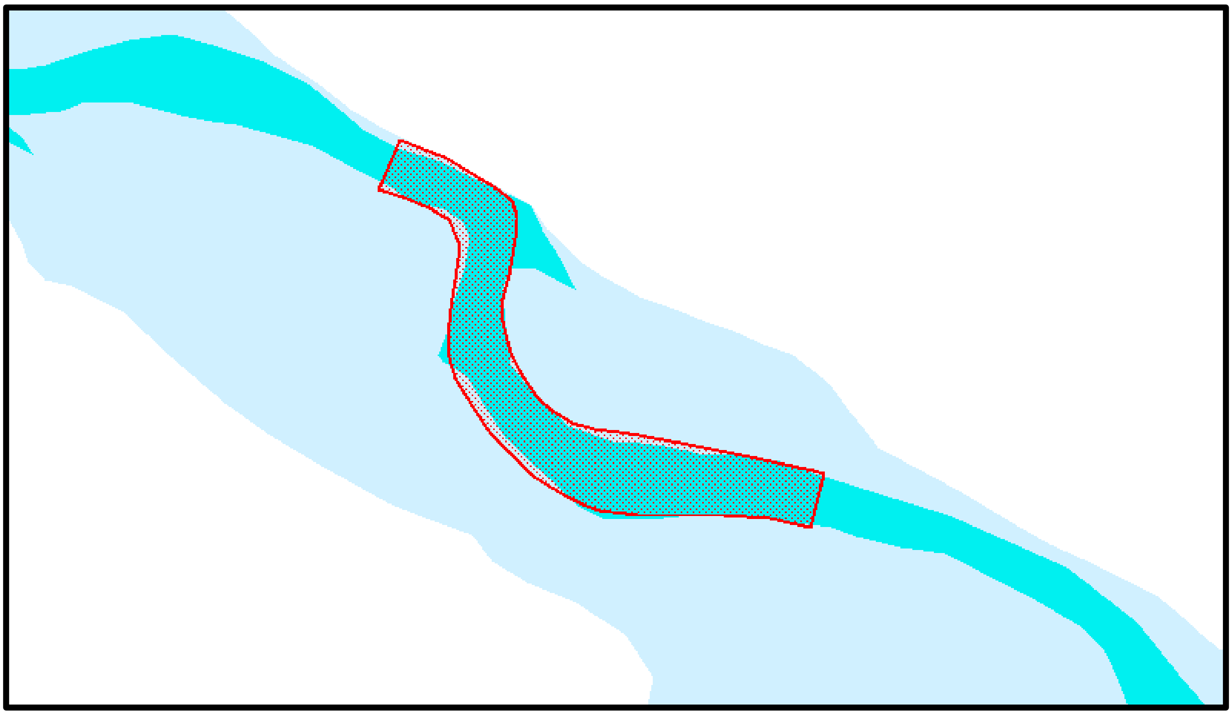

Figure 4-4: Example of position and extent of low density Incised Channel Basal area assessment plots

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.

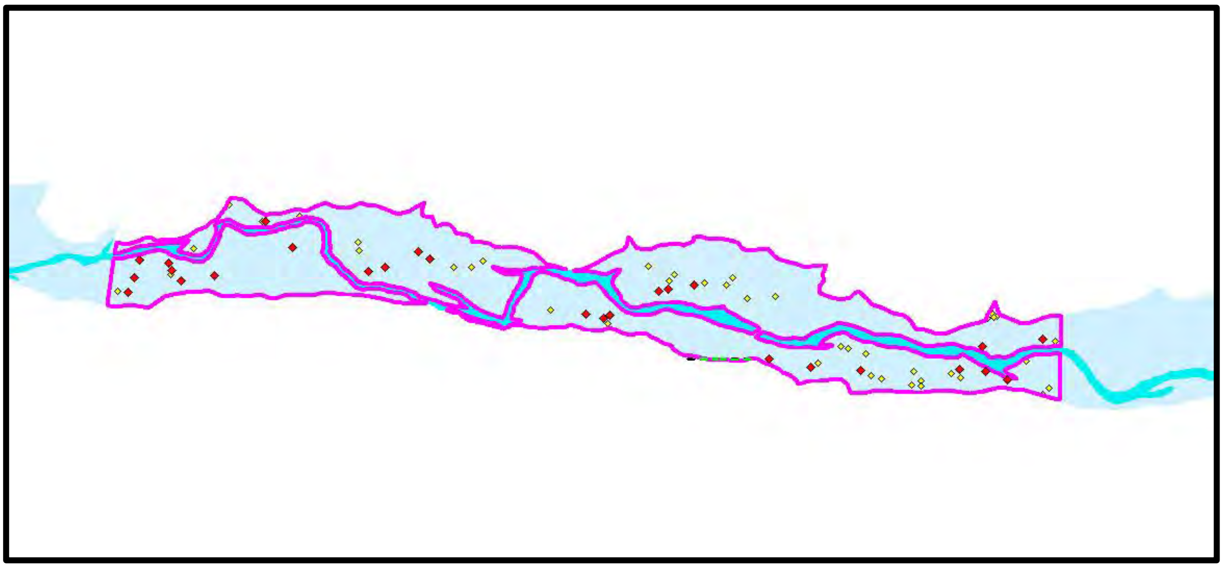

Figure 4-5: Example of position and extent of the floodplain Basal area assessment plots

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**

Phreatophytic Structural and Compositional evidence (plus mesic indicators)	Basal area range (m^2/ha)	Risk
Woodland Low risk Facultative phreatophytes dominant, isolated medium risk facultative phreatophytes	**9-13**	**Low+**
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	**15-40**	**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.

Generally sedges were nit common, but some sedge species were detected within the creek beds and terraces of the study area, these included, *Cyperus vaginatus* and on one occasion *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 Schoenoplectelia *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) within Riparian Zone A and 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.

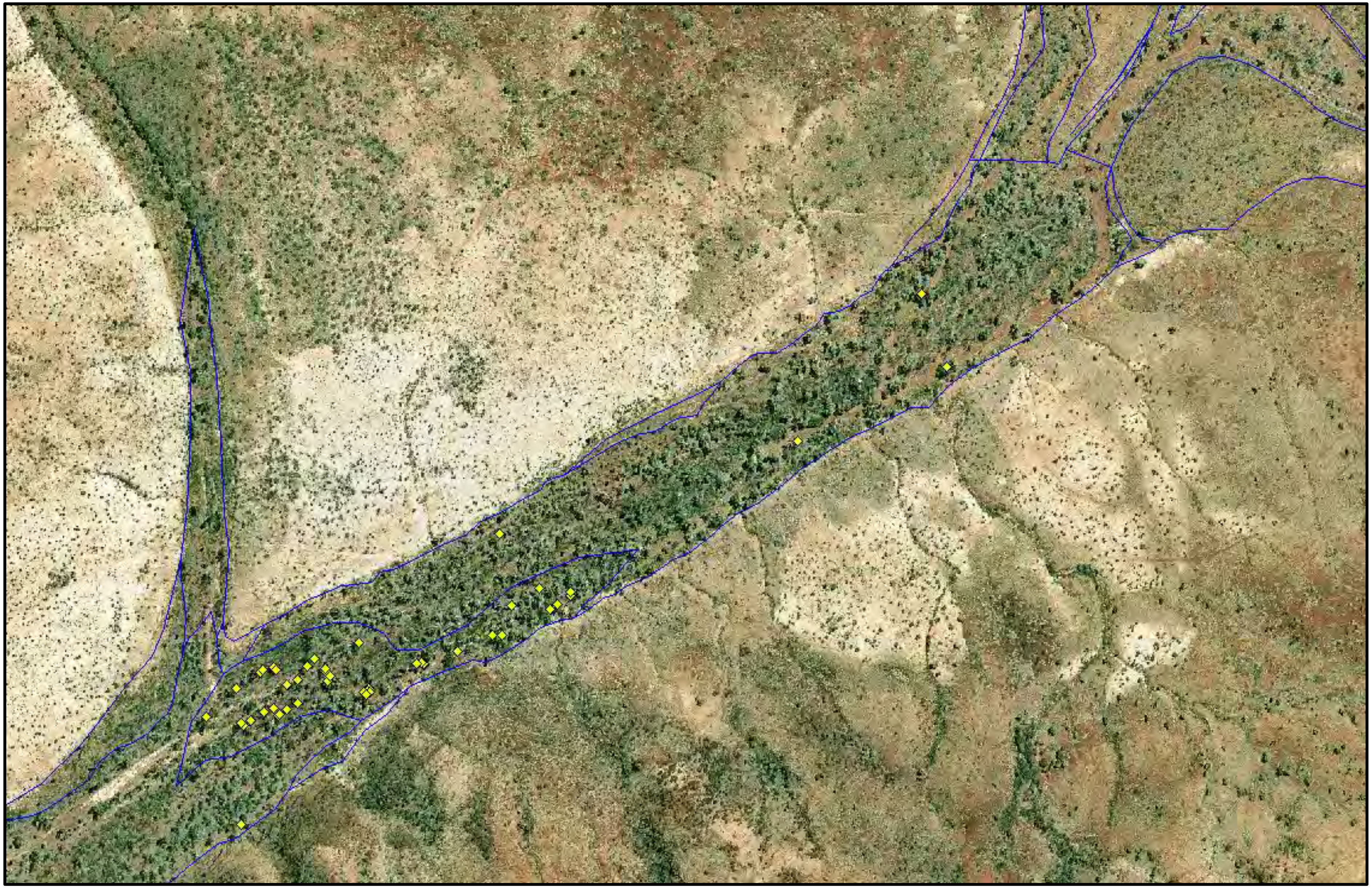

Figure 5-1: Aerial photo map showing the most substantial of the riparian vegetation signatures present on TCEB within the study area, with vegetation mapping boundaries (blue boundaries), and individual mature *Eucalyptus camaldule*nsis locations (Yellow diamonds)

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

<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">C2B</td><td>Incised channel zone - straddling multiple channels including the low flow channel</td><td>E. victrix and E. camaldulensis woodland over Acacia citrinoviridis tall open shrubland over mixed open-shrubland/low-open-shrubland over mixed open tussock grassland</td><td>E. 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.</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 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.</td></tr>
</table>

Vegetation Code	Landscape position	Broad Vegetation Description	Detailed Vegetation Description
C3B	**Incised channel zone** - straddling multiple channels including the low flow channel, but also some creek terrace habitats	***E. victrix* woodland over *Acacia citrinoviridis* tall open shrubland** over mixed open-shrubland/low-open-shrubland over mixed open tussock grassland	*E. 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*.
	List of associated species recorded		
	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.		

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 *E. 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		

<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">F3</td><td>Floodplain zone and associated habitats - including more minor high flow channels</td><td>Scattered to isolated E. victrix low trees over mixed scattered tall-shrubs/shrubs, over very open tussock/hummock grassland</td><td>Scattered to isolated E. 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.</td></tr>
<tr><td colspan="3">List of associated species recorded</td></tr>
<tr><td colspan="3">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.</td></tr>
</table>

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 *E. 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.		

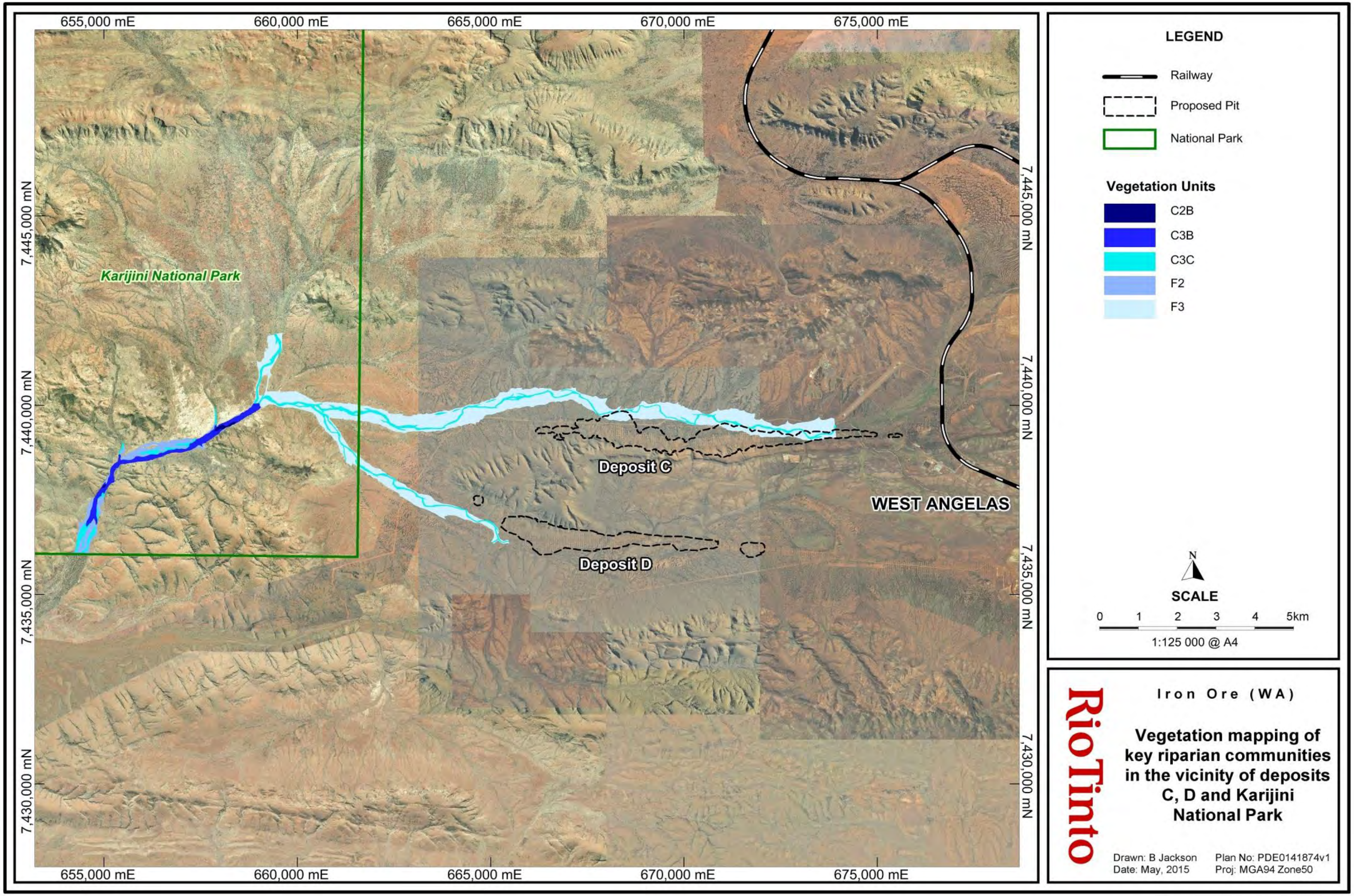

Figure 5-2: Vegetation Mapping of Key Riparian Communities in the Vicinity of Deposits C, D and Karijini National Park

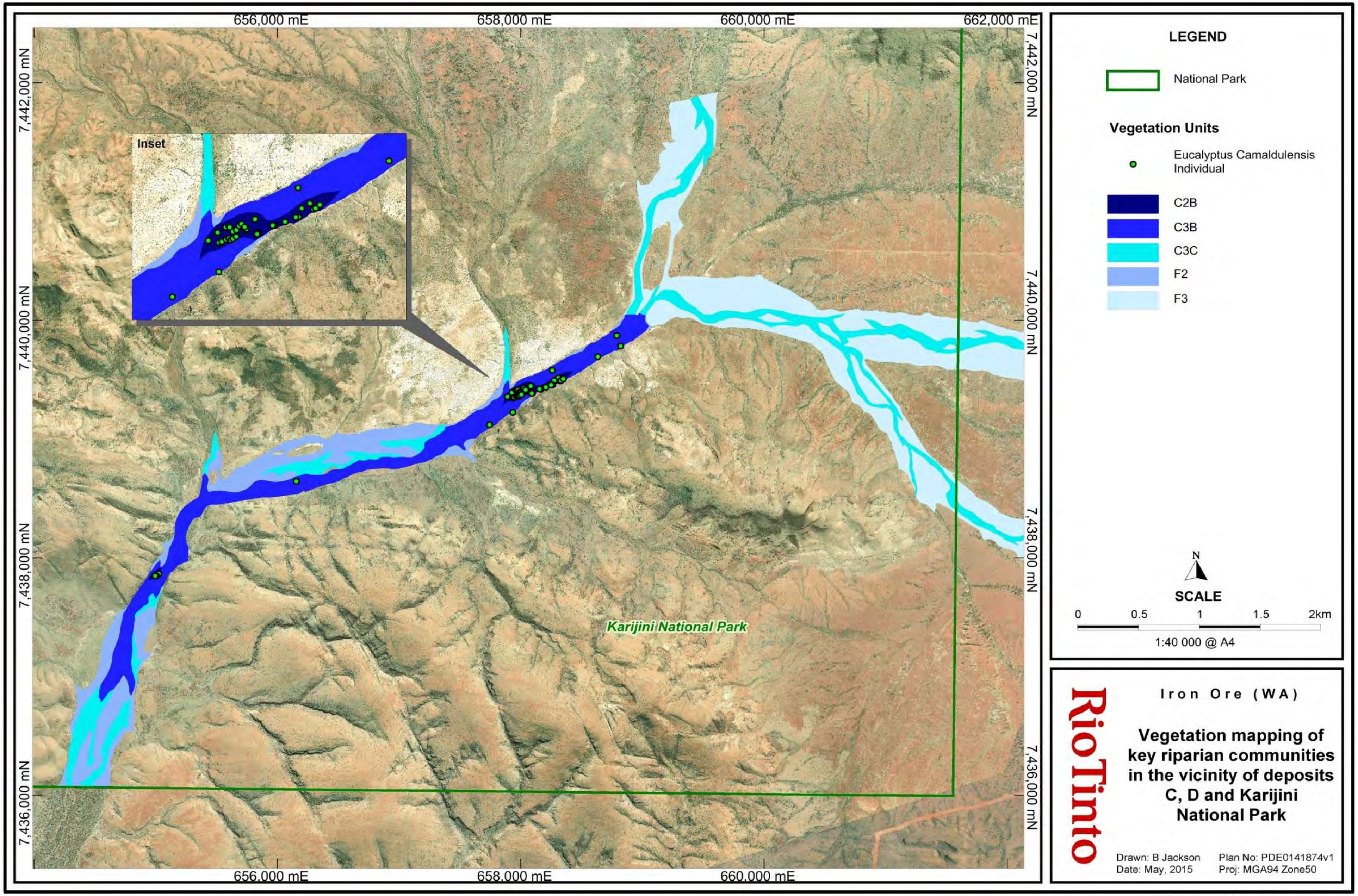

Figure 5-3: Vegetation Mapping of Key Riparian Communities in the Vicinity of Deposits C, D and Karijini National Park

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 Riparian 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.

Based on the residual risk results provided in table 5-3 the following risk mapping results have been concluded (based on an interpreted scale of risk due to groundwater dependence of 'significant impact' from groundwater changes):

- Approximately 93% of the study area is represented by riparian vegetation interpreted to possess a "Very Low to Low" residual risk.
- Approximately 6.6 % of riparian vegetation in the study area (the remainder) has been interpreted to possess a residual risk of "low" and greater.
- Of this remaining 6.6% of assessed riparian vegetation, 4% (42 ha) was attributed a residual risk of "low" and 2 % (22 ha) was attributed a residual risk of "Low-Medium".
- Only 0.4% (4.2 ha) of the study area was attributed a "Medium" risk of 'significant impact' due to potential groundwater changes.

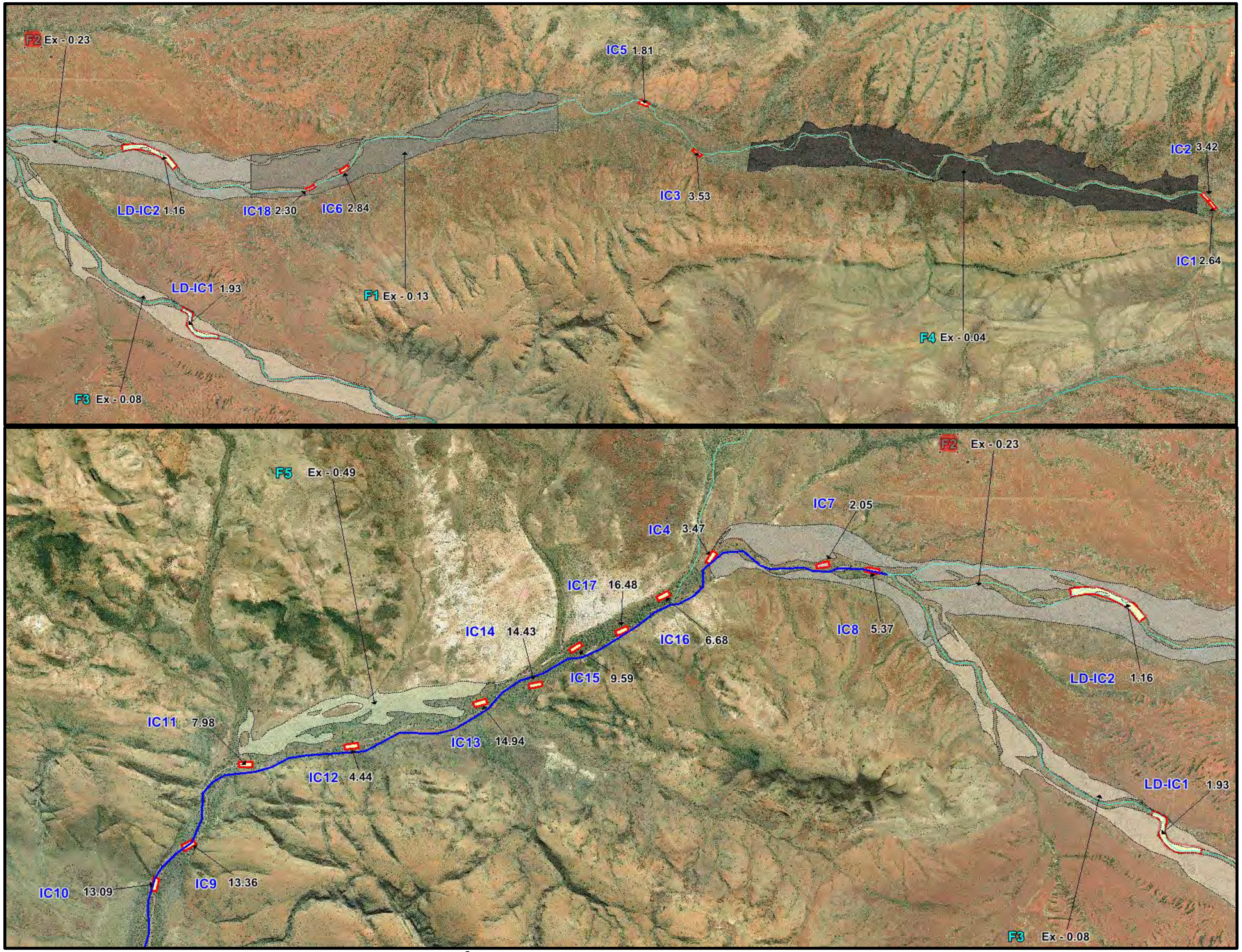

Figure 5-4: **Basal area results map, showing the basal area (in m^2 per ha) calculated for each assessment plot (east and west portions of the study area)**

Figure 5-5: Aerial photo demonstrating potential inaccuracies with interpreting biomass from aerial photo signatures

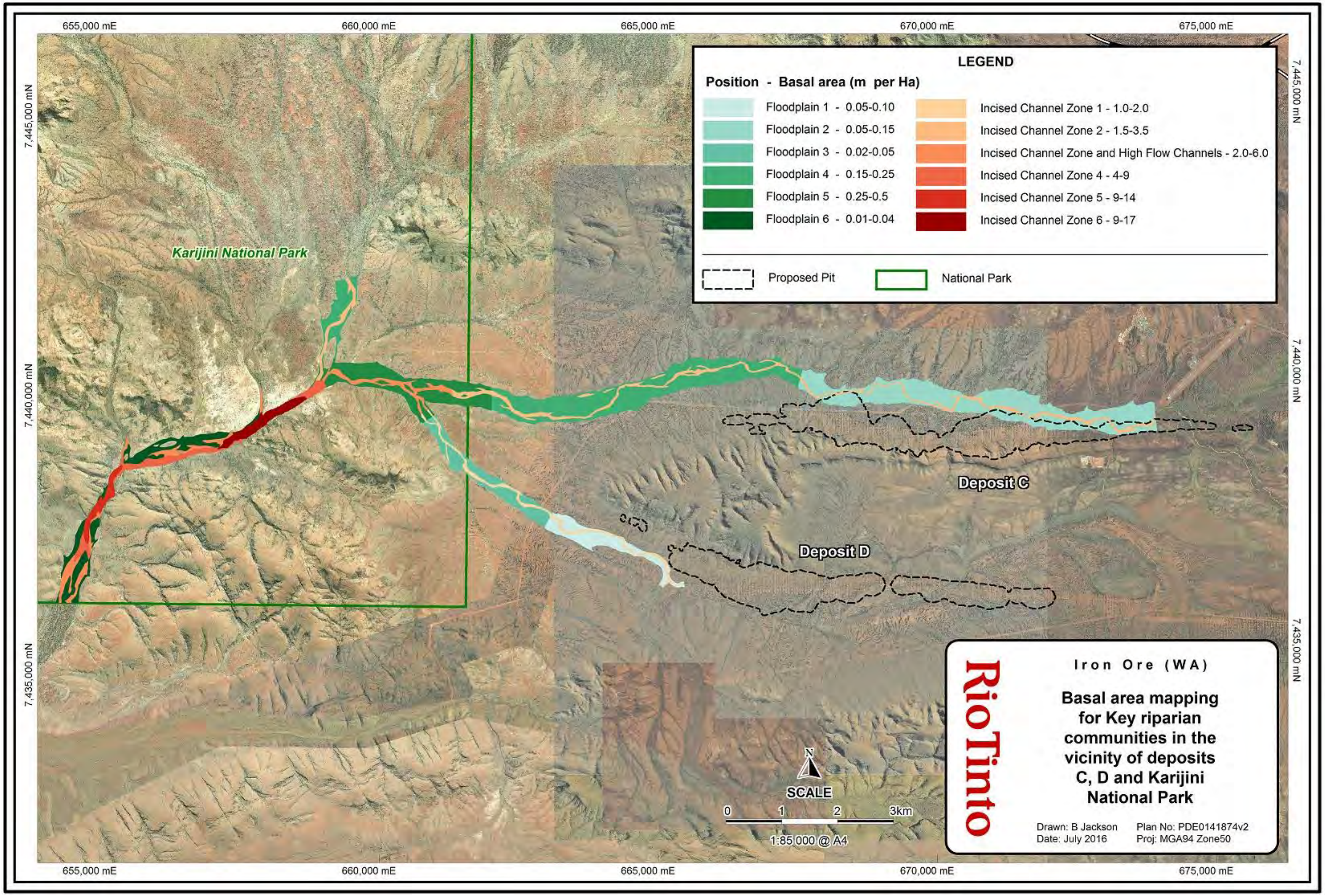

Figure 5-6: **Basal area mapping by zone (Floodplain and Incised channel) and reach (by topography and incremental catchment gain within the study area**

Table 5-3: GDE Risk determination Matrix

Veg unit	Broad vegetation description	Position	Reach	Basal area (m^2/ha)	Phreatophytic over-storey structural/compositional evidence	Matrix prescribed basal area range	Matrix prescribed risk	Modifying or supporting factors	Interpreted residual risk
F3	Scattered to isolated *E. victrix* low trees over mixed scattered tall-shrubs/shrubs, over very open tussock/hummock grassland	Floodplain	1	0.01-0.04	Isolated to scattered - Low risk facultative phreatophytes present	0.01-0.15	Negligible	Neutral	Negligible
			2	0.02-0.05	Isolated to scattered - Low risk facultative phreatophytes present			Neutral	
			3	0.05-0.10	Isolated to scattered - Low risk facultative phreatophytes present			Neutral	
			4	0.05-0.15	Isolated to scattered - Low risk facultative phreatophytes present			Neutral	
			5	0.15-0.25	Isolated to scattered - Low risk facultative phreatophytes present	0.15-1.0	Very Low	Neutral	Very Low
F2	Scattered *E. victrix* and *E xerothermica* low trees over mixed tall-open-shrubland/open-shrubland, over mixed very open tussock/hummock grassland	Floodplain	6	0.25-0.5	Scattered - Low risk facultative phreatophytes present	0.15-1.0	Very Low	Neutral	Very Low

Veg unit	Broad vegetation description	Position	Reach	Basal area (m^2/ha)	Phreatophytic over-storey structural/compositional evidence	Matrix prescribed basal area range	Matrix prescribed risk	Modifying or supporting factors	Interpreted residual risk
C3C	***E. Victrix*** **low open woodland over** ***A. citrinoviridis*** **tall open shrubland, over mixed scattered-shrubs/low-open-shrubland over mixed open tussock grassland**	**Incised channel zone**	**7**	**1-2**	**Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant**	**1.0-6.0**	**Very Low+**	**(+0.5) - Positioned in the riparian zone where groundwater heights are between 5-10 m bgl, in places vegetation forming a low open woodland.**	**Very Low - Low**
		Incised channel zone	**8**	**1.5-3.5**	**Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant**		**Very Low+**	**(+0.5) - Positioned in the riparian zone where groundwater heights are between 5-10 m bgl, at times possessing a basal area approaching the upper limit of the “very low+” class, in the vicinity of creek confluences.**	**Very Low - Low**
					Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant			**(-0.5) – Groundwater unlikely to be accessible, facultative phreatophytes more often representing a scattered cover-abundance.**	**Very Low**
		Incised channel zone and High flow channels	**9**	**2-6**	**Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant**			**(-0.5) – Positioned approximately 10km downstream of drawdown source, located in areas downstream of predicted groundwater divides.**	
					Scattered to low open woodland - Low risk facultative phreatophytes present and co-dominant to dominant			**(+0.5) – Positioned in the riparian zone where the creek profile is constricted and alluvials may be shallow, in places vegetation forming a low open woodland to woodland.**	**Very Low - Low**

Veg unit	Broad vegetation description	Position	Reach	Basal area (m^2/ha)	Phreatophytic over-storey structural/compositional evidence	Matrix prescribed basal area range	Matrix prescribed risk	Modifying or supporting factors	Interpreted residual risk
				3-6	Low open woodland to woodland - Low risk facultative phreatophytes dominant	3.0-9.0	Low (-)	(+1) – Possessing patches of generally higher biomass (3-6 m^2/ha), possessing increasing potential for shallow groundwater, within proximity of groundwater impact zone, positioned in the riparian zone where the creek profile is constricted and alluvials may be shallow.	Low
C3B	*E. victrix* woodland over *A. citrinoviridis* tall open shrubland, over mixed open-shrubland/low-open-shrubland over mixed open tussock grassland	Incised channel zone	10	4-9	Low open woodland to Woodland - Low risk facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes present	3.0-9.0	Low (-)	Neutral	Low (-)
					Low open woodland to Woodland - Low risk facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes present	3.0-9.0		(+0.5) – Positioned in the riparian zone where the creek profile is constricted and alluvials may be shallow, in places vegetation forming a woodland, possessing moderate potential for shallow groundwater, still occurring within the potential groundwater impact zone.	Low
					Woodland - Low risk facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes	5.0-9.0	Low	(+0.5) - Initially positioned at the start of shallow groundwater heights where potential groundwater changes first become relevant, and in all cases located where the creek profile is constricted and alluvial's may be shallow, moderate potential for shallow groundwater remains in the downstream areas, occurring within the potential groundwater impact zone.	Low (+)

Veg unit	Broad vegetation description	Position	Reach	Basal area (m^2/ha)	Phreatophytic over-storey structural/compositional evidence	Matrix prescribed basal area range	Matrix prescribed risk	Modifying or supporting factors	Interpreted residual risk
			11	9-14	Woodland - Low risk facultative phreatophytes dominant, potentially isolated medium risk facultative phreatophytes present	9.0-13.0	Low+	(-0.5) – Only possesses low risk FPS, initially positioned where a new tributary joins TCEB (additional surface water input lowers reliance on groundwater and risk), positioned either side of a topographically constrained gorge section of the creek where geology suggests a high likelihood of groundwater divides restricting drawdown propagation.	Low
						9.0-13.0	Low+	Neutral	Low+
			12	9-17	Woodland - Low risk facultative phreatophytes dominant, medium risk facultative phreatophytes associated - No specific mesic woody species detected	9.0-18.0	Low-medium	Neutral	Low - medium
C2B	*E. victrix* and *E. camaldulensis* woodland over *Acacia citrinoviridis* tall open shrubland, over mixed open-shrubland/low-open-shrubland over mixed open tussock grassland	Incised channel zone	11	9-14	Woodland - Low and moderate risk facultative phreatophytes dominant - No specific mesic woody species detected	9.0-13.0	Low-Medium	(- 0.5) - Highly restricted with very small areal extent, positioned where a new tributary joins TCEB (additional surface water input lowers reliance on groundwater and risk), located within a topographically constrained gorge section of the creek where geology suggests reducing potential for groundwater drawdown propagation.	Low+
			12	9-17	Woodland to open forest - Low and moderate risk facultative phreatophytes dominant - No specific mesic woody species detected	9.0-18.0	Medium	Neutral	Medium

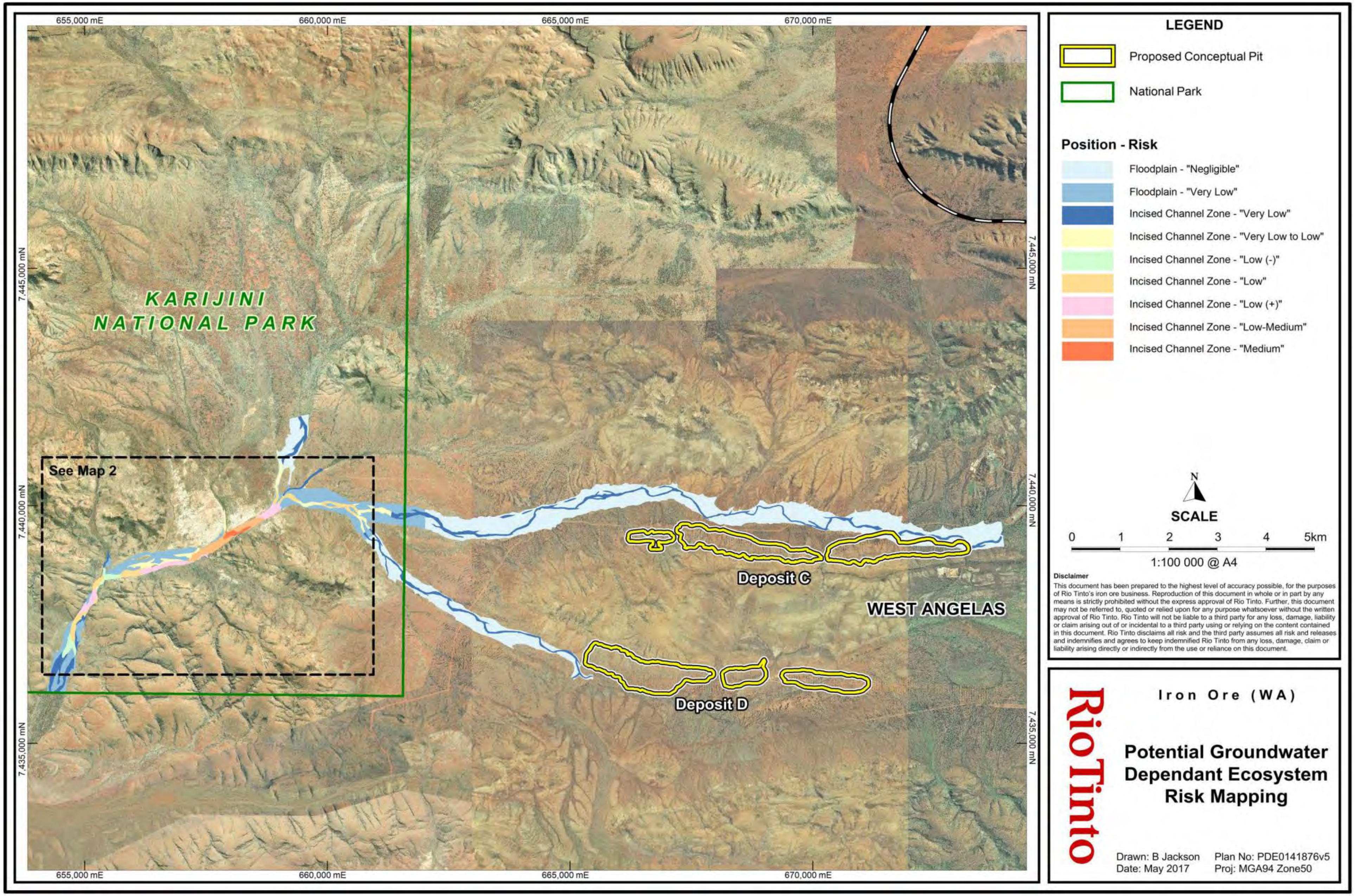

Figure 5-7: GDE Risk Mapping depicting the spatial distribution of risk of 'significant impact' to potentially GDV in the study area from changes to groundwater availability associated with the proposed dewatering of Deposits C and D

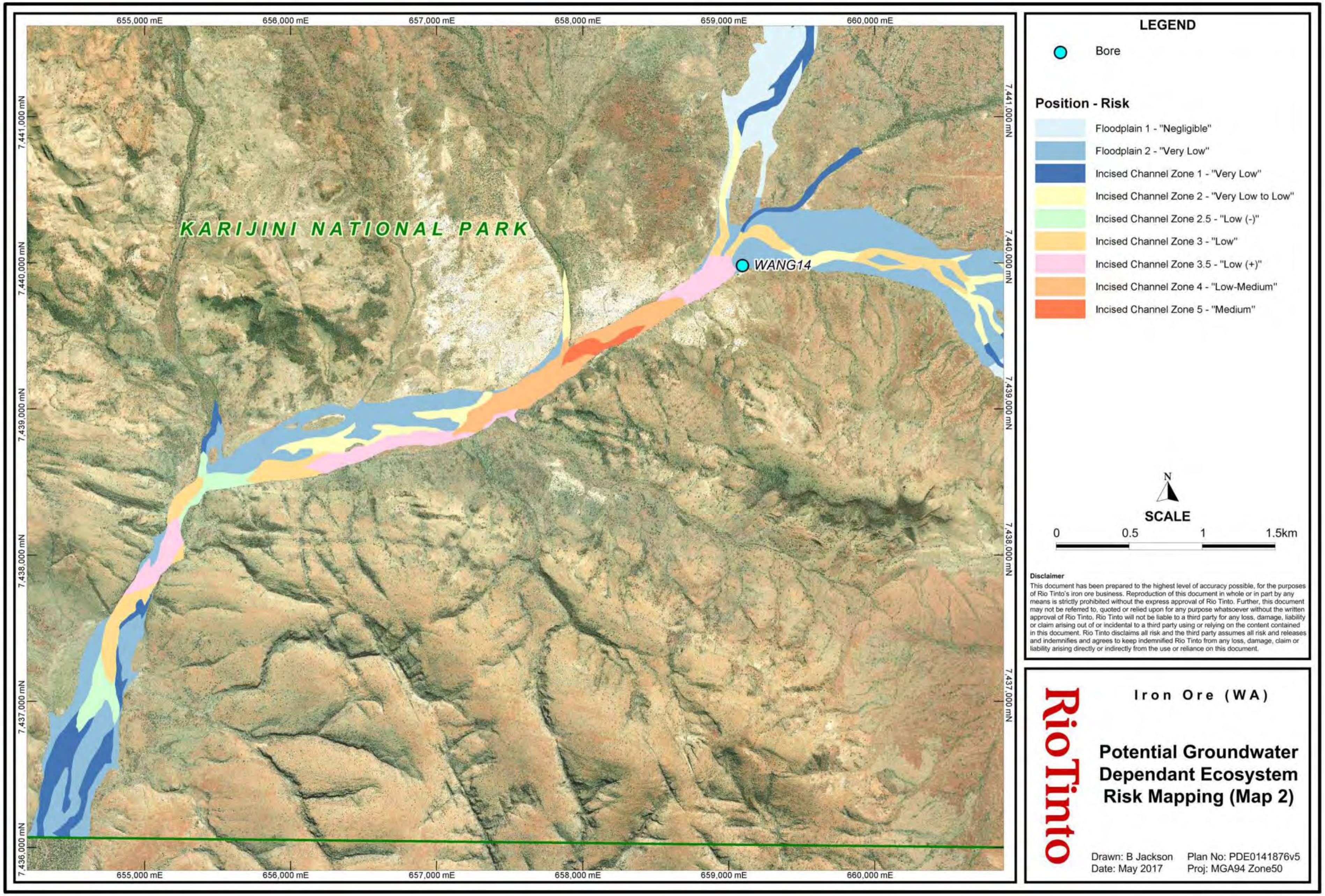

Figure 5-8: GDE Risk Mapping (Map 2) depicting the spatial distribution of risk in the key zone of interest (KNP), and the position of monitoring bore WANG14

6 DISCUSSION

6.1 GROUNDWATER AVAILABILITY/ACCESS

Within the study area and outside of KNP, groundwater below the riparian zone is interpolated to be between 50 m and 70 m bgl (at times as low as 20 m) and is therefore, essentially beyond the reach of local trees. This groundwater depth is based on data from more than 100 monitoring bores throughout the Proposal area.

There is almost no direct information on the depth to groundwater in KNP aside from a single bore (WANG14; Figure 5-8) which is located approximately 2.5 km inside the KNP boundary at the confluence of two key tributaries (of relevance to the study area) into TCEB.

Given the sensitivities around disturbance within the conservation estate, opportunities to increase our knowledge about the hydrogeology inside the KNP boundary are constrained. Monitoring bores show that groundwater depth decreases from east to west through the study area towards TCEB and the head of the valley (at the KNP boundary). Monitoring also shows that the aquifer thins from east to west as it is pinched to a minimum thickness in the vicinity of Riparian Zones B and C. The decreasing groundwater depth from east to west appears to be primarily associated with decreasing elevation in the same direction. Towards the western end of the study area groundwater is within proximity of the surface, as evidenced in the monitoring bore (WANG14) located inside the KNP boundary which indicates that groundwater is approximately 5-6 m bgl. As elevation falls downstream of WANG14, interpolation of the monitoring data indicates that in such areas, and particularly within Riparian Zone C, groundwater is potentially in easily accessible reach of riparian vegetation (i.e. <5 m bgl).

Geophysics work conducted in early 2017 (restricted to Riparian Zone C) interpreted depth to groundwater within Riparian Zone C to be in the vicinity of 3-5 m (1.5-6.5 m range (average 3.5); GBG MAPS 2017) at the time of survey. More detailed consideration of the mapping provided by this work and the actual and average groundwater heights present within two key Riparian Zones are provided in Table 6-1. This table also presents figures for the predicted groundwater heights (due to drawdown) which result from the combination of baseline heights with predicted magnitudes of drawdown at the start of Riparian Zone C. This detailed consideration estimates that within Riparian Zone C-1 groundwater is on average 2m deep, with an average range of 1.5-2.5 m bgl across this zone. Within the remainder of Riparian Zone C, average depth to groundwater was estimated as 3.5 m, with an average range of 2.5-4.5 m bgl. While groundwater depths of up to 6.5 m were interpreted/inferred from the geophysical investigations, there was actually only a couple of dips recorded in groundwater heights to this level (often only over very short distances in the order of 20-50 m), and for the most part interpretations put groundwater at less than 5 m below the surface.

Once the baseline heights (average range) in Riparian Zone C were considered in relation to worst case modelling of drawdown (Sy1% or 6m, predicted at the WANG14 Bore), the maximum depth to groundwater predicted under the most sensitive vegetation type (C2B or Riparian Zone C-1, that containing *E. camaldulensis*) was determined to be in the order of 8.5 m (with base case being approximately 5.5 m). Importantly, this worst case prediction clearly maintains groundwater at a depth which will ensure direct or indirect (via the capillary fringe) contact is maintained between local tree roots and groundwater. For the remainder of Riparian Zone C, where the more resilient *E. victrix* dominated community resides (vegetation type C3B), this same analysis predicts the worst case depth to groundwater to be in the order of 10.5 m; within the range which phreatophytic trees are considered capable of maintaining direct or indirect root contact with. It is important to note at this point that numerical modelling used to determine these degrees of drawdown in KNP does not take into account the recharge influence of typical ephemeral surface water flows along Turee Creek East and as such these potential changes to groundwater heights should be seen as highly conservative. The numerical modelling also does not accommodate additional complexity beneath Karijini National Park due to the presence of calcrete (Rio Tinto 2017). A significant amount of calcrete is present based on the surface geology mapping and observed intersections (Rio Tinto 2017). Calcrete may have much higher storage capacity than the surrounding aquifer and create enhanced recharge and groundwater mounding during the wet season. Hydrogeologists anticipate that the enhanced recharge due to ponded surface water behind the Mount McRae Shale (in Riparian Zone C) and the presence of saturated calcretes will likely substantially mitigate drawdown propagation through the area (Rio Tinto 2017).

When groundwater resides 10 m or more below ground level it is acknowledged that groundwater is generally considered to become a more minor component of tree water use. However, when considering a community with a tree strata dominated by facultative phreatophytes, the key concern generally relates to the maintenance of some access to groundwater (even indirect access via the capillary fringe or matric rise processes), so that in dry periods where the vadose soil water resource may not be adequate, groundwater is available to supplement EWR and maintain turgor pressure. Alternatively, one concern relates to whether impact might arise if groundwater levels approach or exceed 15 m bgl, and the amount of water which is sourced from groundwater approaches negligible proportions of the EWR of a community. However clay pockets and fine grained alluvial sediments in the local fluvial system suggest a high potential for broad (i.e. deep) capillary zones. When combined with a likelihood for relatively high matric potentials (often associated with fine grained soils) within the alluvial's of zone C, indirect influence from the water table on root systems has the potential to extend 2-3m (and up to 5m) above the water table. Under such a scenario, mature trees have the potential to maintain root contact with indirect groundwater sources if groundwater were to approach 15 m bgl.

For Australian systems, evidence suggests that reliance on groundwater by terrestrial vegetation is greatly reduced in areas where the water table exceeds a threshold depth, likely to lie between 7 m and 12 m (Benyon, Theiveyanathan, and Doody 2006; Department of Water 2009; O'Grady, Carter, and Holland 2010; Zolfaghar et al. 2014), with 10 m suggested as a general threshold (Eamus, Froend, et al. 2006). However vegetation may potentially access groundwater when the water table is between 10 m and 20 m depth, although it is thought to be very small in terms of contribution to total plant water use (Zencich et al. 2002), and beyond 20 m depth, the probability of groundwater as a water source for vegetation is regarded as being low. While meta-analyses by Canadell et al. (1996), Schenk & Jackson (2002) and Schenk & Jackson (2005), have shown maximum rooting depths across multiple biomes to extend 20-50 m below ground, significant variation exists. Global scale analysis by Canadell (1996) showed that for tropical grassland/savannah (the included Biome most relevant to our arid-land situation) the average maximum rooting depth from examples in the literature was 15.0+/-5.4.

Models of vertical root resource distribution (and water extraction) and field observations made by Schenk (2008), suggest that the percentage of root resources present below 10 m is likely to be less than 1% of all root resources available. A study by Kath et al, (2014) on groundwater decline and tree change in eastern Australian floodplain landscapes identified groundwater depth thresholds ranging from 12.1 m to 22.6 m for *E. camaldulensis*, beyond which canopy condition declined abruptly. Statistical modelling conducted as part of this study indicated that 27% of variation was explained by survey year, 24% was explained by antecedent groundwater depths, 20% was explained by tree density, and 10% was explained by groundwater decline magnitude. It is hypothesised by Kath et al, (2014) that while maximum rooting depths in *E. camaldulensis* are unknown, critical groundwater depths identified in their study may represent a functional physiological limit to effective root growth and water extraction. However, somewhat conflicting trends were found in work conducted in the south west of WA looking at the role of root channels in the occupation of deep soil profiles by jarrah forest (explored by coring and excavation techniques). Fine roots of *E. marginata* penetrate the clay matrix and occupy the entire profile down to weathered basement at depths of up to 40 m. Such channels were found to extend vertically from fissures and conduits in the shallow subsurface caprock layer deep in the clay subsoil. The channels are permanent features of the profile and are occupied by successive generations of trees (Dell et al., 1983). For roots to form channels this deep and into the fissures of basement lithologies and over successive generations, moisture (likely from fractured rock aquifers) sources in these zones must be important, and are potentially what is enticing roots down to such depths (rather than random establishment).

Considering the available literature and experience with facultative phreatophytes within the Pilbara; where groundwater is approaching or at 10-15 m bgl, mature phreatophytic tree species are likely to have some direct or indirect access to and potential reliance on water sources associated with the broader groundwater table. However, this access is unlikely to represent a significant proportion of EWR. Instead trees generally focus on acquiring bulk moisture from their lateral root systems (the vadose zone water resource), only substituting this source with taproot water when water becomes scarce, but also when signals within the tree are significantly restricting water use (generally through stomatal closure). For phreatophytes occurring where groundwater is 15-20 m bgl, the likely reliance on direct access to groundwater is considered negligible and their presence and survival will be more closely linked to surface and soil water regimes, along with shallow groundwater's and fractured rock aquifers present in the creek bed zone. Furthermore, for *E. camaldulensis* which has established under relatively deep groundwater conditions (i.e. 10 m bgl and lower), or where groundwater changes have been slow (and adaptation has been effective), such populations have been observed to exhibit substantial resilience to changes in groundwater access. In such situations, it has been observed that where groundwater depths have surpassed impact thresholds, this has led to canopy decline (without discernable increases in mortality) and removal of selective weaker branches and canopy complexes (likely through cavitation and vascular failure), until water demand is reduced to a level where the available root system is better matched to vadose soil resources.

Remote sensing analyses conducted by CSIRO on vegetation cover persistence (via a temporal analysis of NDVI (Normalised Difference Vegetation Index)) across the Pilbara indicate a moderate (to at times slightly higher) degree of vegetation cover persistence in the vicinity of Riparian Zone C-1 (CSIRO 2017). Despite this fact greater degrees of NDVI persistence are mapped to occur elsewhere in Pilbara riparian zones where groundwater is consistently at a similar height, but where FPV dominated riparian assemblages have established in conjunction with a suite of mesic indicator species. Furthermore, within the groundwater impact zone of Weeli Wolli Creek where similar vegetation to the C2B community of Turee Creek East occurs, and where similar CSIRO mapped persistence values to that of Riparian Zone C were mapped to occur, groundwater has been reduced from 6-14 m bgl to 30-75 m bgl without detectable changes to mortality within all riparian veg along a 3 km stretch. While it's not yet clear how consistent it is, the relatively shallow depth to groundwater interpreted to be present in Riparian Zone C (Figure 4-1) indicates that vegetation is likely to have a reliance on groundwater in this zone to satisfy a portion of its EWR. However, disparity exists between the interpreted likely depth to groundwater within and downstream of Riparian Zone C and the GDS (and associated GDV) present. 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 shallow basement material based on the positioning of the Electrical Resistivity Sections. According to GBS MAPS (2017), the degree of confidence in this interpretation is significantly influenced by the degree of basement weathering, and so some caveats are placed in this interpretation.

The data on water table heights provided by the geophysics work is at times potentially variable as within a large proportion of the study area (particularly that area under the C2B community) water table heights were inferred (rather than interpreted) where the shallow subsurface material is interpreted as massive/non-permeable and as such fluid content does not significantly influence the electrical resistivity (GBS MAPS 2017).

Between monitoring bore MB16WAW0005 (approximately 2.7 km upstream) and the WANG14 bore, depth to groundwater appears to reduce proportionately with ground height (i.e. elevation drops by approximately 10 m and depth to groundwater reduces from 15 to 5 m bgl). Similar trends are seen between monitoring bores throughout the valley floor adjacent to Deposit C. It is therefore assumed that the drop in elevation downstream of WANG14 (approximately 5 m drop in elevation to the start of Riparian Zone C-1 (800 m downstream) and approximately 10 m drop in elevation to the end of Riparian Zone C-2 (2.3 km downstream)) would likely lead to at least a 2-5 m drop in depth to groundwater within Riparian Zone C (i.e. groundwater 2-3 m bgl). Given the geophysics work supports this and interprets similar groundwater proximity in Riparian Zone C, the geophysical interpretations of groundwater height may generally be correct, but questions still remain about the depth to and presence/absence of basement materials within the subsurface interpretations it provides. Furthermore, given that the aquifer in the valley is modelled as thinning to a terminus at the western end of the valley (Rio Tinto 2017), the degree of hydraulic connectivity between groundwater in Riparian Zone C and that in the broader upstream valley appears to remain undetermined and an area of interest.

Where depth to groundwater is in the order of 2-4 m bgl (and potentially deeper), it is typically expected that *E. camaldulensis* would be a consistent co-dominant component of the over-storey and that a number of common mesic indicator species (such as *M. glomerata* and potentially *M. bracteata* and *Acacia ampliceps*) would be present within resident vegetation. However, the vegetation composition in Riparian Zone C is not typically representative of a depth to groundwater of 2-4m bgl. While an impervious layer existing in the vicinity of the upstream end of Riparian Zone C, and blocking the downstream continuation of groundwater heights equal to or shallower than that present at WANG14 could explain such disparities between vegetation and groundwater height, based on geophysics this is looking increasingly unlikely.

While vegetation density (and potential for groundwater dependence) increases significantly immediately downstream of WANG14, this is thought to be mostly attributable to increased surface water input and topographical confinement occurring at the beginning of Riparian Zone C. At this point, the confluence of the east and west tributaries into TCEB (represented by the two catchments in Figure 3-3) coincides with the topographic constriction of the creek system (floodplain and incised channel zones) into a single incised channel zone. Upstream, the tributaries are 300-500 m wide each, but at the point of constriction the system is only 150 m wide. This attenuation of the creek by the calcrete formations in this area increases the amount of direct recharge which surface water flows will deliver to the alluvial's (i.e. vadose water resources) supporting the core riparian vegetation formations within and downstream of Riparian Zone C. Furthermore, calcrete formations, typically possess increased infiltrative capacity, and as such are known to accumulate substantial internal groundwater formations. With relatively deep calcrete formations known to occur underneath and adjacent to Riparian Zone C, surface water attenuated through this zone is likely to be quite effective at recharging soil pore moisture and groundwater formations, thus supporting riparian formations of elevated density.

Based on geological mapping, occurrences of the Wittenoom Formation along with McRae Shales (both of which can potentially provide impervious lithologies), are interpreted to abut and reside underneath the calcrete formation in the vicinity of Riparian Zone C, and downstream (potentially 100-600 m) of WANG14. Importantly, this occurrence of the McCrae shale layer is likely discontinuous further to the east and west of the creek and is supplementary to the main layer at the western end of Riparian Zone E which is determined to form the aquitard surrounding the West Angelas Project area. The occurrence of these formations, particularly the Wittenoom formation, has the potential to provide at least a partial barrier to groundwater flow towards the upstream end of Riparian Zone C. While such a discontinuation of the broader valley aquifer in this zone doesn't appear to be supported by the geophysics work, it could be supported by the thinning and apparent terminus of the broader aquifer at the west end of the valley (Rio Tinto 2017). Such a discontinuity in the local aquifer could then help to explain the disparity between interpreted trends in groundwater height and riparian vegetation in this area, as groundwater presence and height on the downstream side would likely be primarily driven by surface water recharge events and thus water availability would be much more variable. Furthermore, this could not only provide some explanation of the minimal presence of GDS, but could also prevent or significantly hinder potential groundwater drawdown (and associated impacts) from propagating into and downstream of Riparian Zone C. Despite the significant degree of scepticism generally directed towards geophysical interpretations, it is important to consider the implications surrounding the failure of recent geophysics work to indicate the obvious presence of potential geological barriers in the upper sediments of its transects. At this point, based on caveats around these types of interpretations, the results seem inconclusive, but there is still evidence to suggest that alternative factors are potentially operating in the area to influence the distribution and composition of vegetation present.

Another hypothesis which geophysics work also did not seem to support, was the concept that basement rock may be quite shallow, thus confining the alluvial formations of the creek system (and reducing their volume) in the vicinity of Riparian Zone C. Shallow basement material was not identified in the Electrical Resistivity Sections of the geophysical interpretations (GBS 2017). With geophysical interpretations covering at least 25 m of vertical depth, and with basement expected to be less than 30 m deep in the study area, the absence of basement material in the geophysical interpretations is interesting. In general the ability of ERI geophysical sections to differentiate basement from overlying material, is largely dependent on the degree of weathering present in basement material (i.e. highly weathered basement will not be distinguishable). With drilling at a nearby (2.6km east) bore hole logging highly weathered dolomite and shale just beyond 25 m below ground level, it can be assumed that if this basement follows a similar elevation that highly weathered basement is likely to occur just beyond 15 m bgl or greater in the area of interest. Combined with the mosaic of clay and detrital formations interpreted to occur in the alluvium of the creek bed, it can be argued that there is high potential for an array of weathered rock formations filled with hydrophilic alluvium lying approximately 20 m bgl. In turn this suggests that there is a high likelihood for such formations to provide a potentially complex suite of small fractured rock aquifers potentially within reach of local tree populations, and with the potential to exist relatively independently (from groundwater tables) through regular surface water recharge events.

Based on the geophysical interpretations, it was noticed that the distribution of the C2B community somewhat aligns with the apparent gaps in the distribution of the relatively extensive detritals formations (units 4, 5, and 6 outlined in GBS MAPS (2017); present throughout a significant proportion of Riparian Zone C. These formations are shown on cross section interpretations of subsurface geology under electrical resistivity imaging transects conducted by GBS MAPS (2017). Alluvial conglomerate (at times with a calcrete component) type detritals formations were visually sighted in abundance in the field as part of the current study, particularly in the northern half of Riparian Zone C and generally more commonly distributed to the North West side of the creek channel in this zone. It is postulated that shallow formations such as this, while apparently acceptable for local *E. victrix* populations, may be unlikely to provide suitable substrate conditions for the proliferation of *E. camaldulensis*. Furthermore, within the vicinity of the C2B community (and the gaps in the detrital units) and where geophysics data was available, relatively massive interspersed clay formations/lenses were broadly interpreted by geophysics to occur in the zones where *E. camaldulensis* was distributed. It is noted that the West Angelas locality and the catchment in question here has an abundance of local cracking clay formations, and fine apparently clay dominated alluvial sediments were observed to be present within Riparian Zone C, particularly in the vicinity of the C2B community. Preferring deep moist subsoils with clay content (Costermans, 1989), *E. camaldulensis* is likely to find the clay lenses and calcrete/clay units observed/interpreted to occur in Riparian Zone C, as favourable. For this reason the shallow, extensive and relatively impervious detritals formations in the area are considered to provide a potentially relevant constraint on riparian growth in the area. As a result, some of the perceived disparities between interpreted groundwater proximity and the GDS and GDV present could at least be partially explained by potential constraints on riparian development provided by the shallow substrate conditions present through large parts of Riparian Zone C.

Supplementary to these physical characteristics and their influence on groundwater storage and vadose zone recharge, other features observed in the area provide evidence as to the surface and groundwater sources available to the denser riparian formations of Riparian Zone C. At the time of survey, and on supplementary visits to the Riparian Zone in question, various examples of relevant bedrock outcropping on the edge of and extending into the creek bed were observed to occur adjacent to and beyond where geological mapping had them occurring. Firstly, Chert bedrock layers (typically relatively impervious layers) were noted near the downstream end of the C2B community, within the bed (south side) and extending onto the bank and hillside (See Plate 6-1 (location indicated by a Green square symbol), 6-1 and 6-3). These layers appeared based on bedding direction to run more perpendicular to the line of the creek bed. Calcite precipitation formations on the alluvial surfaces (see Plate 6-1 and 6-5) were also common in the vicinity of the Chert layers extending into the bed, and in combination with moist sediments in their vicinity seem to suggest some degree of groundwater discharge or presence at the soil/air interface in this vicinity. Secondly, on the bank and adjacent hillside, shale like formations in the same vicinity, but slightly downstream were noted to occur and appeared to extend towards and under the creek bed. The appearance and visibility of the bedrock layers sighted at this location (Plate 6-1; location indicated by the red circle symbol) were not as clear as the shale layers slightly downstream, but were none the less present. The third and most convincing section of outcropping (Plate 6-1; location indicated by a red star symbol, and 6-4) found on the South bank clearly represented an apparently continuous McRae Shale formation, and was clearly able to be followed down to the creeks edge and under the alluvial’s (see plate 6-4).

Based on the strike and bedding direction the McRae shale layers sighted on the south bank at the downstream end of Riparian Zone C-1, it appears as though the shale layers are potentially extending across the creek (under the alluvial's) in a 35-45 degree fashion (See plate 6-1). While the presence of such formations under the alluvial's in the vicinity of Riparian Zone C-1 were not noted on the geophysics report, this is potentially because they were not interpreted to extend at such an angle to the creek and so signatures in the right parts of the geophysics transects were not scrutinised appropriately based on this info. Subsequent checking of the resistance data provided by GBS Maps (2017) does show a potential shale signature in the alluvial's and in the vicinity of where the layers are predicted (based on Plate 6-1) to extend through geophysics transects. Plate 6-6 shows this signature in the electrical resistivity section (ZZ array, deemed the most informative) and interpreted section for Transect E, as well as the position of the transects (GBS Maps 2017). This signature has subsequently been confirmed by surveyors at GBS maps (2018) as having potential to be representative of a subsurface shale member.

When the angle of such formations are considered in relation to the distribution and shape of *E. camaldulensis* populations (and the C2B community), there seems to be good correlation (See Plate 6-1), such that there is a high the potential for them to represent at least a partial boundary to groundwater flow which would trap groundwater (and surface ponding) on their upstream side. What the distribution of key phreatophytes in the creek combined with outcropping evidence seems to suggest is that such formations are actively trapping groundwater on their upstream side and forming a bucket of water for trees in the zone to access between surface water recharge events. In addition to the role of surface water recharge events, some groundwater contribution from the terminus of the aquifer extending across the valley to the east may also contribute to such groundwater resources. In light of the disparity between the restricted distribution of E. camaldulensis (and the C2B community) within Riparian Zone C and the relatively consistently shallow groundwater heights inferred by geophysical investigations an alternative explanation for the distribution of consistent groundwater supplies in this zone has significant merit. It is for this reason that the formation of smaller scale groundwater formations behind at least partial subsurface barriers to flow at the downstream end of Riparian Zone C-1 is becoming the preferred explanation for phreatophyte distribution in the area. Importantly, if this is true then the evidence suggests that riparian communities in Riparian Zone C are likely to be more reliant on surface water inputs in this area than the behaviour of the broader aquifer of the Project area.

Table 6-1: Key riparian zones within the study area and their relevant average and actual subsurface groundwater heights interpreted from GBS Maps (2017) and considered in respect to modelled groundwater drawdown predictions.

	Average baseline GW height	Average baseline range of GW heights	Absolute baseline range of GW heights
Riparian Zone	In Meters Below Ground Level and Interpreted/inferred from the geophysical mapping conducted by GBS Maps (2017)		
Riparian Zone C-1 (C2B vegetation type)	**2 m bgl**	**1.5-2.5 m bgl**	**1.2-3.3 m bgl**
Riparian Zone C (outside of Zone C-1 (C3B vegetation type))	**3.5 m bgl**	**2.5-4.5 m bgl**	**1.8-6.5 m bgl**

	Maximum depth (In meters below ground level) of Groundwater Following the assumed base case (Sy3%) potential for ~3 m of modelled drawdown (Rio Tinto 2017) and based on:			Maximum depth (In meters below ground level) of Groundwater Following the assumed potential for between 1-6 m of modelled drawdown (Rio Tinto 2017) and based on:		
Riparian Zone	Average baseline GW height	Average range of baseline GW heights	Absolute range of baseline GW heights	Average baseline GW height	Average range of baseline GW heights	Absolute range of baseline GW heights
Riparian Zone C-1 (C2B vegetation type)	**5 m**	**4.5-5.5 m**	**4.2-6.3 m**	**3-8 m**	**2.5-8.5 m**	**2.2-9.3 m**
Riparian Zone C (outside of Zone C-1 (C3B vegetation type))	**6.5 m**	**5.5-7.5 m**	**4.8-9.5 m**	**4.5-9.5 m**	**3.5-10.5 m**	**2.8-12.5 m**

GW = Groundwater, m bgl = meters below ground level

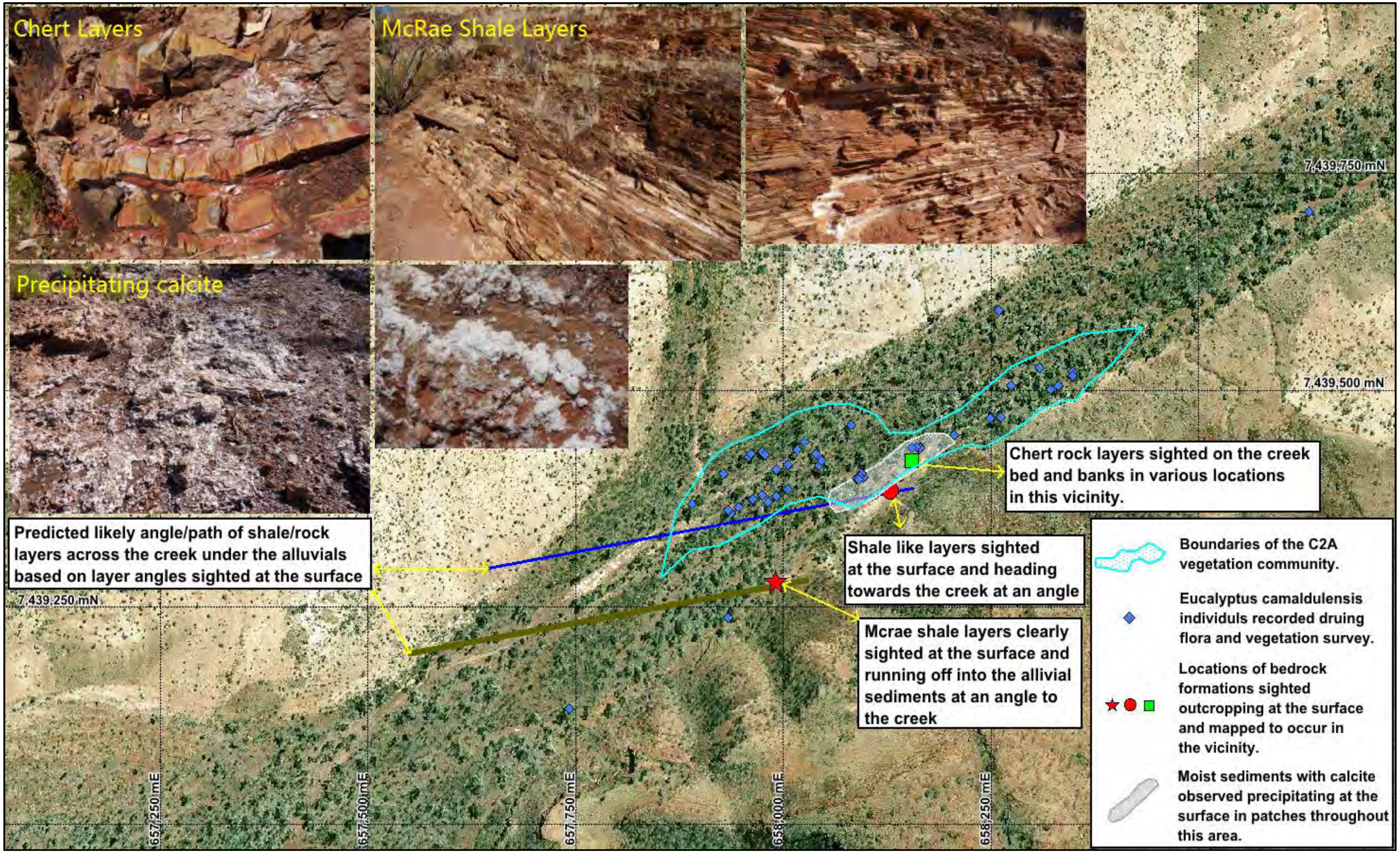

Plate 6-1: Local evidence for the presence of geological formations capable of damming/trapping surface and groundwater in the vicinity of the C2B community (potential GDE).

Plate 6-2: Picture showing Chert bedrock layers extending from the South bank under the alluvial's of the creek bed (near the red circle symbol in Plate 6-1)

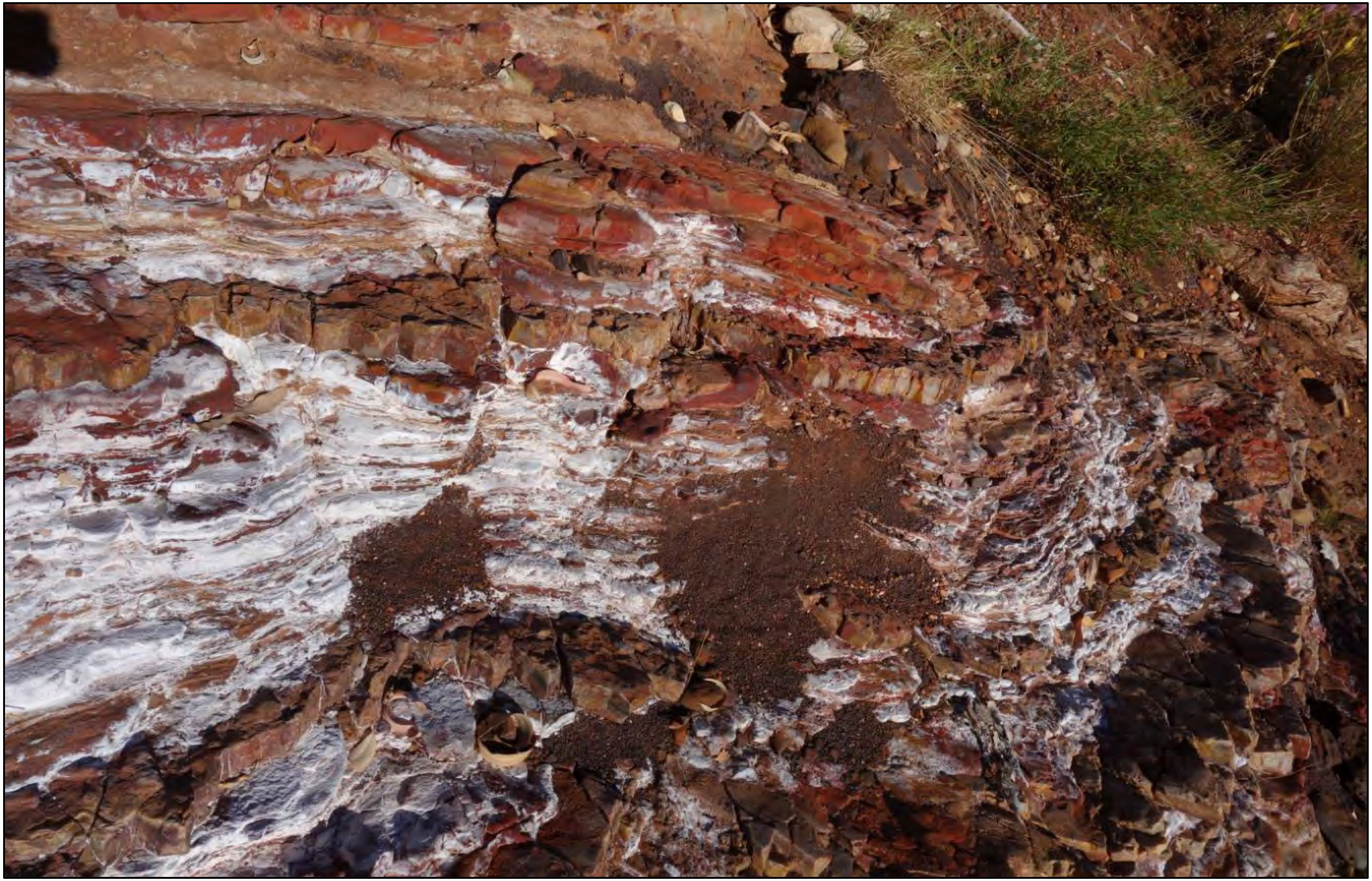

Plate 6-3: Photo of Chert layers in creek bed with calcite precipitating on them (near the green square symbol in Plate 6-1).

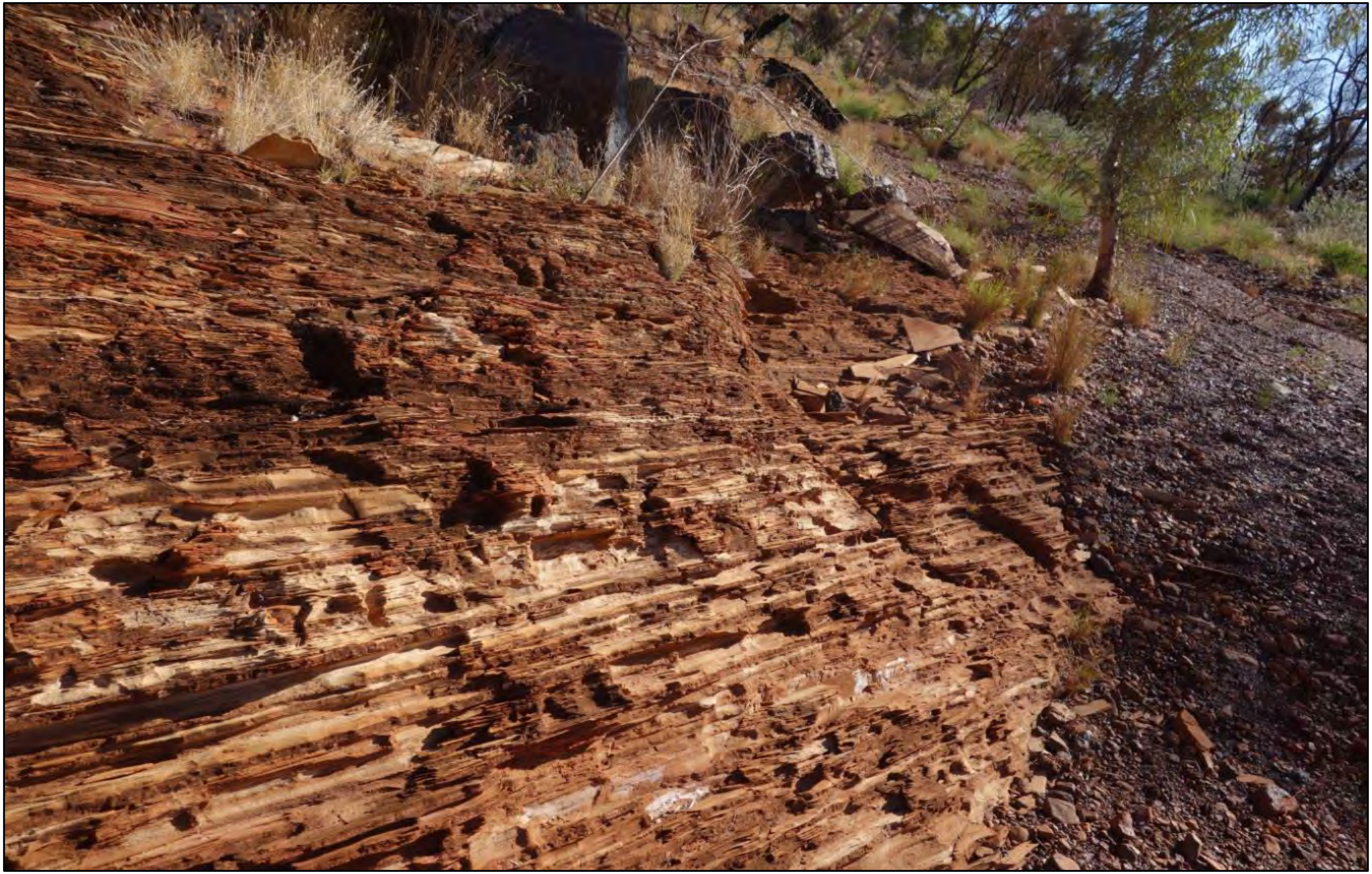

Plate 6-4: Photo clearly showing Mount McRae Shale layers (in the vicinity of the red star in Plate 6-1) disappearing under the alluvials at approximately 45 degrees to the bed.

Plate 6-5: Photo looking downstream in the low flow channel of Turee Creek East towards the Chert formations and showing the vegetation and the start of surface calcite deposits.

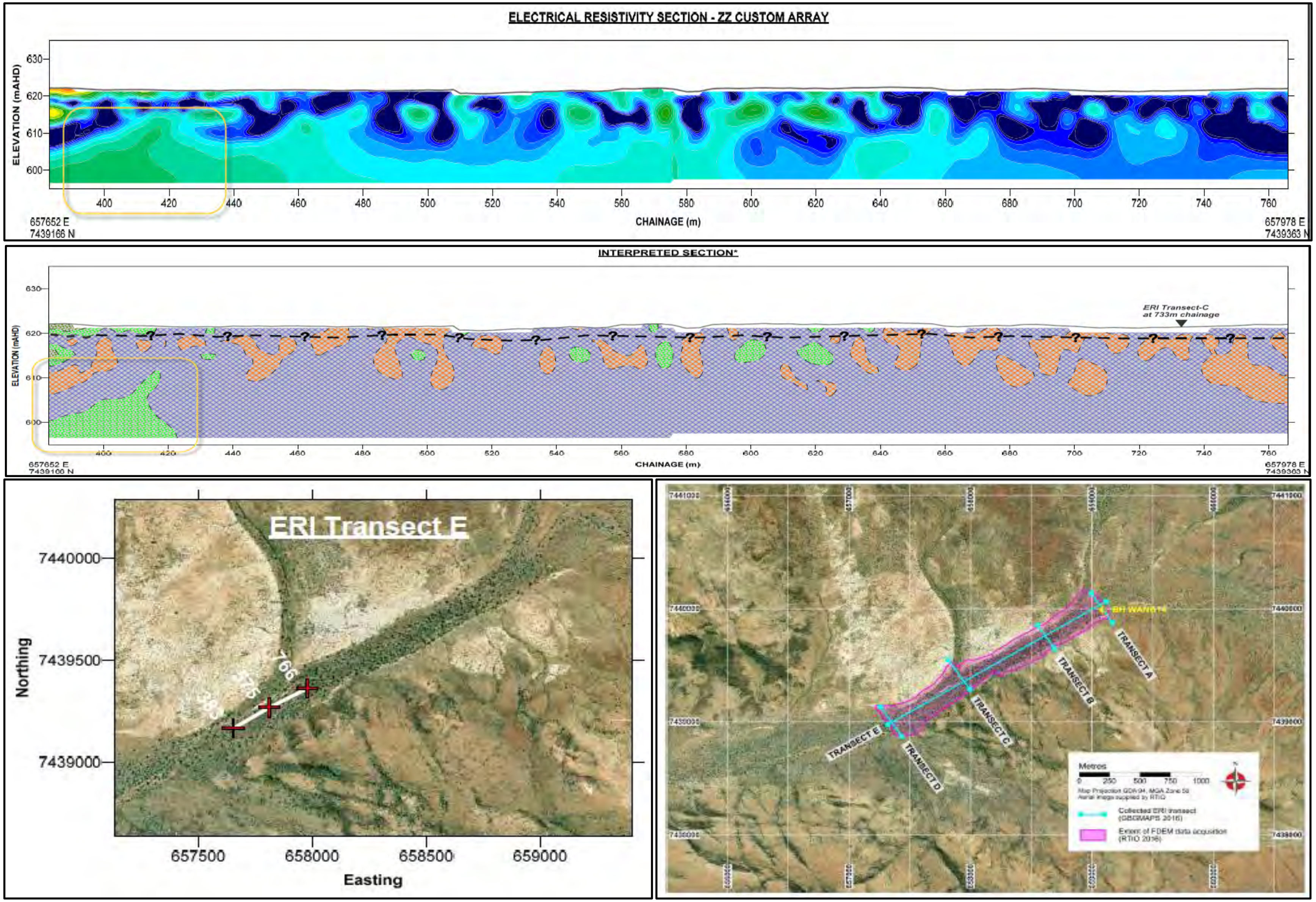

Plate 6-6: Potential shale signature (indicated with an orange circle) within the ZZ array resistivity section and Interpreted section for transect E, along with a map of Transect E and all transects sampled (GBS Maps 2017).

6.2 RELATIVE GROUNDWATER DEPENDENCE OF THOSE SPECIES DETERMINED PRESENT

This study has provided an understanding of the distribution of potentially groundwater dependant receptors in the area which suggests that the risk of sensitive GDV being present in the study area is relatively low (but still present as moderate risk GDV in a small number of cases). Furthermore, for the vast majority of riparian vegetation within the study area, low risk FPS (*E. victrix*) dominates the tree strata and moderate risk FPS (*E. camaldulensis*) is generally absent. While there are areas of elevated risk (particularly the 4 ha extent of the C2B vegetation community), the generally 'Low' to 'Very Low' risk posed by potentially GDV (with some examples of 'Low-Medium' risk GDV) present throughout the study area determines that the low level of hydrogeological information within the KNP is unlikely to have a significant influence on the validity of the conclusions made by this study.

Broadly speaking, the dominance of 'low' risk FPS, and the general lack of moderate risk FPS suggests groundwater dependence in the study area is low, however, within KNP and starting within Riparian Zone C (the orange and red risk mapping polygons shown in Figure 5-81, where groundwater levels are interpreted as shallow but information is low), over-storey biomass measurements suggest water availability is increasing via either surface water, groundwater, or a combination of both inputs.

Some studies (Stromberg et al. 1993; Lite and Stromberg 2005) have demonstrated relationships which exist between standing biomass within a community and the potential groundwater dependence of that community. Furthermore many studies have discussed the likelihood of such a relationship, but have not provided data or analysis to confirm or deny its existence. In general, consistently shallow groundwater typically allows a much greater biomass to be established. For this reason, throughout the range of riparian habitats known to occur, the upper limit of over-storey biomass able to be supported by vegetation relying on the vadose soil resource alone (given its inherent degree of variability) is well below the upper limit of riparian biomass observed to occur. This is generally because the magnitude and consistency of water availability, when groundwater is consistently shallow, allows a much greater biomass to be established and maintained.

In some cases where standing riparian biomass is above average, the reduced sensitivity of the resident FPS may determine that, under changing groundwater conditions, composition can be maintained, but structure may vary. In other cases where standing biomass is also above average, the increased sensitivity of resident phreatophytes (such as OPS) may determine that, under changing groundwater conditions, both the structure and composition cannot be maintained. Alternatively, in some cases where the standing biomass and sensitivity of the resident phreatophytes are low and thus below a threshold, the composition and structure may be broadly maintained under changing groundwater conditions.

Broadly determining and applying these thresholds is something which this study has tried to explore, as it appears to be important for establishing a more detailed understanding of potential groundwater dependence. Besides an ability to gain insight into the potential for a particular community to be groundwater dependent; more value may in fact be represented by the ability to provide insight into the potential for a community to persist without access to the broader groundwater table.

While the basal area of the majority of vegetation (and associated groundwater regimes) present in the study area appears to clearly fall well below such thresholds, some areas of resident vegetation show evidence suggesting they represent vegetation in the vicinity of this threshold, and so provide an interesting case study for establishing and testing such thresholds. Furthermore, making a determination as to which side of such thresholds local vegetation communities reside is quite important as it determines the potential for, and scale of impact likely to result from changing groundwater access.

To explore these thresholds, the study conducted herein has used a combination of structural/compositional phreatophytic evidence along with understorey compositional evidence, an over-storey biomass index (basal area) and consideration of local hydrological and geomorphological characteristics. This has been done to provide a more measured interpretation of potential groundwater dependence and therefore a more detailed assessment of the risk of compositional and/or structural changes to FPV in the study area due to changing groundwater conditions.

The associated risk matrix (Table 5-3) provides a consistent logic and associated justification for risk values attributed to riparian vegetation throughout the study area.

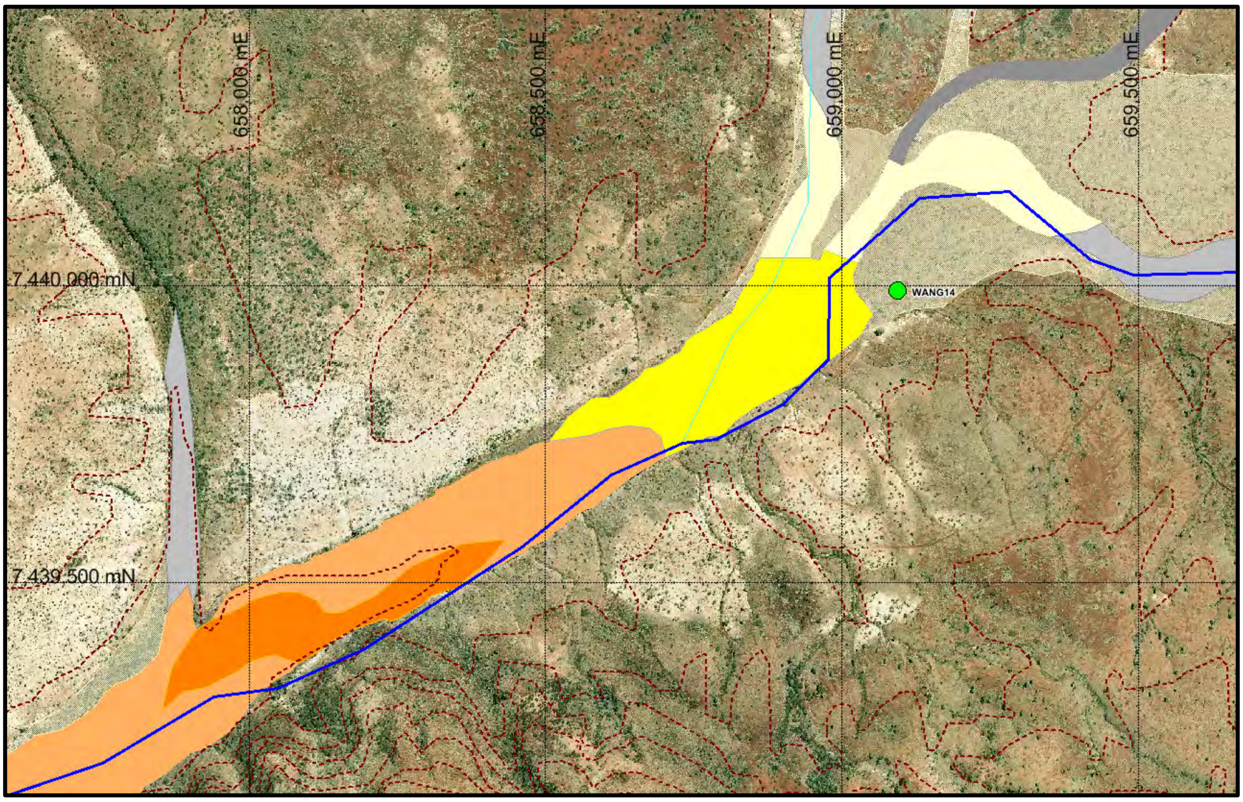

Figure 6-1: Location of monitoring bore WANG14, topographical contours and GDE risk mapping in the vicinity of Riparian Zone C

The interpretation of risk to riparian phreatophytic vegetation made by the study relies on three key evidence based components within the methodology:

1. The degree of groundwater dependence based on; phreatophytic species composition and to a lesser degree phreatophytic species structure/abundance, and the accepted environmental water strategy (EWS) each employs.
2. Understory compositional evidence for increasing/decreasing soil water availability.
3. The standing biomass of over-storey vegetation (i.e. that component of the vegetation more likely to access groundwater), including:
   - the potential associated water demand; and
   - the sub-surface environment and its influence on satisfying water demand.

Given that the resulting interpretations of groundwater dependence of vegetation rely heavily on the degree of influence provided by these key evidence based components, these components are discussed further below.

6.2.1 PHREATOPHYTIC SPECIES IN THE STUDY AREA, ASSOCIATED EWS, AND RELATIVE GROUNDWATER DEPENDENCE

It is generally considered that any vegetation that uses groundwater is potentially at risk of impact if it occurs in a location where the groundwater might be lowered beyond natural groundwater variation. However, the impact on vegetation from lowering the groundwater table is likely to be relative to the species' dependence upon groundwater, and on the alternative sources of water available. For example, phreatophytes, which rely on water sourced directly from the groundwater table are more likely to show signs of decline or mortality than vadophytes that can purely rely on soil moisture from the vadose zone.

Groundwater dependence within phreatophytic species (particularly in arid environments) generally varies along a scale. A scale of groundwater dependence whose potential influence on health and viability varies by species, but also within species due to genetic variability and particularly due to antecedent surface and ground water conditions. An assessment of the groundwater dependence of species present within the study area was informed by a desktop literature review, with specific reference to the previous response of facultative phreatophytes within the Pilbara to changes in groundwater access. As mentioned, 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). The presence of *E. camaldulensis* subsp. *refulgens* (including subsp. *obtusa*), *E. victrix* and *M. argentea,* which are the most common phreatophytic tree species within riparian systems of the Pilbara bioregion, are often used to infer the relative presence of a potential GDE. However, these species vary in their degree of dependence on groundwater and this variation has a strong influence on their distribution and abundance within riparian systems.

Vegetation associations occurring along the tributaries and main drainage channel of TCEB (and associated flood plains) within the study area support two key tree species that are considered to be at low to moderate risk of impact from groundwater drawdown: *E. camaldulensis* subsp. *obtusa* (moderate risk); and *E. victrix* (low to moderate risk). These tree species are classified as facultative phreatophytes or in some cases, vadophytes. *E. camaldulensis* is the most widespread of Australian Eucalypt species and is known to tolerate an apparently wide range of water regimes (Colloff 2014). Based on work by Wen *et al*. (2009), *E. camaldulensis* obtains its water for transpiration via three main sources: groundwater, river flooding (which over tops creek and river banks thereby replenishing floodplain soil moisture), and rainfall (Wen *et al*. 2009). The degree to which *E. camaldulensis* depends on groundwater and soil moisture has been found to vary both spatially and temporally (Mensforth *et al*. 1994, O'Grady *et al*. 2009, Wen *et al*. 2009, O'Grady *et al*. 2010). Investigations at Marillana Creek in the Pilbara found the vigour of large *E. camaldulensis* trees (>10 m tall) declined in response to lower groundwater levels caused by test pumping of water, while the vigour of smaller *E. camaldulensis* remained unchanged (Onshore Environmental 2013). This observation suggests that the species is capable of being both a vadophyte and a phreatophyte, using the former strategy when young and the latter strategy when mature (Halpern Glink Maunsell 1999). Muir environmental (1995) indicates that *E. camaldulensis* and *E. victrix* are generally not restricted in their occurrences along Marillana Creek and thus given local groundwater height variability cannot be considered as being true phreatophytes, but as vadophytes. In the case of *E.*

camaldulensis, general observations in the Pilbara by Rio Tinto suggests that there is some degree of restriction to the distribution of this species along medium to large sized creek systems within the Hamersley's, and so the concept that this species can be both a phreatophyte and a vadophyte (depending on the circumstances) appears most accurate.

Furthermore, genetic barcoding studies by UWA (UWA 2015) on *E. camaldulensis* and *E. victrix* suggest that *E. victrix* is able to hybridise with other species. Furthermore, within the E. victrix complex, there appears to be high within-population diversity, particularly in the North West, compared with relatively little genetic distinction between populations (Li 2000). Any hybridisation of EV with other eucalypts, as well as high genetic diversity among local EV populations may lead to local individuals displaying intermediate EWR, and therefore intermediate degrees of groundwater dependence. It has also been observed during field surveys by Rio Tinto that in some clearly dry conditions, *E. camaldulensis* individuals can apparently tend morphologically (in a number of traits) towards *E. victrix* and in some clearly wet conditions, *E. victrix* individuals can apparently tend morphologically (in a number of traits) towards *E. camaldulensis*. This observation alludes to the potential that, in hydro-ecotonal situations, where it is advantageous to possess some of the eco-physiological traits of other species (particularly those xerophytic or mesophytic adaptations), hybrid or genetically variable individuals may survive/prosper where other members of the same species cannot. This would in effect provide a greater range of conditions over which individuals of one apparently distinct species could survive. Such potential for variability in environmental responses is important when considering the conclusions of research on the distribution of riparian eucalypts under varying hydrological conditions (such as Loomes (2010)), as the difficulties in discriminating between some species along with hybridisation and genetic variability, has the potential to influence the accuracy of such conclusions.

E. victrix has been shown to access groundwater in areas where the depth to groundwater is low (O'Grady et al. 2009) but in non-riparian habitats, has also been shown to exploit shallow soil water to meet is transpiration needs (Grigg *et al*. 2008). *E. victrix* is generally considered for the most part to be a vadophyte, being relatively drought tolerant but susceptible to decline when groundwater becomes limiting (Muir Environmental 1995). Work by Pfautsch *et al*., (2014) in Weeli Wolli Creek used measurements of foliage density and sap flow to assess the effects of depth to groundwater on *E. victrix*. While foliage density provided partial insight, sapwood-sap-flow was determined to be highly informative, and analyses of various drawdown treatments (falling, rising, and stable groundwater heights) emphasised that water use by *E. victrix* is highly plastic and opportunistic. Such conclusions are in line with observed broad scale responses of riparian *E. victrix* experiencing various drawdown conditions, and also agree with the concept that this species could be considered a vadophyte or a facultative phreatophyte depending on the antecedent conditions.

It is important to note that the definitions attached to classes of groundwater dependence possess some degree of overlap. For example, broadly speaking *E. victrix* is a species typically characterised as being a facultative phreatophyte, relying on groundwater, often via the capillary fringe, to satisfy at least some portion of their environmental water requirement (Eamus & Froend 2006). However, if the vadose resource is adequate and of reduced variability, then such species (i.e. facultative phreatophytes) are also considered capable of inhabiting areas where their water requirements can be met by soil moisture reserves alone. This distinction is not always true, and is importantly related to the water demands associated with resident tree densities, the increased size of the vadose soil water resource often associated with larger sized creek catchments and the inherent frequency of surface water inputs which they typically provide. This essentially determines that while facultative phreatophytes are adapted to riparian habitats where groundwater proximity allows enough access to satisfy some of their water requirements, they have also often evolved to survive on other more variable yet sufficient riparian water resources such as soil moisture in the vadose zone. Vadophytes are also defined as able to inhabit areas where their water requirements can be met by soil moisture reserves alone, but can also occur in areas where groundwater contributes to plant water use. These distinctions determine that some species characterised as being facultative phreatophytes are also able to be accurately characterised as vadophytes under certain conditions.

An illustration of the conceptual overlap in water use strategies (e.g. phreatophyte / vadophyte / xerophyte) and the relevant classes of groundwater dependence used to define each is presented in Figure 6-2. Figure 6-2 also gives an interpretation of where some of the most relevant Pilbara species might sit in the spectrum of ground/soil water dependence and the relevant ranges of this dependence which is occupied by defined classes of groundwater dependence. Furthermore Figure 6-2also helps to illustrate the likely water use strategy of *E. victrix* and the increasingly held understanding that *E. victrix* is a relatively drought tolerant riparian species, suggesting that the risk to this species from groundwater drawdown is often much lower than the commonly characterised 'facultative phreatophyte' class of groundwater dependence might advise.

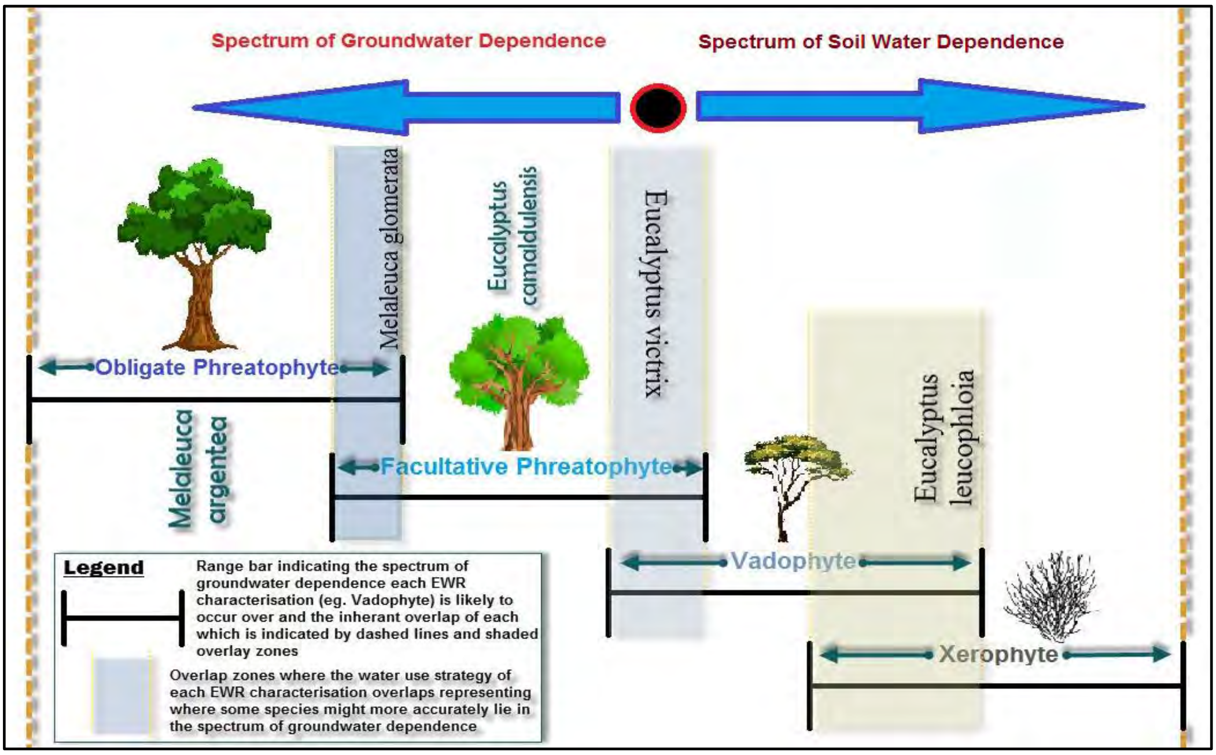

Figure 6-2: Interpreted spectrum of groundwater dependence and soil water dependence

The ranges of this spectrum which are likely occupied by the various groundwater dependence classes (water use strategies) used to characterise the environmental water requirements of Pilbara species, the likely zones of overlap in groundwater dependence classes, and the interpreted position on the scale of groundwater dependence of some key Pilbara species.

For the key phreatophytic species within riparian systems of the study area, the broad eco-physiological differences inherent to each have led to the following key conclusions about the degree of dependence of each on groundwater and antecedent conditions, and therefore the risk which groundwater drawdown from the proposed dewatering of Deposits C and D poses on each.

E. victrix is considered to be fairly drought tolerant, and generally capable of successfully transitioning from good to limited moisture availability, without mortality (Pfautsch *et al*. 2014). In riparian habitats within KNP this is complicated by the above average standing biomass recorded (Riparian Zones C & D; Figure 4-1), which may elevate the water demand per unit area to a point where this ability to transition to reduced water availability is reduced. Therefore despite the potential for *E. victrix* to suffer from a decline in health due to changes in depth to groundwater within the incised channel zone, the potential for *E. victrix* dominated communities in the study area (the C3C and C2C communities) to be significantly impacted is determined to be 'very low' to 'low' for the majority of the study area, and slightly elevated for the higher biomass representations (C2C community) present on TCEB (Riparian Zones C & D).

Consequently it is predicted that the structure and composition of C3C and C2C communities will likely remain relatively un-changed (while likely exposed to some reduction in health) as a result of potential groundwater drawdown from the proposed dewatering for the Proposal such that the predicted impacts are not considered to represent a 'significant impact'. Therefore, overall the risk to this species and the communities within which it forms the dominant tree species is determined to be 'Low', and at times 'Low-Medium' due to elevated biomass based water demands. *E. camaldulensis*, while considered less drought tolerant than *E. victrix*, is also considered relatively well adapted to the increased variability in access to soil moisture in areas where the water table may regularly be out of reach. While this species is generally known to establish as a dominant/co-dominant species in areas where there is good access (at least a proportion of the time) to the broader groundwater table (or capillary fringe) (Loomes 2010), it also appears capable of establishing in or transitioning to an altered hydrological regime and surviving on the relatively regular surface water inputs and associated vadose soil water resource provided by larger catchment creek systems (Rio Tinto 2016b).

The Department of Water (**DoW**) completed a study to determine the range of groundwater levels which Pilbara riparian species occur over (Loomes 2010). Based on this work it is suggested that *E. camaldulensis* generally occur where average depth to groundwater is less than 5 m and are unlikely to occur beyond an average depth to groundwater of ~10 m. As the work of Loomes (2010) focused purely on large river systems of the Pilbara (the De-Gray, Yule, Robe and Fortescue Rivers), it's assumed that it is most relevant to rivers with often shallow water tables, and appears less directly applicable to creek systems of the Hamersley Ranges. In creek systems of the Hamersley's *E. camaldulensis* has been shown to establish in riparian zones where depth to groundwater is >15 m (RTIO 2015b). However, within the study area, the distribution of *E. camaldulensis* in relation to interpolated groundwater heights appears to fit with the results of Loomes (2010). Despite this, the riparian zones in the study area are positioned where the relevant upstream catchment is small to medium in size and where the reduced frequency of surface water inputs (which in turn help replenish the vadose soil resource) would determine that the distribution of *E. camaldulensis* is likely to be more strongly linked to groundwater access.

The publically available report by the DoW titled "Determining water level ranges of Pilbara riparian species" (Loomes 2010) does not provide a clear indication of finer scale field methodologies used (or where to source them), and so direct comment on the applicability of this work to the potentially drier riparian environments of Hamersley Range creeks systems is difficult. While the results of Loomes (2010) was suggested to be inconclusive for E. victrix (*E. victrix* was only recorded in a small number of sites) it is interesting to note that it showed that *E. victrix* was not found in areas where depth to groundwater was greater than 10 m. Within the study area *E. victrix* is shown to consistently establish where depth to groundwater is 20-60 m below ground. Such results may allude to issues with the applicability of the results of Loomes (2010) to Hamersley Creek systems.

6.2.2 Standing biomass

The relationship between vegetation biomass and water demand is well accepted and a logical result of the increased photosynthetic demand and associated water loss per unit of biomass (Salisbury and Ross 1992).

Much less well accepted is the how this increasing biomass per unit of area influences the ability of substrates to supply the commensurate water demand. This is most likely a product of two key factors. Firstly, riparian vegetation possessing a high standing biomass is often present as a result of shallow groundwater access. However, the distinction is rarely made when other riparian vegetation zones of moderate to high biomass have in fact established without effective groundwater access (and may represent the upper bounds of biomass capable without groundwater access). Secondly, if groundwater is within proximity, such that a significant proportion of root systems have access to a zone of saturated sediments, then the typical volume of soil (and associated root volume) required to uptake the EWR of a single tree (without interference from others) is significantly lower than a tree relying on pore water sources alone. The same applies for a situation where multiple trees are occupying a shared volume of soil. Therefore, in a riparian situation where groundwater is readily and consistently accessible more trees can satisfy their EWR from a significantly smaller combined soil volume, allowing for much greater biomass per unit of area. If relying on the vadose soil water resource alone, the soil volume required to satisfy EWR is typically much greater than when groundwater is readily accessible.

These distinctions are important where groundwater is readily available (and shallow), high standing biomass is present and a tight mass of roots within a relatively low volume of soil (that soil zone where groundwater is readily accessible) is established. In such a situation, removal of groundwater access would essentially determine that the volume of soil occupied is not adequate to provide all trees with their EWR (from vadose soil water), and significant impacts would be expected. Alternatively, assuming resident phreatophytic species are of no greater than low to moderate groundwater dependence, if the frequency and magnitude of surface water inputs are adequate (for vadose soil resource replenishment), and root systems are well distributed within a substantial soil volume, moderate to high levels of standing biomass have the potential to be supported regardless of access to groundwater. The key determinants to viability of vegetation in such a situation appear to be the influence of antecedent groundwater conditions and available soil volume on root architecture and distribution, as well as the EWS (i.e. groundwater dependence) and dominance of resident phreatophytic species.

As discussed earlier, models developed for some arid-land riparian species (using both hydrological and vegetational datasets) have shown that stand structure is strongly related to water availability and groundwater depth (Stromberg *et al.* 1993). Work by Stromberg *et al* (1993) demonstrated that biomass indices such as basal area and stem density (proxies of stand biomass) can be a useful indicator of groundwater dependence. The theory being that the survival of vegetation possessing a basal area within a particular lower range was likely, as such a biomass determines that groundwater access is unlikely to be limiting, and that the available vadose water resource is adequate enough to sustain minimum water availability for the resident biomass (through typical periods of climatic variability). This standing biomass concept can also be considered in relation to the height and structure of vegetation in a riparian system. The height and structure of a community also obviously have a relationship with biomass. One of the potential impacts of groundwater drawdown on potentially GDV is that phreatophytic species can no longer maintain previous canopy heights. This is likely a result of differing xylem pressures and susceptibility to cavitation, leading to reductions in stature and horizontal reach within larger more mature trees (through intermittent loss of higher stature canopy components in turn altering canopy architecture to match the changing water availability. Work by Lite & Stromberg (2005) looked at surface water and groundwater thresholds for maintaining Populus–Salix forests in the San Pedro River, Arizona. This research identified hydrologic thresholds above which *Populus fremontii* & *Salix gooddingii* maintain tall dense stands with diverse age classes. This study documented shifts in species composition which corresponded to decreases in maximum canopy height and upper stratum (above 8 m) vegetation volume as site water availability declined. Furthermore the results of this study showed that sites with deeper water tables and more intermittent river flows had greater areal coverage of shrublands and less of woodlands. This study provides further evidence to the concept that changes in groundwater access don't simply lead to phreatophytic species being removed/added, but instead that biomass and structural changes play an important role in matching water demand with availability.

In the study area, the natural distribution of *E. camaldulensis* is restricted to a small area (mainly in Riparian Zone C/C1, but including a small pod in Riparian Zone D) within the incised channel zone of TCEB (the C2B community). Typically the distribution of *E. camaldulensis* is strongly correlated with the distribution of increased surface water inundation frequencies. Such distribution suggests a greater reliance of *E. camaldulensis* on surface water than groundwater, but this is generally observed in, and most relevant to, areas with a substantial volume of alluvial sediments to support extensive lateral root systems. Within Riparian Zones C and D of the study area (and where the C2B community occurs), the incised channel zone is topographically confined resulting in a relatively narrow and potentially shallow (indicated by exposed bedrock in some places) alluvial zone.

In many cases it is postulated that large alluvial formations and associated vadose soil water resources (within riparian zones) can facilitate a certain degree of resilience within vegetation to groundwater changes which might occur. However, within the study area, resident potentially groundwater dependent riparian communities existing in the confined alluvial zones C and D, most likely have access to a smaller than typical vadose soil resource available within the alluvial's. Consequently there is potential for increased dependence on groundwater access (in Riparian Zone C in particular) due to an apparently reduced alluvial soil volume from which to source soil pore moisture. As such, it is suggested that the increased density riparian communities in Riparian Zones C and D of the study area are of increasing potential (given their increased density) to be at least partially dependent on access to groundwater or fractured rock aquifers present in potentially shallow sub-surface bedrock features. If so, *E. camaldulensis,* and to a lesser extent *E. victrix,* in Riparian Zones C and D may rely on groundwater to provide a higher proportion of their total EWR than typical, and as such risk of impact from groundwater changes may be commensurately elevated. However, the sub-surface geological cross-sections provided by the recent geophysics work did not directly interpret basement bedrock features to be present below Riparian Zone C (GBS MAPS 2017). From this result it is inferred that such features must be located deeper than the 25 m sub-surface zone of interpretative confidence provided by such geophysical techniques (GBS MAPS 2017). While this work does not conclusively rule out the presence of smaller scale basement lithologies at times restricting root distribution, it does give a reasonable degree of confidence that broadly speaking such features are not significantly limiting the soil volume and resultant vadose soil resource available to resident riparian communities. As well as confining/reducing the alluvial soil resource, topographic confinement of the creekline can have a positive influence on water availability, by attenuating all surface water inputs through the most relevant (to sustaining potentially groundwater dependent communities) riparian zone. This concentration of inputs within a smaller area may help increase the frequency and effectiveness of successive vadose soil resource and minor fractured rock aquifer replenishment events. Furthermore it is postulated that in comparison to broader systems, a more topographically confined riparian environment will likely possess more favourable microclimates, and is likely to more efficiently store/maintain soil pore moisture between surface water input events. Such effects along with the potential accessibility of fractured rock aquifer complexes (associated with topographic confinement features), will likely mitigate, to some degree, the influence of a reduced alluvial soil volume on the potential groundwater dependence of communities present in Riparian Zones C and D of the study area.

Given the transition of TCEB from an open valley to a more topographically confined environment, other important hydrological characteristics are also likely to be in effect in the in the vicinity of Riparian Zone C. Based on geological mapping and the fairly evident calcrete sheet formations adjacent to the creek in this area, it appears that sub-surface lithologies (such as members of the Wittenoom geological formation) may be influencing groundwater presence in the vicinity of Riparian Zone C. While conceptual hydrogeological models depict the Wittenoom formation as manipulating or constricting groundwater to within proximity of the surface in the area of interest (Rio Tinto 2017), it's not clear yet as to whether such formations are primarily influencing groundwater trends in the vicinity of Riparian Zones A/B/C. However, it is commonly observed that the majority of the larger carbonate sheet (calcrete) formations in the Hamersley Ranges tend to flank creek or river systems transitioning from a valley or flatter landscape/lithology to different, often more topographically confined circumstances, i.e. passing through a slot in a range formation, or something similar. Such transition zones are thought to trap (or dam-up/funnel) groundwater into sediments close to or on the surface. Fluctuations in groundwater height near the surface then lead to cycles of desiccation and carbonate precipitation which ultimately lead to the deposition of calcrete. The presence of such characteristic calcrete formations tend to be a clear indication that the resident lithology or topography may be manipulating groundwater closer to the surface, and so GDEs may be associated. The calcrete formation present in Riparian Zone C hints that groundwater in the vicinity has likely been historically shallow (or even pooling on the surface), and that either topography, confinement by the range or some other product of the lithology there has played a part in this. With available bore data suggesting that groundwater nearby (WANG 14) is becoming shallow (approximately 5 m bgl), geophysics interpreting this trend as being maintained through Riparian Zone C and standing biomass (basal area) spiking in Riparian Zone C, there is mounting supporting evidence that groundwater is and has been historically shallow in the vicinity of Riparian Zone C. This would also tend to suggest an increasing likelihood that local riparian communities are groundwater dependent, however the distribution and abundance of FPS in the area does not completely support such an inference. Typically if groundwater was consistently shallow in this area then *E. camaldulensis* and other mesic species would be expected to be more common than has been observed in Riparian Zone C. Geophysical evidence suggesting some degree of constraint to riparian development is provided by extensive shallow calcrete detrital formations and other potential impervious subsurface features (GBS MAPS 2017). Such evidence supports the conclusion that the composition and structure of resident riparian vegetation may correctly reflect the substrate and moisture conditions present. However the local evidence is not that simple, and if the broader aquifer does extend into Riparian Zone C, the relative stability of this aquifer combined with its shallow depth through this zone would typically be expected to support a more mesic riparian species assemblage than is present. Alternatively, McRae Shale (and Chert) outcropping on the south bank and interpreted continuation under the creek, correlates well with GDS distribution and hints to a barrier (at least partial) ponding groundwater on its upstream side and within the alluvial's of Riparian Zone C-1. Surface water driven recharge of this type of small scale groundwater formation would determine that water availability in this zone would be highly variable, which in turn provides a good explanation for the general lack of GDS and the current vegetation distribution present in Riparian Zone C. Furthermore, if groundwater from the broader valley aquifer were to extend unhindered through Riparian Zone C, and to dam behind the known aquitard at the end of Riparian Zone E, vegetation composition patterns there would surely be different and at least equivalent to that in Riparian Zone C-1. Despite this, there are still a number of unknowns and this determines that groundwater from the broader aquifer should continue to be considered as potentially providing a supporting role to vegetation in at least Riparian Zones C and E.

Beyond the basic compositional and structural evidence present within and downstream of Riparian Zone C, there are a number of different site attributes and observations which provide evidence supporting and denying the likely dependence of local riparian vegetation on groundwater access. Despite this, the key evidence suggests that in the area of most concern (in KNP), TCEB is transitioning from a broad valley with deeper groundwater conditions to more shallow groundwater conditions as it is constricted by, and forced through, the local range formation. As TCEB is constricted through the first range feature, riparian vegetation structure changes significantly, but species composition does not. As a consequence the interpreted risk to local vegetation of impact from groundwater changes can only be considered moderate for Riparian Zone C-1 and generally lower elsewhere. While the combination of elevated standing biomass along with potentially reduced alluvial volume within Riparian Zone C has potential to increase reliance of vegetation on groundwater access, the degree of influence by such an effect is unclear. Importantly, geological interpretations continue to maintain the likely presence of at least a partial groundwater barrier (McCrae Shale/Mt. Sylvia Formation based aquiclude) at the downstream end of Riparian Zone C (Rio Tinto 2017). Such a divide should at least determine that the potential for drawdown impacts on riparian vegetation and groundwater heights within KNP will be somewhat mitigated and confined to areas upstream of this point.

6.3 HOPE DOWNS 1 CASE STUDY

The Hope Downs 1 mining area provides a good case study for understanding how low to moderate risk FPS and FPV might respond to the removal of access to groundwater as a result of dewatering. Since mining has begun in this area, and groundwater heights have fallen, nearby GDV has been without access to groundwater for between 5 and 8 years. A recent riparian Eucalypt health study in the Hope Downs 1 vicinity focused on systematically assessing the current health and historical mortality present in resident vegetation which has been exposed to significant drawdown. Within the Eucalypt genus this assessment had a focus on influences to *E. camaldulensis,* a moderate risk FPS, but also focused on *E. victrix* as a secondary source of information on the response of FPS and associated FPV to groundwater changes. Riparian vegetation health has been monitored since mining began in the area in 2006, so approximately 10 years of canopy cover data exists in this area. The results of the Hope Downs 1 study are summarised below:

In mid-2015, a systematic Eucalypt health assessment was conducted by Rio Tinto along a 3 km section of Weeli Wolli Creek where consistent drawdown from the nearby mining operation has lead, in some areas, to a 7-8 m per year (at Bore BH31) drop in depth to water table (approximately 20 mm per day) (Rio Tinto 2015b). Dewatering began in 2007, with baseline water tables between 7 and 10 m bgl. This drawdown has translated (depending on location) to a depth to water table in the range of 15-30 m bgl since mid-2009 and has peaked at present in the range of 25-70 m bgl in different parts of the creek. To date (based on an assessment of the time it takes to increase the depth to water table from baseline to 30+ m bgl), this represents at least 5-6 years in succession that a portion of the Weeli Wolli creek riparian system, including vegetation within both the incised channel and floodplain zones (likely longer in the floodplain zone), has been without access to groundwater. Importantly, unlike many other areas of known drawdown impact in the Pilbara, this stretch of creek does not receive surplus water discharge from mining.

A health assessment of every Eucalypt with a DBH greater than 10cm in a 3 km stretch (adjacent to the zone of greatest drawdown influence) was undertaken. Of a total of 620 eucalypts recorded, 88% were assessed as being of average and better health. Only 4.5% of *E. camaldulensis* present were assessed as being stressed. Digital multispectral imagery (**DMSI**) interpretation showed that only 2.6% of all eucalypts (16 trees) had died since 2007. The results of the Hope Downs 1 study demonstrated the inherent resilience of moderate risk GDV to significant changes to groundwater access.

The Hope Downs 1 study area is somewhat different from the current study area given the smaller size of the upstream catchment reporting to the current study area. Furthermore, there is evidence that at present (degree of associated historical variability not yet clear) zones within the current study area possess significantly shallower antecedent groundwater conditions. However, the results from Hope Downs 1 study support the suggestion that, in at least the short to medium term, mortality rates (particularly of *E. camaldulensis*) are not significantly increased by a significant change in the availability of groundwater (at vertical change rates in excess of 1-2 cm per day), even in floodplain zones at distance from regular surface water inputs (RTIO 2015b). The results of this work are depicted in Figures A1-A4 within Appendix 4.

7 CONCLUSIONS

The degree of scrutiny applied to the question of groundwater dependence is often a product of the degree of perceived risk associated with the potential impacts and the significance of biological assets subject to those potential impacts. In the case of the study area, the pre-existing evidence suggested that the risk of significant GDE's being present was low. However, the proximity of KNP and presence of moderate interest riparian vegetation signatures inside its boundary indicated that a baseline assessment utilising qualitative (and some quantitative) assessment measures/indicators was most relevant. After considering the limited degree of hydrogeological information available and the current state of knowledge in relation to Pilbara FPS, the level of complexity employed in the current study is considered commensurate with the likely sensitivity of local riparian communities.

Previous GDE studies have generally solely relied upon the structure and composition of baseline riparian communities. While focussing on riparian vegetation 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 (in terms of risk) the groundwater dependence of riparian vegetation (and therefore potential GDEs) in the study area. This risk to riparian vegetation is 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, basement characteristics and interaction with the alluvial zone, fine scale antecedent groundwater conditions under GDV, root architecture/distribution of GDS etc.).
- The likelihood of groundwater changes being realised in the vicinity, which is also dependent on subsurface factors such as the interaction of geological and aquifer variability, surface water regimes and groundwater recharge dynamics, the timing and magnitude of abstraction, etc.

The combined influence of these factors on groundwater dependence and the propagation of groundwater drawdown (the last of which is not quantified as part of this study), ultimately determine that the risks presented in this study are relatively conservative. That is, not only is there some conservatism applied to the interpreted risk of groundwater dependence, but there is also compounding conservatism associated with the risk of groundwater changes being realised some 7-10 km from the proposed dewatering. Furthermore, considering the inherent degree of arid adaptation held by local FPS, and the demonstrated ability of moderate risk FPS to adapt and 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.

There are however, local observations/characteristics which might support rather than mitigate this risk (particularly in Riparian Zone C), Characteristics include; the shallow geophysics based groundwater heights interpreted in key riparian zones within KNP, topographically confined channel profiles and associated reductions in available alluvial volumes, and the constraints on riparian development potentially provided by 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 Riparian Zone C.

However, it is thought that propagation of groundwater drawdown will likely be somewhat limited downstream of riparian zones A and B (Figure 4-1), beyond which alluvial/colluvial formations are less extensive. Furthermore the potential for groundwater propagation beyond Riparian Zone C appears to be increasingly diminished. This can be partially attributed to the geological complexity of subsurface lithologies in the section of TCEB dissecting Riparian Zone D (and parts of Riparian Zone E), which includes abundant dolerite dykes mapped running perpendicular to TCEB, and which typically form a barrier to groundwater flow. Furthermore, the likely presence of secondary McRae Shale boundaries within Riparian Zone C also determines that groundwater flow through this zone is likely to be limited. Ultimately, the continued interpreted presence of an impervious McCrae Shale aquitard at the downstream end of Riparian Zone E (Rio Tinto 2017) determines that drawdown propagation beyond its location is highly unlikely. As a result it is concluded that only a 4 km stretch of TCEB (and potentially less, which includes Riparian Zone C and the northern section of Riparian Zone E) possesses a risk profile warranting concern from drawdown related impact if it were to extend into KNP.

Of this 4 km stretch of TCEB which has potential to be impacted by drawdown, only Riparian Zone C (the initial 2 km stretch) possesses vegetation with GDS of sufficient standing biomass to be considered at risk of significant/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 this stretch which represents the area of greatest risk of groundwater dependence. Conversely this area coincides with that area of diminishing potential to propagate potential drawdown. However, despite initial hydrogeological investigations indicating that a groundwater barrier is likely in the vicinity of Riparian Zone C-1, geophysics did not confirm this, and confidence in information surrounding this potential for diminished propagation is only moderate and therefore unable to be considered in great detail.

Perceived disparity between the interpreted depth to groundwater within Riparian Zone C (and potentially downstream, based on geophysics and bore data) and the GDS and associated GDV recorded, can potentially be partially explained by substrate constraints on riparian growth through Riparian Zone C. However, based on observations made in other Hamersley creek systems, the restricted distribution of *E. camaldulensis* and absence of key mesic indicator species is still perceived as unusual in light of the interpreted 3.5 m average depth to groundwater through this zone (with an average depth of 2 m bgl through Riparian Zone C-1). Therefore, either substrate constraints are playing a bigger role than first conceived, geophysical interpretations are inaccurate , upstream propagule sources of mesic species are extremely limited, and/or historical variability in groundwater height is considerable (downstream of Riparian Zone B) and therefore limiting. It seems most likely that considerable variability in water availability would best explain the situation. Importantly, increasing amounts of complimentary evidence suggest that the continuation of the broader valley aquifer through Riparian Zone C is limited, and that primarily surface water driven recharge and groundwater ponding behind at least partial barriers to flow at the end of Riparian Zone C-1 may best explain the distribution of GDV in Riparian Zone C. This explanation is also strengthened by the observation that vegetation at the downstream end of Riparian Zone E doesn’t support uninterrupted groundwater connection through to the known aquitard in that location. Importantly, regardless of whether vegetation present in the area of interest is reflective of the degree of groundwater access present, along with the predicted resilience of the over-storey, understorey vegetation does not show compositional signs of increasing reliance on groundwater, and as such this component of local vegetation is unlikely to see significant impact.

It is maintained, through geological interpretations (Rio Tinto 2017), that drawdown is highly unlikely to propagate beyond Riparian Zone E, due to the presence of a groundwater divide in that vicinity. Therefore, upstream of this point, drawdown as a result of dewatering for the Proposal has the potential to propagate through and impact vegetation within Riparian Zone C. Different modelled scenarios for the magnitude of drawdown experienced at bore WANG14 indicate that drawdown is unlikely to reduce groundwater heights to a point where vegetation in Riparian Zone C no longer has either direct or indirect access. Groundwater modelling predicts up to 6 m (worst case) of drawdown will potentially propagate to WANG 14, and within Riparian Zone C-1 this figure is likely to be slightly less due to the extra distance travelled to this point (approximately 1 km further). For the worst case modelling scenario (Sy = 1%), geophysical interpretations combined with drawdown modelling suggests groundwater access would be low but acceptable at approximately 3.5-10.5 m bgl within Riparian Zone C (outside of Riparian Zone C-1), and approximately 2.5-8.5 within Riparian Zone C-1 (the most sensitive zone; Table 6-1). Under the base case scenario (Sy3%) geophysics combined with drawdown modelling predicts maximum groundwater depth to be approximately 4.5-5.5 m bgl within Riparian Zone C-1 and approximately 5.5-7.5 m bgl within the remainder of Riparian Zone C (Table 6-1), and thus still accessible to trees. However, with numerical modelling not considering surface water inputs (beyond cyclonic events), recharge complexities at the western end of the model, and the influence of Calcrete formations, all modelling based groundwater predictions should be considered as conservative and unlikely to be realised.

Most importantly, and also considering that FPV in the hot-tropics appears to have the potential to survive with minimal to no groundwater access, the time scales over which this drawdown is modelled to occur indicate that vertical rates of change per year are very small. Based on the various specific yield modelling scenarios, vertical height changes to groundwater potentially experienced within KNP are likely to be in the order of 10-20 cm per year with a base case of 15 cm and worst case scenario of approximately 40-60cm/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 (i.e. 1 cm per day; Kranjcec, Mahoney and Rood 1998; Scott, Shafroth, and Auble 1999; Horton and Clark 2001; and Canham 2011). This adaptation is primarily achieved through root systems tracking groundwater down through the soil profile, and via the allocation of increased root resources to vadose soil water sources. It is acknowledged that the ability of mature trees to achieve this type of adaptation could be severely limited under certain edaphic conditions, but that for younger individuals; adaptive change is a much more realistic expectation.

In conclusion, if groundwater drawdown of 1 m to 6 m (but likely less) were to extend beyond the KNP boundary (i.e. 2-4 km), the overall risk of significant impact would be considered “Moderate” and would be restricted to Riparian Zone C, particularly Riparian Zone C-1. However, considering the very slow rates of vertical change in groundwater height modelled as reaching KNP, the low potential for complete removal of groundwater access, the high potential for local FPV to adapt to such change and ultimately the likelihood that riparian vegetation in KNP is not primarily dependent on the broader valley aquifer proposed to be dewatered, the resultant risk to vegetation in this area is likely to be lower. Downstream and upstream of Riparian Zone C, the risk of significant impact is considered low. Ultimately compositional changes in the dominant species present in Riparian Zone C (within KNP) are considered unlikely, while changes in cover/abundance (and thus potentially structural changes) and health of overstorey communities are considered the impact of greatest potential, albeit low-to moderate in significance and extent. While it is acknowledged that there is some potential for changes in the cover/abundance of understorey vegetation within Riparian Zone C due to groundwater changes, the absence of any intermediate (and higher) level mesic understorey components within the riparian flora of the area suggests that the vast majority of this change will be driven by typical seasonal variability.

Based on consideration of the interacting factors surrounding the potential for groundwater changes to significantly impact potentially groundwater dependant riparian vegetation, it is concluded that overall, the interpreted risks attributed herein are deemed relevant, adequately conservative and therefore the best estimate currently available.

In line with this assessment, it is concluded that monitoring and management efforts should be focussed on the incised channel zone of TCEB, starting approximately 2 km inside the KNP boundary (in the vicinity of the calcrete formations), and further focusing on Riparian Zone C, with some consideration for the northern section of Riparian Zone E and the southern section of Riparian Zone B. Some monitoring of Riparian Zone D should also be conducted in order to confirm that impacts downstream are not being realised. Substantial historical tree health monitoring data collected in Riparian Zone C (qualitative reference sites associated with the Turee creek bore field) should form some of the basis of important baseline data relevant to contextualising the variability in tree health likely to be seen in such a system. Cover indices (based on World View or equivalent remote sensing), combined with representative “basal area” and “understorey abundance” plots is recommended to form the broader basis of health monitoring to track the distribution of potential cover-changes and stem-density changes in the study area.

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9 APPENDICES

Appendix 1: Flora sampling sites recorded during historical surveys and utilised in the current study for the purpose of vegetation mapping

ID	Type	Phase	Survey	Author	Year	Easting	Northing	Document control Number
FS-2010-736	Quadrat	Phase 1	A Flora and Vegetation Survey of the Proposed West Angelas Gas-Fired Power Station and Pipeline Corridor	Biota Environmental Sciences	2010	670209.4	7439566	RTIO-HSE-0103735
FS-2010-3252	Quadrat	Phase 2				673488.9	7439510.5	RTIO-HSE-0103735
FS-2011-3450	Quadrat	Phase 2	Flora, Vegetation and Fauna Assessment of the Re-Aligned Gas Pipeline Corridor at West Angelas	ENV. Australia	2011	671202	7439469.05	RTIO-HSE-0131727
FS-2012-5518	Relevé	Phase 1	Flora, vegetation and fauna assessment of the West Angelas gas pipeline deviation		2012	663074	7437471.06	RTIO-HSE-0156742
FS-2012-5510	Quadrat	Phase 2				663089	7437588.05	RTIO-HSE-0156742
FS-2012-6230	Quadrat	Phase 1	Rio Tinto Greater West Angelas Vegetation and Flora Assessment	ecologia Environment	2012	672580	7439183	RTIO-HSE-0185831
FS-2012-6137	Quadrat	Phase 1				669629.99	7439904.14	RTIO-HSE-0185831
FS-2012-6208	Quadrat	Phase 1				667450.17	7440007.34	RTIO-HSE-0185831
FS-2012-6204	Quadrat	Phase 1				662935.63	7437760.12	RTIO-HSE-0185831
FS-2012-6228	Quadrat	Phase 1				662967	7439466	RTIO-HSE-0185831
FS-2012-6143	Quadrat	Phase 1				672930.07	7439386.28	RTIO-HSE-0185831
FS-2012-6176	Quadrat	Phase 1				673420	7439350	RTIO-HSE-0185831
FS-2012-6203	Quadrat	Phase 1				671233.1	7439484.48	RTIO-HSE-0185831
FS-2012-6207	Quadrat	Phase 1				672023.59	7439634.47	RTIO-HSE-0185831
FS-2014-11331	Relevé	Single Phase	Western Hill Native Vegetation Clearing Permit Report	Biota Environmental Sciences	2014	661777.95	7439934	RTIO-HSE-0235895

Appendix 2: Flora sampling sites recorded within the study area as part of the current survey

ID	Type	Survey	Date	Easting	Northing
WAR-1	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	12/03/2016	673124.49	7439264
WAR-2	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	12/03/2016	667782.49	7439782
WAR-3	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	13/03/2016	667232.95	7440319
WAR-4	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	13/03/2016	664101.95	7439601
WAR-5	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	13/03/2016	662109.04	7439794
WAR-6	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	660286.97	7440006
WAR-7	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	659889.12	7440048
WAR-8	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	16/03/2016	662539.85	7437855
WAR-9	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	659033.31	7440108
WAR-10	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	658672.48	7439812
WAR-11	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	658353.28	7439534
WAR-12	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	658001.71	7439395
WAR-13	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	657682.51	7439104
WAR-14	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	657266.16	7438960
WAR-15	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	656280.82	7438618
WAR-16	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	655480.51	7438484
WAR-17	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	655059.54	7437850
WAR-18	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	654781.98	7437531
WAR-19	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	15/03/2016	654675.57	7437018
WAR-20	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	13/03/2016	663975.94	7439675
WAR-21	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	16/03/2016	663294.03	7437543
WAR-22	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	660529.13	7439721
WAR-23	Relevé	West Angelas Deposit C and D; Groundwater Dependent Vegetation Assessment	14/03/2016	660266.38	7440137

Appendix 3: Vegetation structural classification used to describe vegetation

Stratum	Canopy Cover (%)				
	70-100%	30-70%	10-30%	2-10%	<2%
Trees over 30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees under 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs over 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs under 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, Sedges, Herbs	Closed tussock grassland / sedgeland / herbland	Tussock grassland / sedgeland / herbland	Open tussock grassland / sedgeland / herbland	Very open tussock grassland / sedgeland / herbland	Scattered tussock grasses / sedges / herbs

*Based on Keighery (1994), adapted from Muir (1977), and Aplin's (1979) modification of the vegetation classification system of Specht (1970):

Aplin T.E.H. (1979). The Flora. Chapter 3 *In* O'Brien, B.J. (ed.) (1979). *Environment and Science.* University of Western Australia Press;

Muir B.G. (1977). Biological Survey of the Western Australian Wheatbelt. Part II: Vegetation and habitat of Bendering Reserve. *Records of the Western Australian Museum, Suppl*. No. 3;

Specht R.L. (1970). Vegetation. *In The Australian Environment.* 4th edn (Ed. G.W. Leeper). Melbourne.

Appendix 4: Hope Downs 1 Case study

Systematic Eucalypt health assessment to demonstrate the response of riparian eucalypts to drawdown within the incised channel & floodplain zones of Weeli Wolli Creek in the Hope Downs 1 area (without the influence of artificial perennial flows).

<u>Figures A1-A4, illustrating the results of the systematic eucalypt health assessment at HD 1</u>

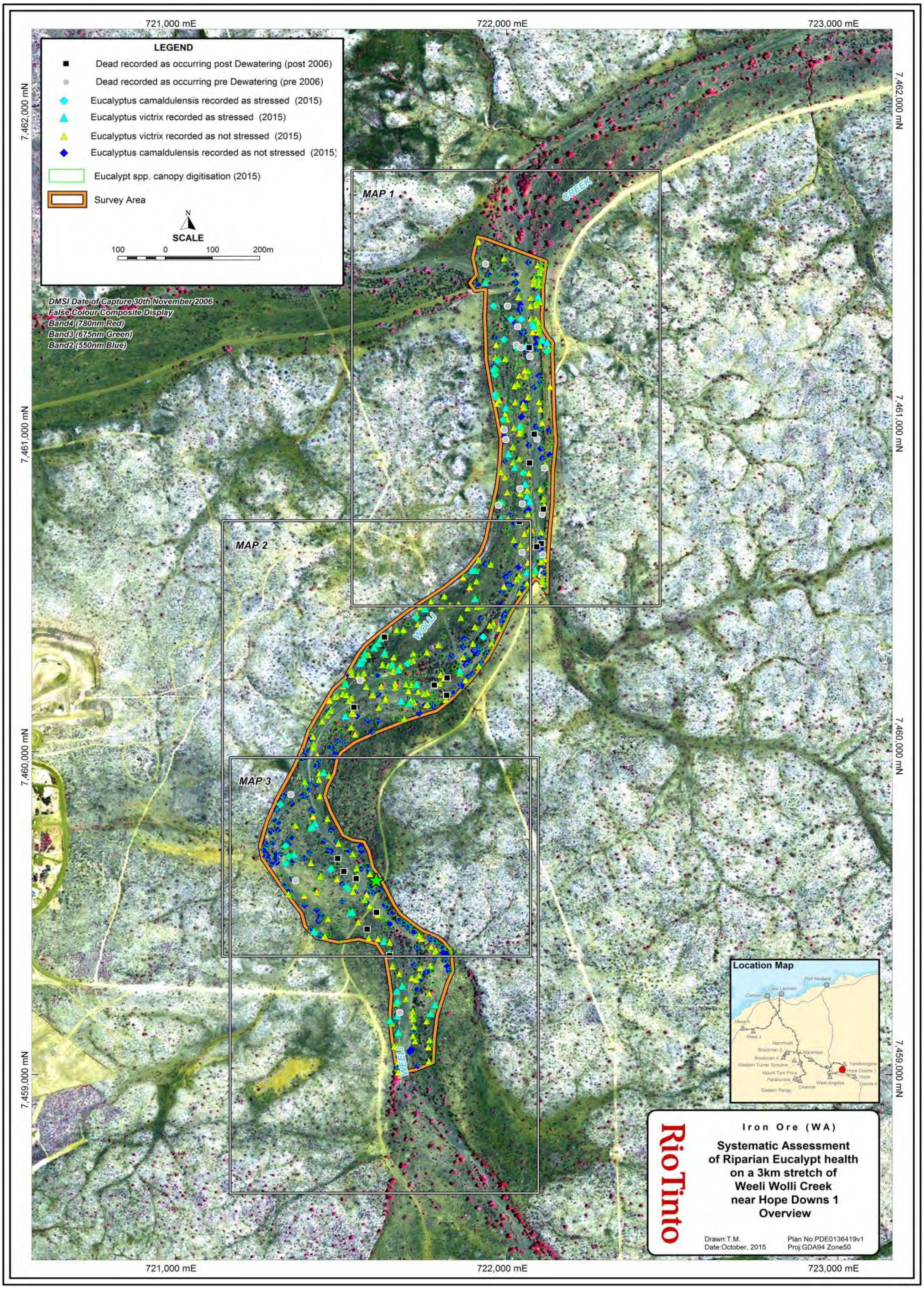

Figure A1: Systematic Assessment of Riparian Eucalypt health on a 3 km stretch of Weeli Wolli Creek near Hope Downs 1 and centred on the zone of most significant drawdown from the adjacent Hope downs 1 mining pits; - Overview map

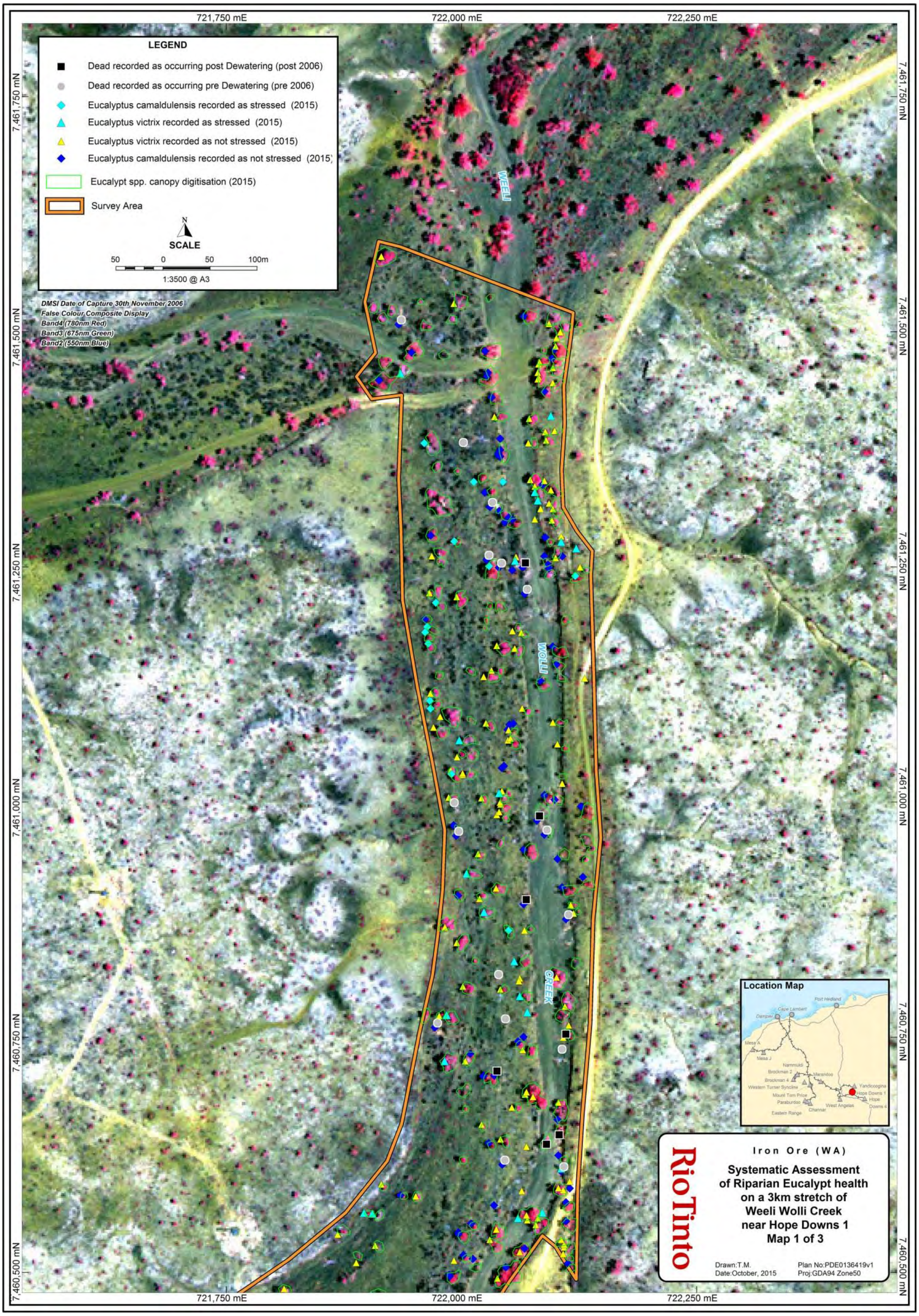

Figure A2: Systematic assessment of riparian eucalypt health on a 3 km stretch of Weeli Wolli Creek: Map 1 of 3

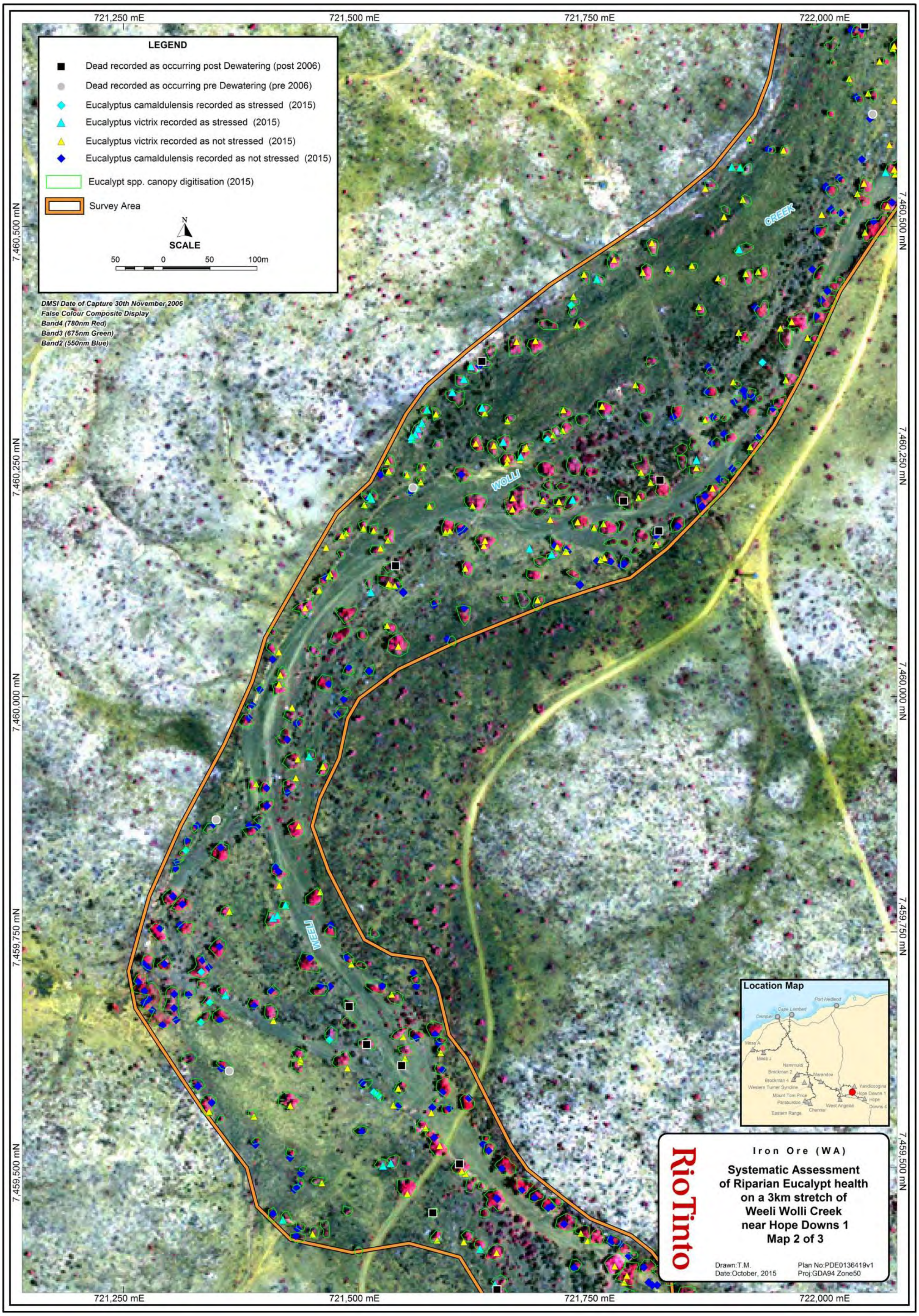

Figure A3: Systematic assessment of riparian eucalypt health on a 3 km stretch of Weeli Wolli Creek; Map 2 of 3

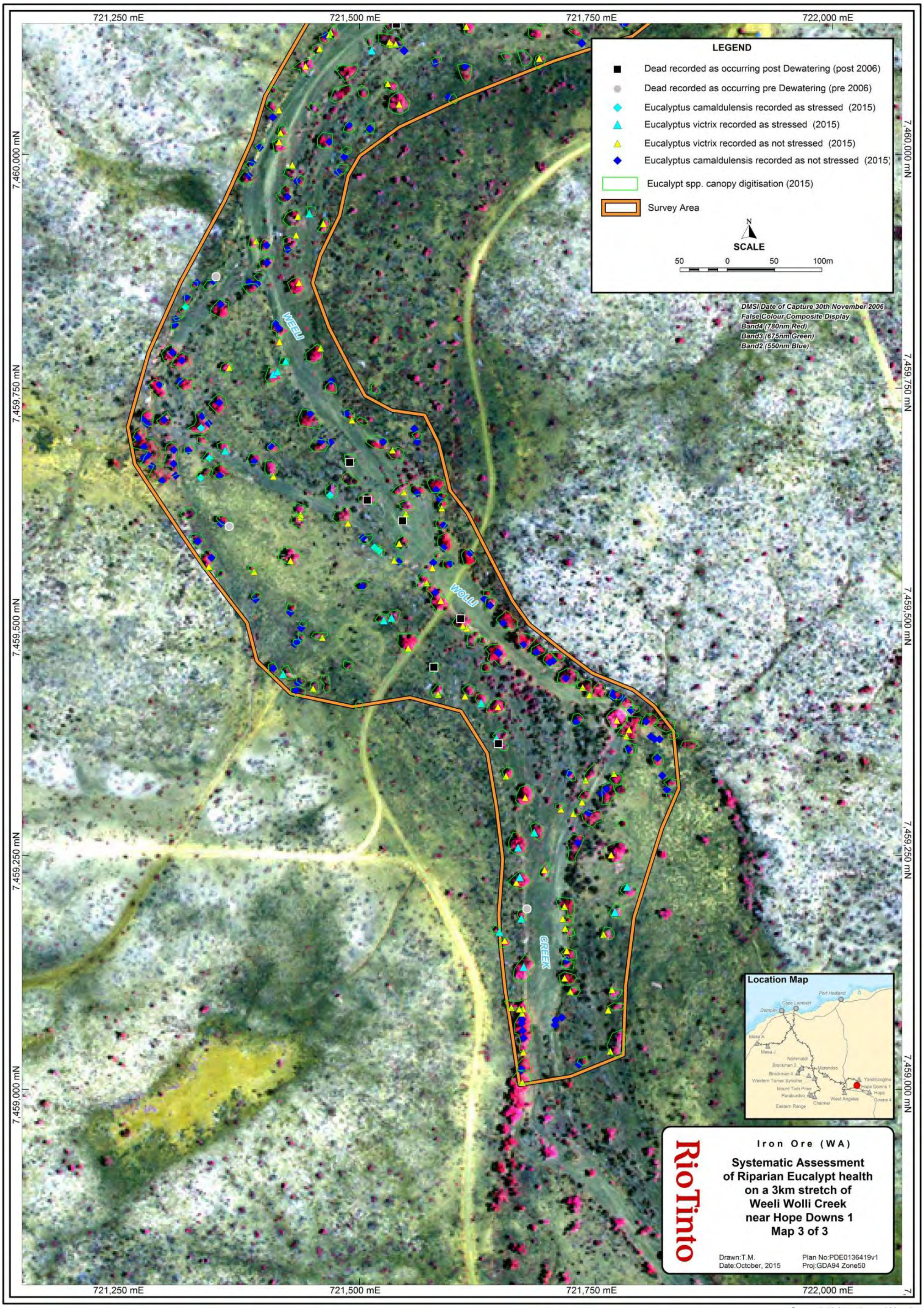

Figure A4: Systematic assessment of riparian eucalypt health on a 3 km stretch of Weeli Wolli Creek; Map 3 of 3