Assessment of Groundwater Dependent Vegetation distribution on the Robe River - Targeted Riparian Vegetation Survey – Stage 1

High confidence mapping of the distribution of Obligate and Facultative Phreatophytic Vegetation between Mesa A and East Deepdale deposits on the Robe River

June 2018

RTIO-HSE-0325261

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Document Status					
Rev	**Author**	**Reviewer/s**	**Date**	**Approved for Issue**	
				To Whom	**Date**
1	J. Naaykens	T. Souster	29/06/2015		
2		H. Bishop	21/03/2017		
3		Melinda Brand	24/03/2017		
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1 INTRODUCTION

In the West Pilbara region of Western Australia the Robe River drains a sizeable portion of the catchment of the Western Hamersley Ranges. The historic paleo-channel of this River system has formed a string of pisolitic mesa shaped hills (also known as Channel Iron Deposits (**CID**)). Concurrent to this process, the hydrology of the West Pilbara in combination with local geology and topography have created the current pathway of the drainage has formed the Robe River, which provides habitats, riparian ecosystems and ecological values of local and potentially sub-regional significance.

As part of the process of recovering CID mineral resources, consideration of the potential to impact these local environmental assets is essential. For riparian systems, where the resident biological features are typically a clear reflection of the hydrological (and physical) characteristics of the river system, identifying the sensitivity and significance of these features is critical to inform an assessment of potential hydrological change.

In addition to considering potential impacts, the respective spatial distribution and significance of the ecological values present are of key importance to better understand the characteristics of riparian communities in the Robe River. Of particular focus is the distribution of Groundwater Dependent Ecosystems (**GDE**s) and Groundwater Dependent Vegetation (**GDV**) within the area, in addition to the varying scales of hydrological sensitivity held by resident vegetation types throughout the relevant stretches of the Robe River.

The groundwater dependent ecosystems of Australia represent a diverse, yet distinct component of the nation's biological diversity. Based on initial work by Hatton and Evans (1998), and further considerations by SKM (2001); six major types have been identified:

- **terrestrial vegetation** – vegetation communities and dependent fauna that have seasonal or episodic dependence on groundwater;
- **river base flow systems** – aquatic and riparian ecosystems that exist in or adjacent to streams that are fed by groundwater base flow;
- **aquifer and cave ecosystems** – aquatic ecosystems that occupy caves or aquifers;
- **wetlands** – aquatic communities and fringing vegetation dependent on groundwater fed lakes and wetlands;
- **terrestrial fauna** – native animals that directly use groundwater rather than rely on it for habitat;
- **estuarine and near-shore marine ecosystems** – coastal, estuarine and near shore marine plant and animal communities whose ecological function has some dependence on discharge of groundwater.

Three GDEs are of relevance to the Robe River; Pools (Wetland or River base-flow system types), Riparian Vegetation (Terrestrial vegetation type), and stygofaunal assemblages (Aquifer and cave ecosystem type).

The current study focusses on identifying GDV as an indicator for the presence of "Terrestrial Vegetation" type GDEs. As part of this process, key pools within the study area will be delineated to provide information about the distribution and abundance of Aquifer type GDEs.

Vegetation mapping is one of the primary tools for identifying key riparian ecological values; their spatial location within a system; and their inherent sensitivity to perturbations. Accurate, sufficiently detailed and complete riparian vegetation mapping is also important for guiding current and future riparian monitoring, and contextualising local to sub-regional significance. Furthermore; when considering in detail the potential for complex hydrological impacts, a more detailed scale of mapping is required for accurate, measured and more meaningful management and mitigation.

The four key aims of this study are:

1. To gather widespread, detailed and high confidence spatial information on the distribution of Robe River GDV, particularly those Obligate Phreatophytic Vegetation (**OPV**) communities surrounding resources in the Robe Valley.

2. Gather and incorporate information on the structure, age distribution, maturity and potential permanence/transience of resident OPV communities such that the resultant vegetation mapping is more strongly positioned to assess significance and groundwater dependence.

3. Describe and map all riparian communities throughout the study area, to a high level of detail, and in a manner prioritising the identification of all potentially groundwater dependent ecosystems and their distribution.

4. Based on the structure, maturity and distribution of mapped phreatophytic vegetation: provide an interpretation of the significance and inherent sensitivity of these communities to potential hydrological change in the form of interpreted risk mapping throughout the area of interest.

The current report outlines the Stage 1 work undertaken to achieve these aims within the relevant stretches of the Robe River surrounding Rio Tinto Robe Valley operations. Figure 1-1 shows the extent of the current study area and the boundaries of previous flora and vegetation surveys.

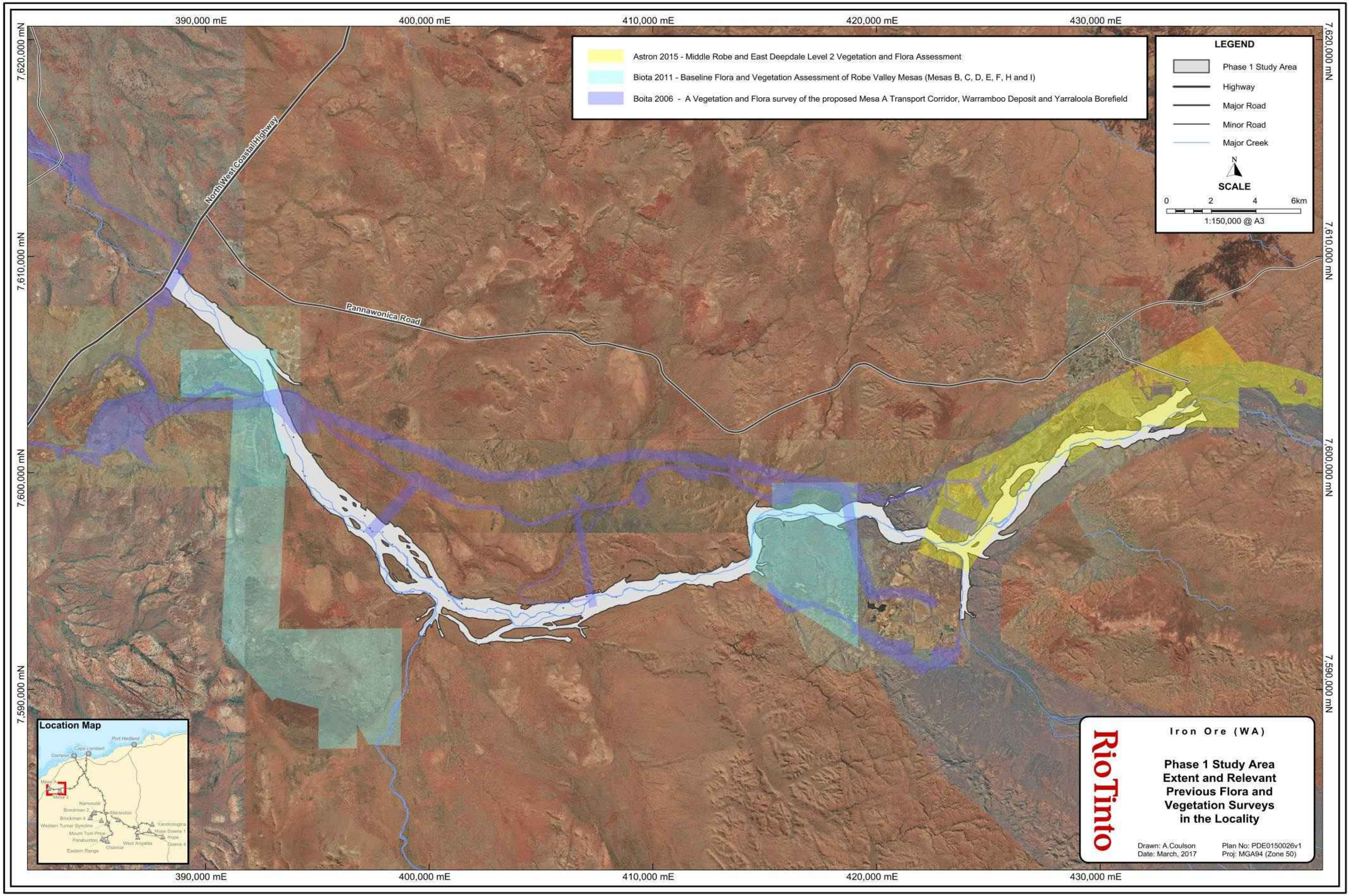

Figure 1-1: Extent of Robe River covered by the Stage 1 Study Area; includes the study boundaries of previous key flora and vegetation surveys.

2 BACKGROUND

2.1 RIVERS OF THE PILBARA REGION

The Pilbara is a relatively large arid region of the North West of WA. This region incorporates a number of large rivers which includes but is not limited to; the De Grey, Maitland, Harding, Turner, Oakoaver, Nullagine, Shaw, Yule, Fortescue Ashburton and Robe. Within the Pilbara region; major catchment divides are provided by the Chichester and Hamersley Ranges. The Chichester Range, a great undulating plateau forms a water shed between north flowing river systems (including the Harding, Maitland, Yule Turner and De-Grey) and the westerly flowing Fortescue River. The north flowing rivers begin dendritic and lead downstream to well-developed coastal drainage systems; with braided channels and discontinuous anabranches. On the southern flank of the Chichester Range and the north and south flanks of the Hamersley Plateau; streams are generally relatively short, dendritic, and often terminate in coalescing outwash fans on the alluvial plains of the Fortescue and Ashburton Rivers. The Fortescue River is long but is interrupted by extensive floodout lowlands of the Fortescue Marsh and associated claypans (Massini 1988).

The ephemeral rivers of the Pilbara are generally dry, experiencing major seasonal flows in a number of rivers almost every year. These flows are typically derived from tropical lows and cyclones which frequent the tropical north between December and April.

2.2 PHREATOPHYTIC VEGETATION / SPECIES, AND GROUNDWATER DEPENDENT ECOSYSTEMS IN THE PILBARA

Riparian systems of the Pilbara bioregion are subjected to extremely seasonal and variable hydrologic regimes in which stream flow typically occurs following cyclonic rainfall events (Ruprecht and Ivanescu 2000). Large flow events can result in the formation of isolated pools, replenish floodplain soil moisture and recharge groundwater within the riparian system.

In creeks and rivers of the Pilbara, groundwater is typically contained within shallow, unconsolidated sedimentary aquifers close (<20 m) to the surface (Landman 2001). In some instances, groundwater reaches the surface and natural springs are formed, maintaining permanent surface water pools. These shallow aquifers and springs often support GDEs; natural ecosystems that require access to groundwater to meet some or all of their water requirements to maintain their communities of plants and animals, and ecological processes (Sommer and Froend 2011).

While this study is focused on identifying GDV as an indicator of the broad “terrestrial vegetation” GDE type, it is also of importance to consider the hydrogeological processes and characteristics which might be supporting such vegetation to further understand the potential dependency of local phreatophytic vegetation. In recognition of the river landforms which are the focus of this study, it is also pertinent to consider broad GDE linked to such landforms and how they might influence the characteristics of local GDV. In Australia, several types of GDEs have been recognised (Clifton and Evans 2001), including river base-flow systems that comprise lotic aquatic and riparian ecosystems that rely wholly or partially on groundwater for their maintenance, function and integrity. Base flow is the component of total stream flow that is derived from groundwater, and reflects aquifer permeability, local and regional geology, bank and floodplain storage and the topography of the water table (Newson 1994). Under certain geomorphic conditions, some of this groundwater enters streams and rivers from discrete springs and seeps, frequently supporting specialised aquatic fauna and flora (Williams *et al.* 1997; Halse *et al.* 2002; Fensham *et al.* 2004). More commonly, most base flow derives from groundwater that seeps in from the channel margins and floodplains via the parafluvial zone or enters from below via the hyporheic zone. The hyporheic zone is defined as the saturated sediments below and alongside the river channel where stream and groundwater exchange, and its functional significance to the ecology of surface river ecosystems is being increasingly recognised (Brunke and Gonser 1997; Boulton *et al.* 1998; Dent *et al.* 2000).

In many rivers draining arid and semi-arid Australia, discharge for most of the time is solely from the base flow (Boulton and Williams 1996). Furthermore; in many ephemeral rivers of the arid tropical zone, base flow typically only ever appears as very intermittent surface expressions (pools). For this reason, the ongoing interaction of the various source and sink components which influence the magnitude and at times cessation of local base flow, are generally wholly unknown.

GDEs comprise plant species that, in the absence of rainfall, rely directly on groundwater (and associated surface expressions) but may also contain grass and herbaceous species relying on recent rainfall (Sommer and Froend 2011). Plant species which draw water from the saturated zone (the phreatic zone) or capillary fringe of the water table are known as phreatophytes and the presence of GDEs is often inferred from the presence of such species (Eamus *et al.* 2006). Phreatophytes can usually be found along streams where there is a steady flow of surface or groundwater, or consistent still pools in areas where the water table is near the surface.

At the opposite end of the scale is a “xerophyte”, which is essentially a species of plant which has adapted to survive in an environment with little access to water (Salisbury and Ross 1992). Terms used to describe the water use strategies of plants occupying various positions within the Phreatophyte to Xerophyte scale are: “Obligate Phreatophyte”; “Facultative Phreatophyte”; and “Vadophyte”.

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 would be lowered beyond assumed 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 moisture available to it in any one situation. For example, plants that rely on water sourced directly from the groundwater table (phreatophytes) are more likely to show signs of decline or be lost than those that can rely on sources of soil moisture (i.e. vadophytes) such as precipitation and soil pore moisture anomalies from other sources. An assessment of the groundwater dependence of species present within the study area has been informed by a desktop literature review, with specific reference to previous vegetation association mapping and an understanding of the surface water and underlying groundwater environment.

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).

The tree species *Eucalyptus camaldulensis* subsp. *refulgens* Brooker & M.W. McDonald (River Red Gum), *Eucalyptus victrix* L.A.S.Johnson & K.D.Hill (Coolibah) and *Melaleuca argentea* W.Fitzg (Silver Cadjeput – historically identified as *M. leucadendra*) are the three most common phreatophytic species within riparian systems of the Pilbara bioregion. A fourth, *Sesbania formosa*, while less widespread and less accepted as a phreatophytic species, is also a relevant phreatophyte in Pilbara riparian systems. The presence of these species is often used to infer the presence of a GDE. These species vary in their degree of dependence on groundwater and this variation has a strong influence on their patterning and abundance within riparian systems. The most dependent of these species upon groundwater is *Melaleuca argentea*, which is considered to be an obligate phreatophyte.

Melaleuca argentea have previously been recorded within the study area in varying quantities. *Sesbania formosa*, another potentially obligate phreatophyte, is commonly scattered throughout those more mesic communities present within the study area. Table 2-1 presents an interpretation of the different classes of groundwater dependence (water use strategies) relevant to riparian plant groups in the Pilbara, and the most relevant species considered as being attributable to each. It should be noted that some of the detail presented in this table is the culmination of substantial observational experience gained by the author in the Pilbara. While broad concepts presented tend to be agreed with by relevant studies, some of the nuances presented in Table 2-1 are neither well accepted nor adequately supported by empirical data. Instead the detail is presented as a guide as to how these species are broadly observed to behave, for the purpose of informing the risk assessment conducted in this report. What is generally well accepted is that *Melaleuca argentea* is an obligate phreatophyte, and that *Eucalyptus camaldulensis* and *E. victrix* are facultative phreatophytes. Generally speaking there is a paucity of data on the remainder of species presented in the table.

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, Sesbania formosa (?)*
Moderate	Facultative phreatophyte (in anomalous cases a vadophyte)	*Eucalyptus camaldulensis*
Low to Moderate	Vadophyte or Facultative phreatophyte (in anomalous cases)	*Eucalyptus victrix, Melaleuca glomerata and Eucalyptus xerothermica*
Low (virtually negligible)	Xerophyte	E.g. *Eucalyptus leucophloia*, *Corymbia hamersleyana*, *Corymbia deserticola*, Corymbia candida

*The degrees of dependence on groundwater implied in this table are more relevant to specific species listed in this table rather than individuals of each species. It is acknowledged that individuals of a specific species may have established under conditions of high water availability, and thus may possess high degrees of groundwater dependence (and vise versa). Furthermore plant water use strategies listed are not mutually exclusive; vadophytes may access groundwater, and vice versa, phreatophytes will also access vadose soil water.

Vegetation associations occurring along the main drainage channels and associated flood plains within the study area support three native tree species that are considered to be at moderate or lower risk from groundwater drawdown: *Eucalyptus camaldulensis* subsp. *refulgens* (moderate risk);

Eucalyptus victrix (low to moderate risk); and *Corymbia candida* (low to minimal risk). These tree species are classified facultative phreatophytes or at times as vadophytes.

Eucalyptus camaldulensis is the most widespread Australian Eucalypt species and is known to tolerate an apparently wide range of water regimes (Colloff 2014). Eucalyptus camaldulensis (River Red Gum) is considered a facultative phreatophyte as it 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). *E. camaldulensis* typically occurs along inland rivers and may be dependent on shallow groundwater for survival, although the root system may penetrate considerably deeper than 10 m. Studies in the Pilbara indicate that *E. camaldulensis* occurring along the larger drainage lines may have access to groundwater up to 21 m below the surface (AGC Woodward-Clyde 1992). Investigations at Marillana Creek found the vigour of large *E. camaldulensis* trees (>10 m tall) declined in response to lowering of 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 River red gum (*E. camaldulensis*) and Coolibah (*E. victrix*) are generally not restricted in their occurrences along Marillana Creek and thus cannot be considered as being true phreatophytes, but as vadophytes (i.e. primarily unsaturated soil dependent). In the case of *E. camaldulensis*, general observations in the Pilbara by Rio Tinto Botanists suggests that there is some degree of restriction to the distribution of this species along large creeks, and so the concept that this species can be both a phreatophyte and a vadophyte (depending on the circumstances) appears most accurate.

Eucalyptus victrix is a small to medium sized eucalypt which typically occurs on the drier zones of creeks and rivers throughout semi-arid Western Australia. Like *E. camaldulensis*, *E. victrix* is also considered to be a facultative phreatophyte. This species 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 its transpiration needs (Grigg *et al.* 2008). *Eucalyptus victrix* is known to inhabit an ephemeral wetland (i.e. Mount Bruce Flats, Karijini National Park) despite the absence of a permanently saturated regolith (Rio Tinto 2011a). Comparisons of groundwater and stem xylem water stable isotope compositions as well as pre-dawn and midday leaf water potential measurements suggest that *E. victrix* within the Mount Bruce Flats in Karijini National Park uses water drawn from the unsaturated soil profile during extended dry periods (Rio Tinto 2011a). Further to this, *Eucalyptus victrix* (and potentially *Corymbia candida*) are generally considered to be examples of vadophytes being relatively drought tolerant but susceptible to decline when groundwater becomes limiting (Muir Environmental 1995).

Melaleuca argentea is a tree which grows to approximately 20 m (and higher) and is found along larger watercourses of the Pilbara. *Melaleuca argentea* is thought to be dependent on groundwater almost exclusively to meet its water requirements 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, this species is typically found in parts of creeks and rivers characterised by permanently inundated pools and springs or where the water table is permanently close to the surface (McLean *et al.* 2013). *Melaleuca argentea* is generally considered to be the plant taxon within the Hamersley Ranges at highest risk of impact through changes to groundwater availability associated with drawdown.

The water use characteristics of *E. camaldulensis, E. victrix* and *M. argentea* influences their response to mining related impacts such as dewatering and discharge. Dewatering, which causes localised lowering of groundwater levels, may be expected to have a significant impact on the health of *M. argentea* but lesser impacts on *E. victrix* and *E. camaldulensis*, provided adequate soil moisture is maintained from periodic, rainfall-generated stream flow. On the other hand, artificial discharge of surplus groundwater along ephemeral creeks and rivers may favour *M. argentea* (resulting in increased recruitment and vigour) by creating a perennial hydrologic regime. Change from a steady-state ephemeral hydrologic regime to a more perennial one may adversely impact *E. victrix* and to a lesser extent *E. camaldulensis*. Florentine (1999) found that *E. victrix* exhibits some tolerance to waterlogging (e.g. production of adventitious roots) but overall growth, transpiration rate and net photosynthesis are negatively affected under waterlogged conditions. By contrast, *E. camaldulensis* is considered to be one of the most waterlogging-tolerant eucalypt species (Bell 1999; van der Moezel *et al.* 1988), though empirical studies of its waterlogging tolerance in the Pilbara bioregion are lacking and results may be somewhat dependent on subspecies. At the local and micro scale the impacts of excess water will differ depending on the substrate and channel morphology and thus the relative position of trees (particularly on a vertical plane) to available water.

Probably the most important concept to consider when classifying the water use of plant species by attributing particular species to one of the above described water use strategies, is that typically plants and their associated environments do not always behave in definitive manners. While the physiological constraints and demands of the plant tend to be quite definite, the way in which the environment provides for this physiology and the way in which the plant acquires its needs from the environment can vary quite considerably in time and space (O'Grady *et al*. 2009). The most relevant area of variability in relation to the risk of death from changes in water availability is represented by a plants ratio of resource allocation between its canopy and root systems. The size and distribution of a plants root system (and conversely the size of its canopy and associated water demands) has a direct link to its ability to acquire sufficient moisture when soil conditions change (Salisbury and Ross 1992). The rate of water availability change therefore has important consequences for the ability of a plant to re-allocate these resources in time and therefore potentially to transition between the bounds of a phreatophyte and a vadophyte. Furthermore; the stem density of the vegetation a tree resides in has a strong influence on the stand water demands per unit of area and hence the resources available for each individual tree to compete for.

Another important point to consider when assigning species or communities to phreatophytic water use strategies is the source of moisture. While phreatophytic species are considered to be dependent on groundwater this is not always accurate in the context of the typical definition for groundwater. Groundwater is often considered to be represented by the underlying water table, but in the case of plant water use it is more accurately any source of water on, in or under the ground as long as its presence remains fairly consistent. For example; phreatophytic species can establish because stream morphology and/or underlying geology are such that specific areas sustain consistent alluvial water bodies or surface water pools and patches of moisture which are perched well above the underlying groundwater table. Subsequently these communities can be sustained by intermittent but relatively consistent fluvial flows, regardless of the behavior of deeper groundwater bodies. The reason such distinctions are important, is that in an impact assessment scenario, potential changes to clearly detectable and therefore more broadly evident groundwater aquifers often comprise the only measurable features of hydrological influence acting on riparian systems. However despite such a focus, changes to broad scale groundwater features can often occur with little or no influence on small scale aquifers and surface water features consistently present in certain fluvial positions and situations.

The resounding message which becomes apparent when considering phreatophytic species is that not all phreatophytic species are equal. Each species considered has evolved in a different habitat using different life strategies and each habitat has varying degrees of water availability. An additional layer of complexity is represented by the various niches which these species have adapted to take advantage of within each habitat. As a result *Eucalyptus victrix* and *E. camaldulensis* have quite different adaptive capabilities and as such can survive and prosper in quite different water availability regimes.

GDEs and their associated species and landforms represent features of elevated ecological value. Phreatophytic species often represent fast growing pioneers which are highly resistant to disease. They also provide, shelter, specialised foraging grounds, and nesting/denning areas for native fauna. Phreatophytes are also known to be indicators of potable groundwater, and to provide water purification services, as their roots are known to fix heavy metals via the provision of bacteria driven filtration (World Heritage Encyclopedia 2014).

GDEs, generally represent areas with relatively permanent water (surface and/or groundwater), and as such tend to support relatively dense and diverse vegetation communities. 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 support; their value is generally accepted to be high. It is for this reason that those species which are considered obligate phreatophytes, and therefore most dependent on water permanence, are those species which are the key indicators for the presence of these high value ecosystems. As an obligate phreatophyte *Melaleuca argentea* is a key indicator species for the Pilbara; 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 groundwater dependent ecosystems. However, communities which occur in generally ephemeral habitats, and which do not possess an “obligate phreatophytic species” such as *Melaleuca argentea*, but instead only possess facultative phreatophytes such as *Eucalyptus camaldulensis;* can also be described as GDEs. For this reason it becomes important to make the distinction between general groundwater dependent ecosystems/vegetation, and those which are more specifically highly groundwater dependent, or “truly phreatophytic”.

In the Pilbara, *M. argentea* is widely considered a strict obligate phreatophyte, and because of the potentially variable water use strategies of some of the other phreatophytic species in the Pilbara (namely facultative phreatophytes), *M. argentea* clearly represents the best indicator for true groundwater dependence. Therefore to provide a term or label which can be used to make the distinction between the less significant vegetation types, generally dominated by one or more facultative of phreatophytic species (general GDEs) and those adequately possessing “true” or obligate phreatophytes, the terms “Obligate Phreatophytic Vegetation” (**OPV**), and “Facultative Phreatophytic Vegetation (**FPV**) are proposed.

For the purpose of this study, the label/term "Obligate Phreatophytic Vegetation" (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 Melaleuca 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 obligate phreatophyte Melaleuca 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 studies from associated, well accepted terms such as "Obligate Phreatophytes" and "Groundwater Dependent Vegetation").*

The distinction this term makes is important for this study, as communities in which this species comprises a significant component, are best placed to indicate perennial water availability, and therefore indicate the distribution of ecological values associated with permanent water availability. By making this distinction this study can then differentiate between OPV and more commonly distributed GDEs represented by facultative phreatophytic vegetation (FPV) such as the *Eucalyptus camaldulensis* woodlands which tend to surround OPV. Consequently, for the purpose of this study, and to aid in the process of assessing the significance of riparian communities and their distribution within the study area; communities and vegetation associations/sub-associations within which *Melaleuca argentea* forms a co-dominant species are described as OPV (Obligate Phreatophytic Vegetation). The remaining communities only dominated by other facultative phreatophytic species (but potentially including those possessing *M. argentea* as an associated species only), are from here on in to be termed "Facultative Phreatophytic Vegetation" (**FPV**).

While it is acknowledged that such terms are not accepted in the wider ecological community, their use in this type of assessment is advantageous. Obviously it is acknowledged that vegetation includes all plant species in an area/ecosystem/habitat, and whilst some species may be phreatophytic, many are not. As a result the Terms OPV and FPV are not suggesting all components of the vegetation in question are groundwater dependent. Instead such labels are suggesting that the presence of the relevant phreatophytes are important riparian characteristics/components of the vegetation; particularly in relation to targeted vegetation surveys focusing on potential presence of GDE's. Phreatophytic components whose continued existence is likely dependent on continued access to groundwater are distinctive in terms of their attribution to vegetation units. For such vegetation; hydrological change leading to phreatophyte removal would in turn convert the resident vegetation into a vegetation unit which is compositionally, structurally and functionally different to the original unit to which the OPV/FPV label was applied.

The set of statutory listings for vegetation communities and ecosystems by the WA State or Commonwealth Government are not exhaustive and are generally based on a system of nomination, such that they do not represent a systematic treatment of features of high value or significance. Therefore unlisted flora and vegetation may be locally or regionally significant for similar reasons to those features chosen or nominated for listing. The EPA's Factor Guideline for flora and vegetation states that flora may be considered significant if the flora is locally endemic or associated with a restricted habitat type (e.g. surface water or groundwater dependent ecosystems), and vegetation may be considered significant if it provides an important function required to maintain ecological integrity of a significant ecosystem (EPA 2016a). However, this is not the only means by which biota can be attributed significance. Based on the *Technical Guide; Flora and Vegetation Surveys for*

Environmental Impact Assessment (EPA 2016b), and other sources; vegetation may be significant because its areal extent is below a threshold level and a range of other reasons, including:

- scarcity;
- high diversity or species richness;
- high diversity or species richness within special functional plant groups (e.g. mesic species, ephemeral taxa, xerophytic taxa etc.);
- unusual species, or range extension species;
- novel combinations of species (associations);
- a role as a refuge;
- a role as a key habitat for threatened species or large populations representing a significant proportion of the local to regional total population of a species;
- being representative of the range of a vegetation association (particularly; a good local and/or regional example of an association in "prime" habitat, at the extremes of known range, recently discovered range extensions, or isolated outliers of the main range);
- of restricted distribution at a local/sub-regional/regional scale or occupying a rare landform; and
- exceptional condition.

When considering development and associated impacts to vegetation, it is also important that a measure of sensitivity/resilience and in relevant cases transience be considered and attributed to riparian features of significance so that an element of risk can be attributed to their ultimate significance.

While *Melaleuca argentea* dominated/co-dominated communities generally represent the high significance OPV communities of the Pilbara because of their associated values and local perennial water availability, it is this dependence on a perennial water source which makes them the most sensitive to anthropogenic hydrological changes. Despite the inherent sensitivity of these communities the age structure and distribution of the respective sub-associations of *M. argentea* co-dominated communities present has some degree of influence on their sensitivity to impact. While young obligate phreatophyte individuals (when compared to mature individuals), typically tend to be more sensitive to changes in groundwater height (than mature individuals); this is not the full picture. Compared to mature obligate phreatophyte individuals; the temporal stability of young individuals/populations is generally significantly reduced due to the magnitude of peak flow scouring/deposition processes. Furthermore areas devoid of mature individuals can indicate that water availability is not stable enough to support their long term development. Based on field observations, the distribution of OPV communities dominated by a young age class appear to be restricted to specific habitats and areas where water availability is changing (either reducing, or increasing). As a result it is inferred that riparian OPV communities with an age frequency distribution restricted to young to semi-mature age classes are likely to delineate zones within the fluvial system where flow patterns and locally higher variability in water availability are limiting factors determining that the presence of OPV is highly transient. This temporal instability inferred to be a character of immature OPV communities is most likely to be a product of the increased degree of hydrological variability present in such areas. This conclusion is supported by the fact that an age structure dominated by a narrow age range can often be aligned with a significant and recent hydrological (and/or potentially physical change) change that has enabled a mass colonisation event. Importantly; if hydrological change is high in such areas, and vegetation stability is low, then this will also determine that the vegetation supported will be inherently variable and so will the attributed significance. As a consequence; for such communities it is concluded that the significance of resident communities at any one time is significantly reduced.

For mature OPV communities the opposite is generally true. Those communities with structures increasingly dominated by large mature obligate phreatophytes are delineating the areas where vegetation is relatively stable and water availability is highly consistent thus enabling colonisation and development of high value ecosystems. The temporal stability and significant ecological values provided by such climax OPV determine that the attributed significance is inherently high. Furthermore; the most mature and commensurately significant representations of *M. argentea* woodland/forest are likely to be the most sensitive to change due to their generally high water demands (per unit of area), often broader lateral distribution within the fluvial profile, and their mature age frequency distribution. *Melaleuca argentea* communities which fall in between these two ends of the scale of maturity will generally possess sensitivities and associated significance commensurate to their water demands, predominant age and maximum distance from areas of consistent water availability.

2.3 LANDSCAPE FEATURES, FLUVIALS SYSTEMS AND THEIR ROLE IN SUPPORTING HIGH-VALUE RIPARIAN VEGETATION COMMUNITIES WITHIN THE HAMERSELY SUB-REGION

The climate of the Pilbara is essentially classified as arid-tropical possessing an average precipitation to evaporation ratio of less than 0.2 (McKnight and Hess 2000). With precipitation generally falling within the range of 250-450 mm, the Pilbara can be mistaken for being semi-arid, but with high average temperatures and an average evaporation rate in the vicinity of 2,000 mm per year, the effective precipitation in the region is minimal and therefore classified as arid. Because of such climatic factors, water gaining sites which are exposed to surface water supply from larger catchments and which can lock away significant amounts of water from evaporation, become quite important. Such fluvial systems create riparian corridors which provide refuge for a diversity of moisture loving species which wouldn't otherwise be present in areas possessing a similar climate classification. Consequently these features provide value to the region as custodians of biological diversity through their provision of ecological services and habitat diversity/complexity.

Beyond the general importance and functions of large river/creek systems in hot and often dry climates such as that of the Pilbara; drainage systems which provide the right catchment size and subsequent environmental conditions to create surface or groundwater permanence are considered most valuable. Those factors helping to create or contribute to surface and groundwater permanence within fluvial systems are generally represented by combinations of underlying geology (such as porous or impervious lithologies), topographic confinement, elevation, slope, meander shape and creek profile. Other landscape factors influencing water availability within fluvial systems can also be represented by the intersection of local perched aquifers, the distribution and size of groundwater recharge zones, sources and sinks to river base-flow, adjacent extensive clay-pan landforms (important for storage and sustained moisture release) and physical intersection of barriers to groundwater flow. These factors and more combine to provide the range of unique conditions valuable for the maintenance of permanent water availability and consistent groundwater levels. This value is primarily a product of the highly restricted and diverse ecosystems they can sustain, and by association the fauna assemblages they support. These landscape attributes become increasingly valuable in arid environments due to the restricted distribution of their associated habitats and their ability to buffer the influence of climate variability and change.

2.4 THE ROLE OF MESIC SPECIES, PHREATOPHYTIC VEGETATION AND GDES IN IDENTIFYING VARYING DEGREES OF WATER AVAILABILITY

Within the Pilbara, riparian habitats which provide permanent surface or groundwater access are only common along certain reaches of the regions large river systems. While the more mesic reaches of such river systems are not common, they are large, and OPV is generally common through such areas. Beyond the river systems of the Pilbara, the remaining representations of OPV are quite restricted to parts of those large creek systems which function as drainage for significant catchments and contain optimal substrate conditions to maintain perennial surface and groundwater sources.

As discussed earlier; in the Pilbara, obligate phreatophytes such as *Melaleuca argentea* are highly dependent on permanent access to shallow freshwater. As a result of this dependence; this species is considered one of the best indicators of water permanence in the Pilbara. In general; the structure and composition of river and creekline vegetation tends to be driven by the degree of moisture present, and so vegetation is an important indicator of surface and groundwater permanence and can be used to assess the associated value and significance of the system. This approach is important as there are often no effective alternatives (at a finer scale) for establishing water permanence in an area. Human records are generally not extensive or detailed enough to truly determine if a site actually possesses surface or groundwater permanency. Furthermore, climatic factors can have a strong influence from year to year, and the underlying water table heights established from an often limited array of bores are difficult to accurately interpolate. Generally, the best and often only true indicator (over relevant timescales) of surface and groundwater permanence is the composition and structure of resident vegetation.

In the Pilbara, a list of sub-perennial to perennial moisture indicating (i.e. combinations of moisture present from 1 or more sources such as soil pore moisture, groundwater, capillary fringe etc.) genera/species (mesic indicator species) are likely to contain a number of the species presented in order of importance within Table 2-2 (Western Australian Herbarium 2018) (bold species identifies the best indicators). It should be noted that a paucity of information available on the ecophysiology of the majority of the species listed in Table 2-2 determines that empirical data to determine whether these species truly possess plant functional traits associated with low water use efficiency is relatively unavailable. Instead their attribution to mesic-habitats/wetlands and the implied hierarchy within this list is based on known spatial distribution patterns (some gained from the Western Australian Herbarium (2018), with the remainder gained from field observations by the author). Consequently, riparian zones or water gaining sites which contain *Melaleuca argentea* and varying proportions of the following species are considered to provide good evidence of perennial water availability. Conversely if a riparian zone instead only supports some of the mid-level species/genera in this table moisture availability is considered to be below, but approaching levels equivalent to perennial/permanent availability. It is important to note that it is not yet clear which of these species are more associated with increasing volumes of water, or which are more associated with increasing degrees of consistency in availability. What is clear is that their presence is clearly correlated with increasing degrees of water availability and consistency, and therefore of value as an indicator of either.

Table 2-2: Flora genera and species of the Pilbara determined to be good indicators of increasingly high moisture availability/consistency.

• ***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.*

Note: Species in **bold** identify some of the best upper level indicators of moisture availability / permanence. Order of importance reads down the page, left to right.

While the species composition of vegetation provides a significant insight into water permanency; an additional level of detail on the degree of water permanency is observable in the structure of the vegetation present. This essentially involves making inferences about the degree and extent of permanency based on the age structure and relative dominance of resident obligate phreatophyte populations. If water remains permanently available to these phreatophytic species then at least a percentage of the population is likely to present as "semi-mature" to "mature" individuals of approximately 40-100 cm diameter. While environmental perturbations such as floods and similar peak flow events will have an influence on the age structure; where conditions are suitable, it is still considered likely that mature trees (older large individuals) will resist flooding and remain to provide insight into the stability of the moisture conditions present over reasonable temporal scales.

In addition to the maturity of OPV communities; the degree of lateral restriction within the fluvial system may also be a good indicator of groundwater proximity and persistence. In many cases within the Pilbara, woodlands of OPV are represented by a very thin (almost single tree width) strip of vegetation which forms on the banks (often the lowest colonisable position in the landscape) of some permanent to near permanent surface pools. In some areas mature OPV vegetation is spread across a broader lateral range of the bed; indicating more general groundwater persistence through a larger proportion of the creek profile, and thus providing greater habitat and structural diversity values. Laterally broader representations appear to be relatively restricted in their distribution within the Hamersley subregion, and can be considered locally to sub-regionally significant.

Beyond the more extensive and significant stands of *M. argentea/Eucalypt* spp. woodland; where water availability is generally perennial; surface and groundwater availability in the remaining sections of the larger Hamersley Range fluvial systems are generally more variable. However at the smaller scale, fluvial landforms and features such as bends & corners, constricted channels and complimentary small scale geological anomalies can combine to more consistently retain surface water (or close proximity groundwater and small perched alluvial aquifers) than the majority of the general creek bed. In such cases, narrow isolated patches of OPV can be found lining large pools or occupying the low points in the bed profile.

The remainder of the phreatophytic vegetation within fluvial systems of the Hamersley Ranges are essentially represented by woodland (to open forests) of *E. camaldulensis* and/or *E. victrix* over patches of mixed low open woodland/tall open shrubland scattered throughout anabranching channels and broad, open bed zones. This vegetation community is typically one of the more common of the larger topographically confined riparian systems within the Hamersley Ranges (i.e. those dissecting range systems rather than occupying the finer soils of plains and broad alluvial valleys). The other more common and least significant community on systems such as these is represented by low open woodland (to scattered low trees) of *Eucalyptus victrix* over mixed *Acacia* spp. tall open shrublands. In the larger riparian systems, this community typically occupies the outer drier extremities, high flow channels, and elevated points within the fluvial profile with less frequent flooding and inundation.

2.5 STUDY AREA

The study area determined to be the focus of this work incorporates a 60 km stretch of the Robe River and approximately 3 km of Jimmawurrada Creek. With over two thirds of the area of interest located within the Yarraloola Pastoral Station and the remainder within Yalleen Station, the combined area of both River and Creek systems are herein referred to as the “study area”. The stretch of the Robe River represented by the study area is wholly located within the Hamersley subregion of the Pilbara Bioregion (IBRA 7.1) (DoE 2014a).

The boundaries of this study area are presented in Figure 2-1 (and previously in Figure 1-1).

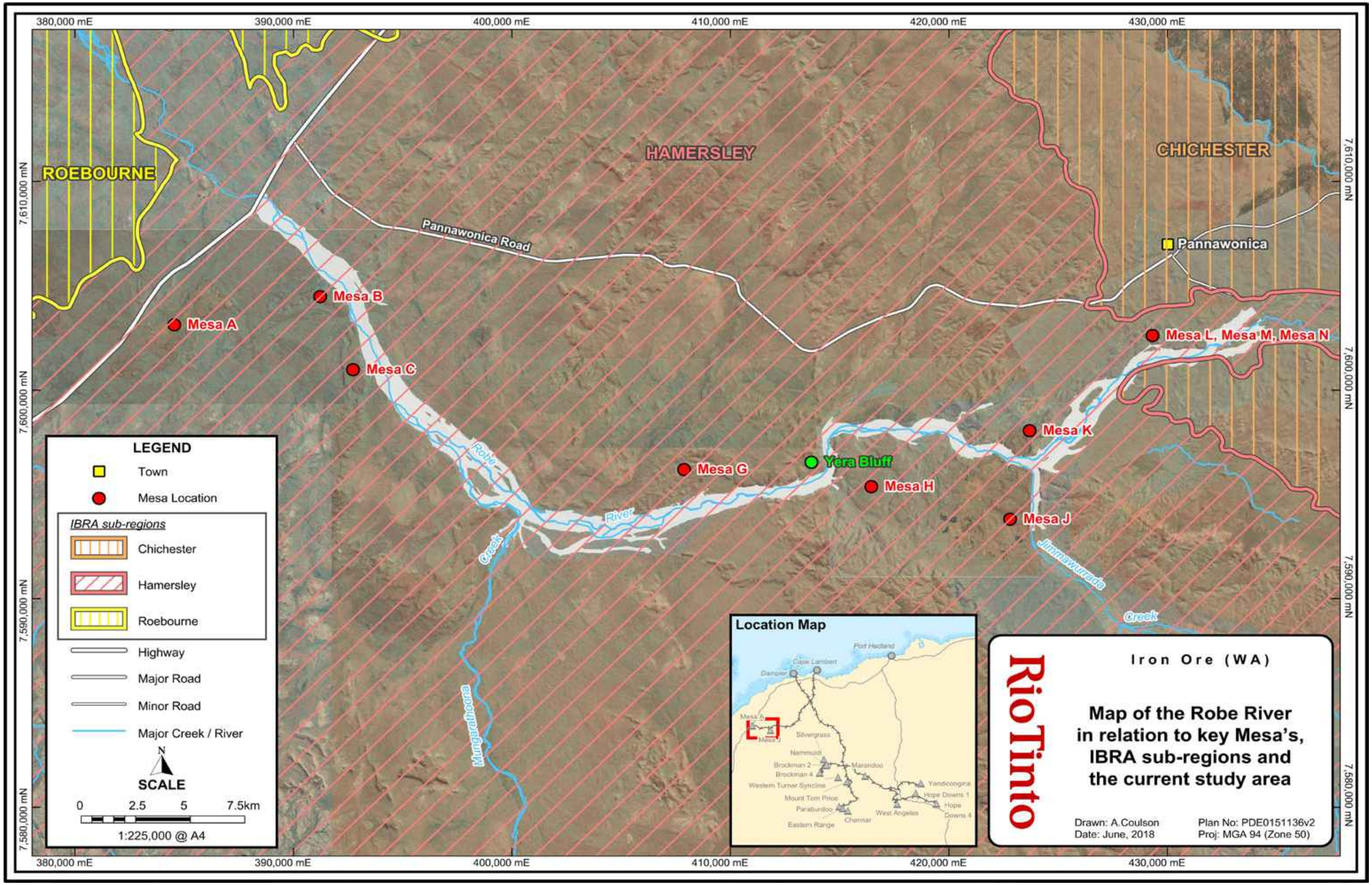

Figure 2-1: **Map of the Robe River in relation to key mesas, IBRA sub-regions and the current study area.**

2.6 THE ROBE RIVER RIPARIAN SYSTEM

The Robe River is situated in the north-west corner of the Pilbara region of Western Australia. The river itself is approximately 280 km long and has a catchment size of 3,350 km^2. The headwaters rise in the Hamersley Range near Marana Spring then flow in a north westerly direction through the Robe Valley, crossing the North West Coastal Highway near the Pannawonica turnoff then discharging into the Indian Ocean near Robe Point. The Robe River has three main tributaries; Jimmawurrada Creek & Mungarathoona Creek, both of which are partly covered by this survey; and Kumina Creek.

The Robe River is ephemeral and surface water is restricted to a series of permanent pools that act as important refugia for native fauna through the dry season. Those pools which are considered relatively permanent are described in long term monitoring work conducted by Dobbs & Davies (2009). Key pools identified in the study area are presented in the vegetation mapping within section 4.1.

The Pilbara biogeographical region is characterised by low annual rainfall (annual average 400 mm) and, when coupled with high annual evapo-transpiration rates (e.g. typically about 12 times the annual rainfall) results in restricted aquatic ecosystems. Pannawonica receives the majority of its rainfall over summer in association with cyclone events. Peaks in rainfall typically occur during January to March with months of lowest rainfall occurring in September and October.

Rainfall is highly episodic as well as highly variable and rainfall across years can be highly unpredictable with significant variation in annual rainfall. The coefficient of variation (**CV**) for the Pilbara ranges from 0.4 to 0.7 in comparison with a CV for south-west Western Australia of 0.2 and for the Kimberley of 0.3 (DoE 2004). River discharge patterns are tightly coupled to the seasonality of rainfall events. Following trends in rainfall data, maximum flows are typically recorded between January and April and low or no flow from September to December. As a result the Robe River experiences periodical flooding. The Robe River was last in full flood following Cyclone Monty in 2004. In 2009; following heavy rainfall, the river burst its banks cutting roads and railway lines.

The Robe River / Jimmawurrada Creek riverine habitat is dominated by moderately-dense to dense mixed woodlands to open forests of Cajeput (*Melaleuca argentea*), River Red Gum (*Eucalyptus camaldulensis*) and Coolibah (*Eucalyptus victrix*). The open understorey of tall shrubs is dominated by *Petalostylis labicheoides* and *Acacia trachycarpa* with scattered *Sesbania formosa* and *Gossypium robinsonii* over sedges and mixed herbs. Filamentous green algae are common in the waterways, together with emergent macrophytes, such as *Typha domingensis*, *Potamogeton* and *Vallisneria* species, and fringing rushes such as *Schoenoplectus* sp. and *Eleocharis* sp. Further from the water's edge, the narrow zone of riparian vegetation gives way to low plains of soft spinifex (*Triodia epactia*) and hard spinifex (*Triodia wiseana*) steppe with scattered gums *Eucalyptus leucophloia* (Snappy Gum) and *Corymbia hamersleyana* over-mixed *Acacia* species, *Hakea chordophylla* and *Grevillea pyramidalis* (Beard 1975a; 1975b).

Major disturbances to river bed and pool vegetation have resulted from variation in the pattern and volume of rainfall. The local topography, and resultant force of floodwaters can uproot young to semi-mature plants and other plants may die from being submerged for extended periods. Qualitative assessments of riparian vegetation have shown significant physical uprooting evident in both riparian and floodplain vegetation. These changes were a direct result of the high flows and widespread flooding associated with high flow events, particularly Tropical Cyclone Monty in early March 2004. In the Robe River, the distribution and abundance of the weed, Indian Water Fern (*Ceratopteris thalictroides*), is considered related to both patterns of river flow and unrestricted livestock access to drainage channels (Streamtec 2008).

The peak flow patterns and flow regime of the Robe River, coupled with the confining topography in the areas of relevance to this study have determined that the resultant river profile is dominated by a large and broad gravel bed flood zone flanked by rarely breached terraces or steep rocky sides. Within the broad gravel bed, a main (primary) incised low-flow channel, and one or more secondary incised channels punctuate the relatively flat gravel bed zone. In certain zones, raised finer grained sediment islands support woodlands over hummock/tussock grass communities, while the bulk of more densely vegetated communities are restricted to within and flanking the primary and secondary incised channels. In some areas secondary channels leave the main gravel bed and follow other low zones before re-joining further downstream. Terrace zones are substantially higher than the gravel bed, and are generally composed on fined grained sediments with shrublands over relatively dense hummock/tussock grasslands. A cross-sectional schematic of this typical creek profile within the study area is provided in Plate 2-1.

In initial reports (ecologia & Streamtec 1992); pools within the Robe River were considered dependant on the high rates of algal primary production to drive ecological processes. High algal growth is often observed in monitored pools and it is likely that this is a major contributor to secondary water quality issues as the vegetation decays i.e. highest levels of nutrients have been recorded in pools with increased algal growth and increased turbidity levels.

Stream discharge volumes and water levels of the Robe River are monitored by the Department of Water (**DoW**) at the Yarraloola gauging station (DoW 2017). At present, the Robe River has experienced a relatively extended dry period (with respect to flows) after a relatively long period of seasonally wet years (see Figure 2-2). Recently, water levels in the River were anecdotally reported to be the lowest they have been observed for over two decades (Mr Peter Davies, pers. comm., 28 March 2017).

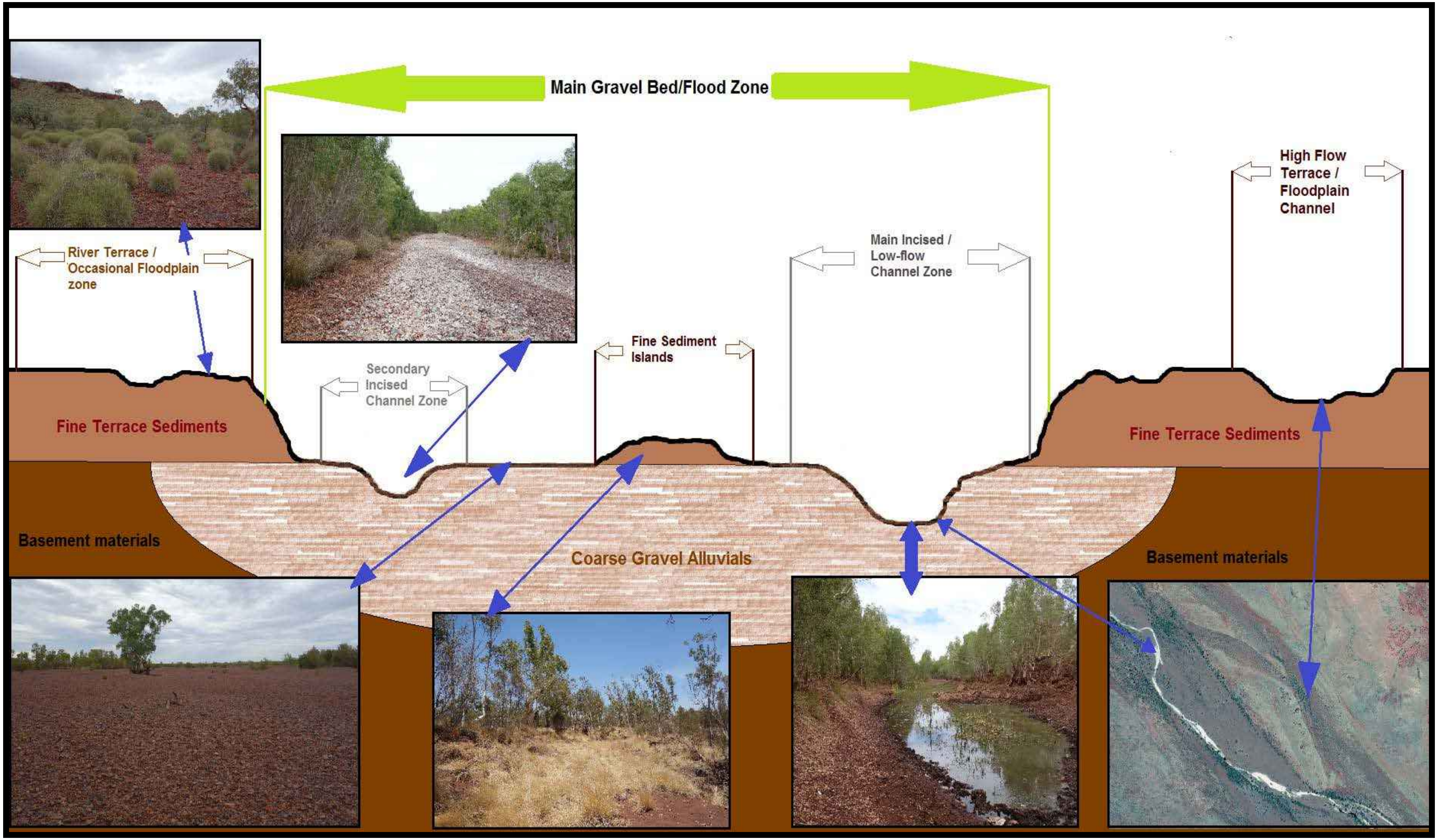

Plate 2-1: Cross-section schematic showing the typical channel profile of the Robe River within the study area, along with photos illustrating the typical appearance of key zones.

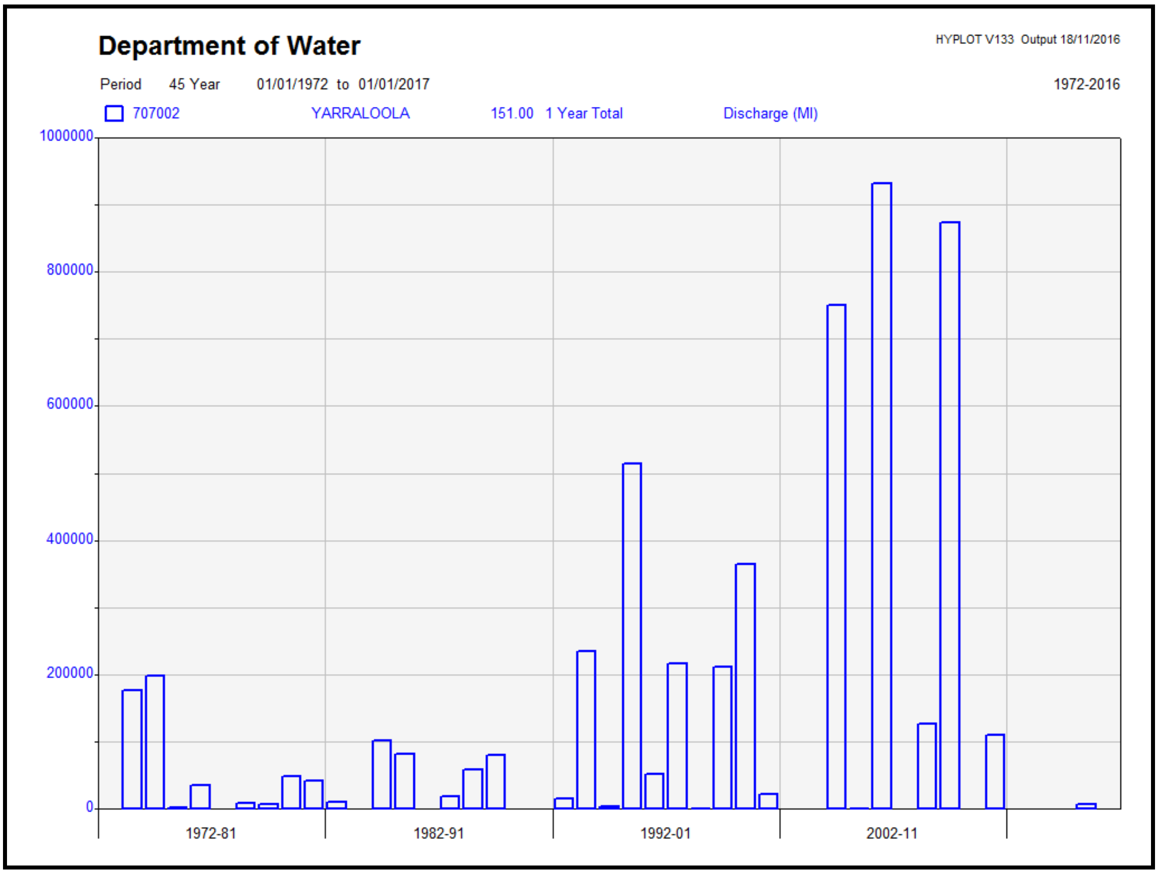

Figure 2-2: Department of Water (DoW 2016) historical river flow data from the Yarraloola gauging station on the Robe River.

2.7 JIMMAWURRADA CREEK

Jimmawurrada Creek, and the adjoining Bungaroo Creek, is part of a pair of broad, low-gradient valleys (with substantial adjoining rugged upland areas), which are prone to flooding after seasonal, tropical storms and cyclones. Cutting through the Buckland Hills and Mount Dempster areas, the creek valleys are bounded to the south, and in some parts to the north by steep scarps, mostly formed of the resistant Dales Gorge member of the Brockman Iron Formation (Rio Tinto 2011b). The Bungaroo Valley is approximately 0.5 km wide at the upstream end and 4 km wide where it confluences with Jimmawurrada Creek about 30 km downstream. The valley formed by Jimmawurrada Creek is approximately 9 km wide at the eastern end. Both valleys (particularly Bungaroo Valley) contain numerous braided, dry creek beds that are prone to flooding during the wet season (Rio Tinto 2011b).

Bungaroo Creek joins Jimmawurrada Creek in the lower part of the catchment area, to provide approximately 1600 square kilometres of total catchment area. On its own, Jimmawurrada Creek has a catchment area of about 400 square kilometres, while the catchment for Bungaroo Creek is in the order of 1200 square kilometres.

2.8 ROBE RIVER HYDROGEOLOGY

The major aquifer underlying the Robe River is contained within the gravelly alluvium which has a saturated thickness of up to 15 m adjacent to the main channel and extends laterally up to 5 km across the Robe River Valley (Antao & Braimbridge 2010). Groundwater flow through the gravels is thought to maintain permanent pools in the Robe River (Wetland Research and Management (WRM) 2016). The gravelly aquifer is underlain by fractured, permeable Trealla Limestone and highly transmissive Robe Pisolite. Robe Pisolite is a pisolitic alluvial sedimentary rock that fills the broad valley between ridges of the Brockman Iron Formation and outcrops along the Robe palaeochannel (EPA 1991). The ore deposits at in the mesas along the Robe Valley are CIDs derived from pisolite limonite within the Robe Pisolite. The CID is comprised of iron ore detritus from weathering and erosion of the Brockman and Marra Mamba Iron Formations (Morris & Ramanaidou 2007).

Groundwater flow in the Pisolite is towards the Robe River and where the Pisolite is deepest, probably contributes to base-flow within the Robe River (Aquaterra 2005). The gravel and Pisolite aquifers are recharged primarily via river discharge. Modelling by DoW indicates the aquifers have the potential to absorb a significant percentage of river flow, however, due to the unpredictable flow regime, recharge is very low in two out of every five years (Antao & Braimbridge 2010). Near the Jimmawurrada-Robe confluence, the Pisolite is very shallow and unsaturated. Stream-aquifer interaction upstream in the Bungaroo and Jimmawurrada valleys contributes to recharge along with direct rainfall infiltration (WRM 2016).

2.9 PREVIOUS SURVEYS

A significant amount of survey work has been conducted in the Robe Valley locality since mining development began in the 1980's. Table 2-3 outlines the relevant flora and vegetation surveys conducted in the area which intersects the Robe River. The most relevant and recent studies have been conducted by Astron Environmental Services Pty Ltd and Biota Environmental Sciences Pty Ltd (Table 2-3). This body of work has essentially sampled/surveyed a riparian environment which had already seen some degree of impact from pastoralism, mining and from surplus dewater discharge from mining activities at Mesa J and natural events (cyclones, flooding and fires). The survey boundaries of previous relevant flora and vegetation studies are presented in Figure 1-1 in relation to the Boundary of the current study area. A recently conducted flora and vegetation survey (MWH Australia Pty Ltd (MWH) 2016) which intersects the Robe River in the vicinity of Mesa A, does not shed any additional light on the riparian communities of the Robe, as it covers the same region of the Robe River as that covered by Biota (2011). The sampling work conducted as part of MWH's 2016 survey does however elevate the survey coverage in this area to that of a seasonal survey given that Biota only conducted one phase of sampling in 2011.

Table 2-3: Summary of relevant vegetation and flora surveys intersecting the Robe River.

Study (Reference)	Area Surveyed Within Study Area	Survey Description Survey Timing (Conditions for Plant Growth)	Available Data
Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment, September 2015 (Astron Environmental Services Pty. Ltd.) (Astron 2015) (plus an additional phase of work conducted by ecologia (2013)	11,816 ha	Two phase (Level 2 - Detailed) vegetation and flora assessment survey of the Middle Robe to East Deepdale area to expand upon previous work conducted by Biota (2006), Astron (2011), and ecologia (2013). 15 to 27 June 2015 (favourable); 21 September to 3 of October 2015 (acceptable). ecologia – single phase – July & August 2012 (Sub-Optimal conditions)	− Quadrats/relevés/mapping notes. − Conservation significant flora and weeds. − Floristic analysis − Vegetation mapping. − Vegetation condition assessment. − Species list.
Baseline Flora and Vegetation Assessment of Robe Valley Mesas (Mesas B, C, D, E, F, H and I), April 2011 (Biota Environmental Sciences) (Biota 2011) (plus an additional phase of work conducted by Astron (2014)).	9,494 ha	Single phase (level 1 – reconnaissance) vegetation and flora assessment of various mesas in the vicinity of Pannawonica. This comprised; Mesa B (980 ha), Mesa C (850 ha), Mesa D (737 ha), Mesa E (1,502 ha), Mesa F (2,626 ha), Mesa H (2,252 ha), and Mesa I (547 ha). 11 to 19 October 2011 (sub-optimal) Second phase conducted by Aston 2014 (acceptable conditions)	− Quadrats/relevés/mapping notes. − Conservation significant flora and weeds. − Vegetation mapping. − Vegetation condition assessment. − Species list.
Level 2 Flora and Vegetation Survey: Mesa B-C, Warramboo BWT, Highway to Tod Bore and Mesa A Extension, August 2016 (MWH Australia Pty. Ltd. (MWH) 2016).		Two Phase (Level 2 – Detailed) vegetation and flora assessment over a study area that incorporated four separate Project Areas; Mesa B-C, Highway to Tod Bore, Warramboo BWT and Mesa A Extension, as well as the establishment of a vegetation monitoring program and baseline assessment at Warramboo Creek. 8 to 21 June 2015 (acceptable) 2 to 8 September 2015 (sub-optimal) 3 and 8 May 2016 (sub-optimal)	− Quadrats/relevés/mapping notes. − Conservation significant flora and weeds. − Floristic analysis − Vegetation mapping. − Vegetation condition assessment. − Vegetation monitoring establishment − Species list.
A Vegetation and Flora Survey of the Proposed Mesa A Transport Corridor, Warramboo Deposit and Yarraloola Borefield, January 2006 (Biota 2005; Biota 2006)	7,878 ha	Two phase (seasonal) vegetation and flora survey of two transport corridors (haul road (500m wide) and Rail (200m wide)) from Mesa A to Mesa J, the Warramboo deposit study area (approximately 2.5 x 2.5 km in size), and a bore field on Yarraloola station with pipeline corridor to Mesa A. July 2004 (Favourable) September 2005 (Favourable)	− Quadrats/relevés/mapping notes. − Conservation significant flora and weeds. − Floristic analysis − Vegetation mapping. − Vegetation condition assessment. − Species list.

2.9.1 Resultant Vegetation Mapping

Previous vegetation mapping covering the study area has been completed at a resolution commensurate with the environmental impact assessment (**EIA**) objectives for which it was commissioned. Generally, flora and vegetation surveys conducted for the purpose of EIAs are commissioned with the aim of sampling and documenting all the values present. As a result sampling effort is spread widely and the level of detail attained is typically proportionate to the size of the area, number of landforms present, and the extent of areas of elevated ecological value.

The "Middle Robe" flora and vegetation survey conducted by Astron (2015) represents the most detailed and extensive of the vegetation models available on the Robe River. This mapping provides an important platform for the current study; however the objectives of the current study determined that mapping with much greater spatial confidence and at a finer resolution was required. Improving the spatial confidence and detail of riparian vegetation mapping would help increase knowledge in the riparian zone and increase the understanding of the local environmental values (and their distribution), and hence increase the effectiveness of environmental management. The key point of difference between the current study and previous vegetation studies is the consideration of age structures within OPV, the resultant degree of differentiation proposed within these communities and the focus on accurately mapping the distribution of the higher sensitivity OPV and Facultative Phreatophytic Vegetation (**FPV**) communities.

3 METHODOLOGY

3.1 VEGETATION MAPPING WITH A FOCUS ON GDE CHARACTERISTICS AND DISTRIBUTION

3.1.1 Introduction

To achieve the vegetation mapping aims of this study; a "Targeted Survey" was conducted as defined under the EPA Technical Guidance; Flora and Vegetation Surveys for Environmental Impact Assessment (EPA 2016b). The vegetation mapping conducted as part of this study focused on gathering high confidence and relatively detailed information on the distribution and characteristics of GDEs within the Robe River. This was achieved by primarily focusing on gathering information about the maturity and distribution of OPV. A secondary data focus was placed on gathering information on the distribution of FPV; particularly the distribution patterns exhibited by *Eucalyptus camaldulensis* (River Red Gums). The primary focus on OPV is motivated by the fact that this vegetation represents that possessing the highest degree of sensitivity to surface and groundwater hydrological changes potentially associated with mining.

As the most hydrologically sensitive Pilbara communities are typically those with a significant component of *Melaleuca argentea*; an initial review was undertaken to identify desktop tools and resources suitable for helping identify the likely distribution of OPV communities. A field plan capable of ground-truthing the predicted and potential spatial distribution markers for OPV and FPV communities in the study area was developed following completion of the desktop mapping process. This field plan was also developed with the aim of compiling additional fine scale information about the spatial distribution and composition of other less sensitive/significant vegetation communities (FPV) within the study area, for the purpose of supplementing the vegetation mapping process.

The desktop resources and mapping, together with the field plan allow for the acquisition of a relatively comprehensive dataset on the spatial distribution (mapping) of key riparian vegetation communities throughout the study area. This desktop and field-based assessment is also designed in a way which collects information which provides a framework for contextualising and assessing the potential for hydrological changes to impact riparian communities in the study area.

It should be noted that the vegetation mapping process and the resultant field survey effort attributed to the study area was conducted on riparian units occurring within the major riparian habitats of the study area. As part of this process, a high degree of survey effort was afforded to the riparian units in the main incised channel zone (low flow channels) of the river compared to the outer fringing communities and the river terrace and outer floodplain communities (see plate 2-1 for a schematic of the key river profile features of the Robe River).

In an effort to maintain the logic and intent of coding attributed to recent GDE mapping conducted by the author, the same coding regime as Rio Tinto (2015) was attributed to vegetation types identified in this study.

With respect to data collection methods; this survey noted the adequate amount of Quadrat/Relevé based data collection which has previously been conducted within various parts of the study area. This survey also noted that mapping traverses had previously been used to a lesser extent than quadrat/relevé based techniques in the riparian zone of the study area. Coupled with the GDE focus of the study; it was concluded that the degree of information on the associated floristic composition of riparian communities already captured within the Robe Valley area was sufficient to meet the objectives of this study. Mapping traverses were, therefore, considered to be the most effective method for targeted vegetation mapping in this study. Mapping traverses, generally comprise walking through the target area and regularly taking notes and spatial information on the apparent vegetation associations/sub-associations present, and the location and pattern of boundaries which separate them (see Section 3.1.3). By aligning these traverses to maximise their potential to regularly test the spatial position of these vegetation boundaries, the resultant traverse pattern quickly establishes an effective and extensive database with which to correlate on ground vegetation distribution with vegetation signatures present within aerial photography. The use of mapping traverses oriented to repeatedly intersect and establish the location of vegetation boundaries allows for the development of robust (high confidence) fine scale vegetation mapping in the areas investigated.

It should be noted that vegetation mapping is essentially a model, such that the spatial validity of boundaries and the vegetation associations depicted to lie within those boundaries, is only true a portion of the time. In general, the proportion of time which the model is correct is directly correlated to the amount of ground-truthing which is done per unit area of the model, and the scale of the community descriptions created. The third influencing factor is generally considered to be the complexity of environmental factors influencing vegetation ecology, but for the surveyor this is an uncontrolled factor and is therefore not generally considered in detail.

For the vegetation mapping model presented as a part of this study; a key aim was to provide a high degree of accuracy in relation to the spatial location and distribution of resident OPV communities. As a result the degree of ground-truthing effort conducted within the core riparian zone (particularly the incised channel zone) was very high, such that the mapping is considered to be significantly more accurate than typical quadrat/relevé dominated sampling methodology and subsequent vegetation mapping undertaken in typical flora and vegetation surveys within WA.

3.1.2 Tools developed at a desktop level for increasing the effectiveness of in field mapping traverses

Photosynthesising vegetation covering the Robe River was assessed using Normalised Difference Vegetation Index (**NDVI**) images generated from high resolution (0.5 m pixel) remotely sensed digital multispectral imagery (**DMSI**). NDVI relies on the fact that photosynthetic organisms have the unique characteristic of reflecting nearly all infra-red electromagnetic radiation, and absorbing significant amounts of the red visible wavelength of electromagnetic radiation (used for photosynthesis) (Specterra Services 2010). As a result, an index calculating the ratio between the intensity of the two wavelength ranges provides a simple measure of vegetation cover/density or greenness. NDVI imagery of the relevant river stretches were visually assessed by a specialist botanist for patterns in and occurrences of high-density vegetation signatures (i.e. areas where a comparatively high degree of vegetation cover was evident in comparison to surrounding riparian vegetation cover signatures) likely to indicate the presence of mesic conditions, and therefore potential GDEs. GDEs such as OPV are recognised to be associated with a high degree of water availability and often groundwater presence. This persistent presence of moisture generally facilitates the establishment of relatively dense combined vegetation cover (i.e. canopy cover, combining with shrub and groundcover strata to provide aerially dense cover signatures) when compared to surrounding, more widespread riparian vegetation. Areas of the riparian system showing comparatively higher measures of vegetation cover are often the areas where groundwater is close enough to the surface to provide adequately consistent soil moisture availability and conditions suitable for the establishment of species such as *M. argentea*. Plate 3-1 presents an example of a high density NDVI signature and one example of a sparse NDVI signature. At a desktop level, anomalously high vegetation cover signatures were identified and mapped throughout the study area, and used in conjunction with NDVI maps for the purpose of guiding field based ground-truthing of mesic vegetation signatures. Plate 3-2 presents an example of the summarised NDVI imagery (for the stretch from Yeera Bluff to the confluence with Jimmawurrada Creek) produced over the study area which was used as a supporting tool for the GDE interpretation and ground-truthing process.

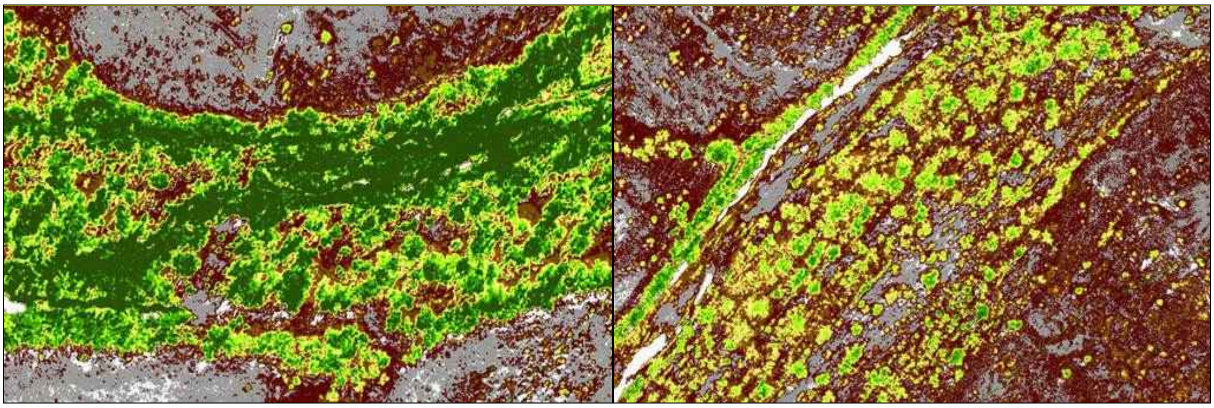

Plate 3-1: Samples of NDVI image showing a high density NDVI (vegetation cover) signature on the left and a sparse cover NDVI signature on the right

Historical aerial photography and true colour DMSI was also visually assessed to identify and digitally map areas of anomalously dense vegetation and consistently formed canopy cover which might identify the spatial location of OPV or more mesic FPV. As part of this process; an alternative set of digital polygons were produced which represented the pure shrubland communities, and separately all the open woodland and above treed riparian communities.

Polygons digitised from both NDVI images, DMSI and historical aerial photography were uploaded to a GPS, along with other relevant environmental layers such a 50k hydrology and historical vegetation mapping.

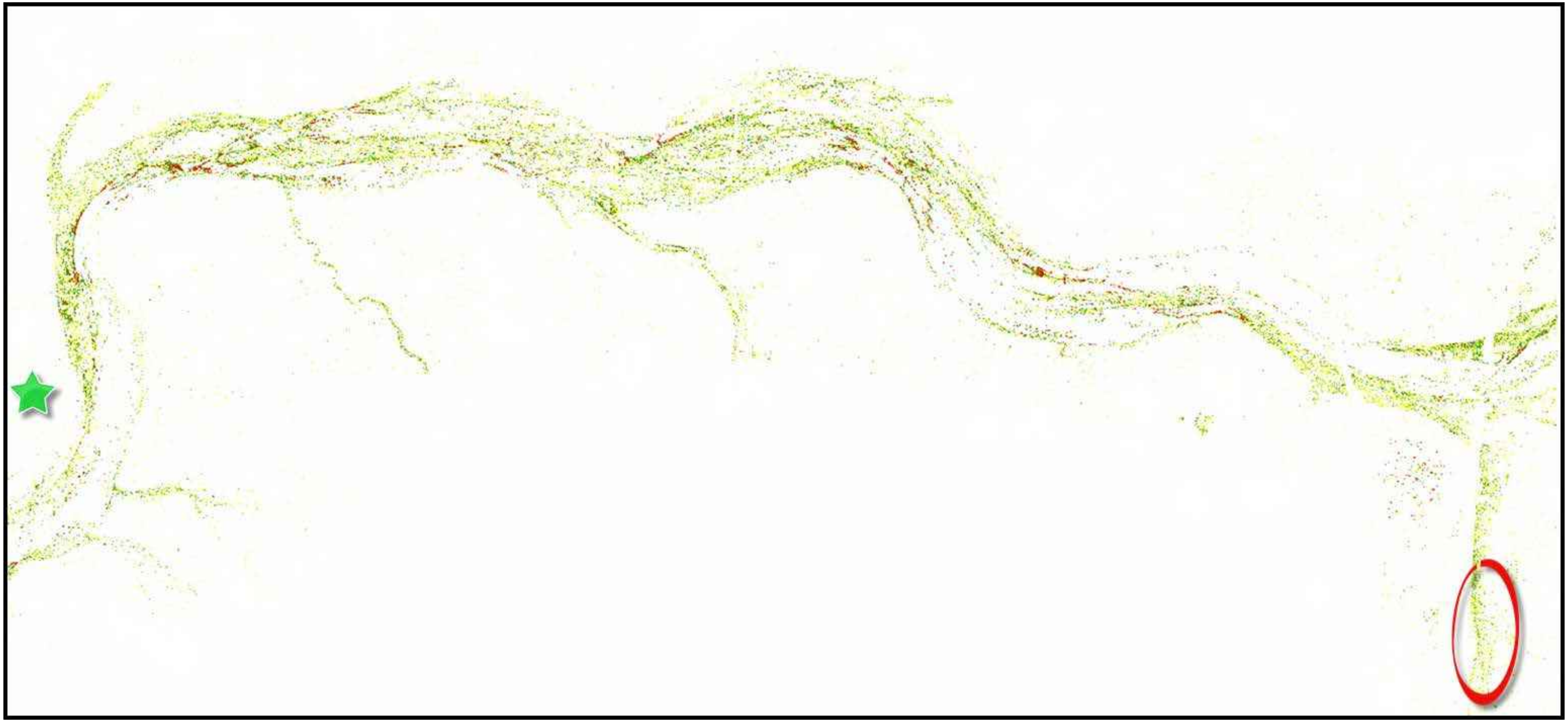

Plate 3-2: Example of the summarised NDVI imagery produced as a ground truthing tool for use when surveying the Robe River (between Yeera Bluff (position indicated by green star) and Jimmawurrada Creek (identified by red circle))

3.1.3 Ground-truthing and Mapping Refinement Field Work

A field data collection framework was devised to focus on the following key tasks within the Robe River study area:

- Traverse the entire width of the gravel bed and incised channel profile (while periodically intersecting the inner portion of the adjacent terrace features) and key high-flow channels to gain an understanding of the ecology and distribution of significant riparian communities present within their boundaries. In addition; gaining an overarching awareness of the variability, morphology and spatial distribution of the different creek profiles and associated substrates present throughout;
- Ground-truthing of all relevant identified dense vegetation signatures and anomalous NDVI signatures to confirm the presence/absence of phreatophytic species (namely *Melaleuca argentea*, and to a lesser extent useful GDE indicator species such as *Eucalyptus camaldulensis, Acacia ampliceps, Sesbania formosa*, Cyperaceae spp., etc.) and associated communities, and
- Record specific data about the spatial boundaries/distribution of OPV, and the size and age structure (and spatial boundaries) of *Melaleuca argentea* populations encountered throughout.

Within the relevant section of the Robe River; the incised channel width is variable but generally observed to be in the order of 300 to 1,000 m wide, and likely inundated by 3-5 year ARI (Average Recurrence Interval) stream flow events. Due to the surrounding topography of the relevant stretch of the Robe River, the surrounding terrace/floodplain zone is relatively narrow for the most part due to the wide gravel bed zone effectively incorporating a significant proportion of the river floodplain.

It was anticipated that these key tasks would be carried out by directing field traverses and associated survey effort in a way which ultimately was a guided by the interaction of four key drivers to traverse pattern:

1. Firstly; it was determined that typical vegetation distribution patterns were likely to be aligned in a linear fashion parallel to the direction of primary/secondary and minor flow channels. A traverse pattern which intersected perpendicular to these perceived boundaries was deemed most effective at ground-truthing digitised vegetation polygons and collecting the most representative spatial dataset for the fine scale extrapolation of vegetation boundaries. Therefore a zig-zag style traverse pattern was determined the best technique to use when traversing the creek.
2. The second process was the use of the NDVI image and desktop NDVI, DMSI and aerial photo signature mapping to influence the surveyor’s fine scale travers pattern decisions. Essentially this relates to the process of aiming successive zig-zag traverses across the creek in a manner which will intersect digitised vegetation patches of most relevance to mapping GDE presence. This process of successive aiming is primarily driven by the use of the desktop mapping tools previously described or by visual cues described below in point 3.
3. The density, height and distribution of the vegetation present would determine that not every part of the creek could be viewed and assessed for the presence of OPV. To reduce the chance of missing such communities the direction and path of successive meanders would also be influenced by the visual cues to these communities which were gathered each time the surveyor moved through sections of the creek which allowed clear view of vegetation over longer distances.
4. The final driver to traverse pattern was the observed patterns in the morphology and variability of the creek profile. Such patterns and characteristics significantly influence the associated distribution patterns of phreatophytic vegetation, and can therefore be interpreted in field to predict the ongoing distribution of such vegetation. In certain river sections;

interpretation of these morphological patterns (in concert with desktop mapping) gave additional confidence that certain zones of the creek were devoid of OPV, thus allowing much smaller wavelength zig-zag traverse patterns to be employed. This in turn meant that lateral traverse distances were typically much smaller allowing a much greater degree of focus on the most relevant river bed zones.

The resultant traverse pattern and data capture array realised in the field is presented in Figures 3-1 to 3-8 as track logs and data points recorded via GPS. Throughout this traverse pattern; the following types of data were recorded at the resultant array of waypoints recorded within the study area.

- "Structurally Present" or "Structurally Absent" *Melaleuca argentea* populations – "Structurally Present" equating to a cover/abundance considered as comprising a dominant/co-dominant structural component of the stratum which it occupies, and not generally representing a cover/abundance below 1-2 %. "Structurally Absent" represents either not detected within the vicinity of the record whatsoever or only present as an associated species. For the purpose of this work, and more generally; associated species are defined as those species not comprising a dominant structural component of vegetation and typically not representing a cover/abundance above 1-2 %.
- The presence of *M. argentea* if only present as an associated species. In these cases records were generally prefixed with an "N" cover/abundance so that its cumulative distribution could be considered spatially.
- The intersected boundary locations of riparian communities where *M. argentea* populations are deemed "Structurally Present" (i.e. OPV).
- The cover/abundance *M. argentea* populations recorded as a "Structurally Present" (i.e. representing a dominant/co-dominant member of the vegetation).
- The position (and where able to be easily conveyed; the dimensions) of any sizeable "patches", "strips", or "thin strips" of riparian vegetation where *M. argentea* was considered "Structurally Present". In most cases, where appropriate, the close alignment/association of such "patches" with bodies of water or clear channels was noted in the data recorded.
- The size class (as a proxy of age) range of any recorded *M. argentea* populations and any spatial boundary points which are relevant to the recorded size-class range – In all cases the recordings were for the population either in the vicinity of the recorder ("internal" record) or throughout the area delineated by the relevant recorded spatial boundary points ("boundary" record). These size classes were inferred based on a visual assessment of the average trunk diameter, or the average range of trunk diameters present throughout the relevant population in sight. The size class/range determined at data points was allocated to populations via the use of terms which represented the various size classes used. In many cases (where appropriate – i.e. the size structure showed minimal variability) an average size class was recorded (such as Young), and in other areas where size structure was more variable a range was given (i.e. Young to Semi-Mature-minus). The size class terms used were:
  - 'Mature' (M);
  - 'Semi Mature Plus' (SM+);
  - 'Semi Mature' (SM);
  - 'Semi Mature Minus' (SM-);
  - and 'Young' (Y).

  The definition of each of these size classes and the representative terms used in the field are presented in Table 3-1.

- Mapping notes – general notes on vegetation or mesic species present at point locations. This often involved assigning vegetation to pre-determined associations/sub-associations or previously identified and mapped riparian communities/units.
- Photo points – points where multiple photographs (minimum 4) were taken of the vegetation surrounding the record. These were used to gather a quick database of vegetation information across the study area. This data is particularly relevant in areas of more benign (from a GDE perspective) vegetation where detailed information was not required, but for which high resolution photos help to significantly increase the accuracy of the entire vegetation model produced.

The above data collection framework was used to collect data in the field over two field trips conducted by Rio Tinto Botanist Jeremy Naaykens and with the assistance of RTIO Environment staff Hanouska Bishop and Caitlin O'Neil. The first field trip focused on the downstream half of the study area and was conducted from the 18th to the 23rd of December 2016. The second field trip focussed on the upstream section and was conducted from the 14th to the 20th of January 2017.

Table 3-1: Definitions for the stem size classes used to classify the average trunk diameter (or range of trunk diameters) of *Meleleuca argentea* populations encountered in the field, and allocate these populations to a perceived age class (or age class range) and an infered degree of permanency.

Stem Size classes (as a proxy for age)	***Melaleuca argentea* individuals/populations which were visually estimated to possess:**	**Vegetation which was generally dominated by individuals/populations of this size (but not larger) were generally inferred to :**
M - Mature trees	Trunk diameter(s) at knee to waist height in the **Range of 50cm and above**	Represent areas where bed and subsurface conditions are likely to have consistently supported *M. argentea* communities for a relatively long period of time within the relevant section of river bed. For this reason, their presence in this location was considered to be stable and therefore of higher significance when considering potential for impact.
SM(+) - Semi Mature plus	Trunk diameter(s) at knee to waist height in the **Range of 30-45cm**	Represent areas where bed and subsurface conditions have somewhat consistently supported *M. argentea* communities within the relevant section of river bed. However, in such areas, conditions may have only become suitable for *M. argentea* to proliferate in the last 10 years or more.
SM - Semi Mature	Trunk diameter(s) at knee to waist height in the **Range of 20-30cm**	Represent areas where bed and subsurface conditions are either only moderately variable or have more recently become suitable to support *M. argentea* communities within the relevant section of river bed. Communities dominated by this size class are often fringing secondary channels within the main river bed and appear to be more influenced by surface water regimes than increasingly mature *M. argentea* communities.
SM(-) - Semi Mature minus	Trunk diameter(s) at knee to waist height in the **Range of 10-20cm**	Represent areas where bed and subsurface conditions are likely to either be quite variable, or have changed in recent to very recent times, such that *M. argentea* populations are now supported. Communities possessing a dominance of *M. argentea* individuals in this size class are most likely to represent areas which are currently only able to support more transient populations of this species.
Y - Young	Trunk diameter(s) at knee to waist height in the **Range of less than 10cm**	Represent areas where bed and subsurface conditions are likely to either be too variable, or have changed in very recent times, such that *M. argentea* populations are now supported. Communities possessing a dominance of *M. argentea* individuals in this size class are most likely to represent areas which are currently only able to support more transient populations of this species. For this reason the significance attributed to their presence (when considering potential for impact) is heavily reduced due to their likelihood of being absent more often than not.

Note: *M. argentea* populations were allocated to size classes in the field based on visual estimates of trunk diameter and as such there is some potential for inaccuracy. In all cases the recordings were a range estimate for the entire population in view of the recorder. In many cases (where appropriate – i.e. the size structure showed minimal variability) an average size class was recorded (such as Young), and in other areas where the size structure was more variable a range was given (i.e. Young **to** Semi-Mature-minus). Diameter estimates are based on the diameter at knee to waist height of the observer, as the branching habit of individuals in the younger size classes make it impractical to estimate diameter at breast height – a more commonly used standard for tree diameter measurements.

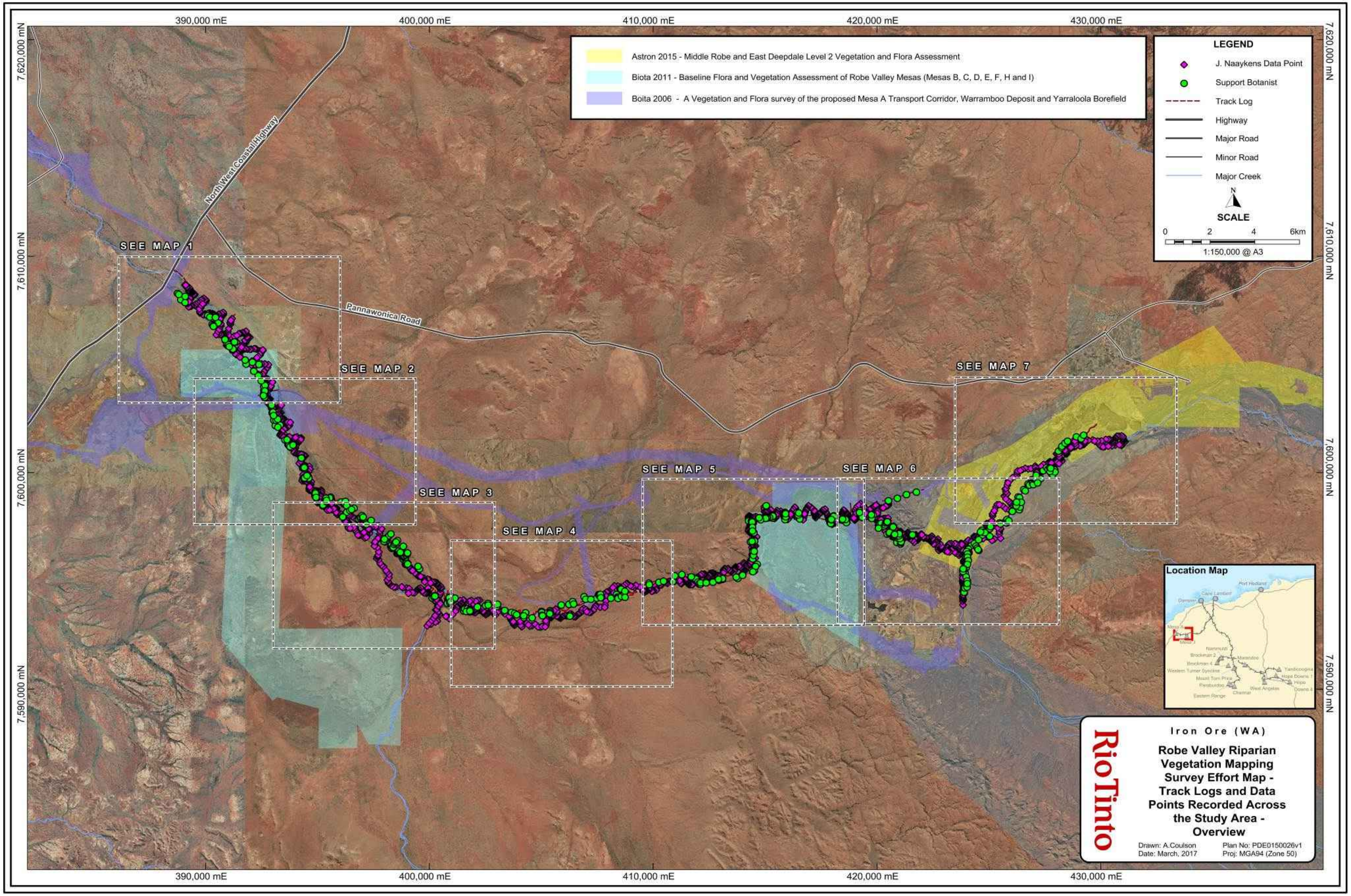

Figure 3-1: Overview of survey effort maps 1 to 7. Maps 1 -7 depict the survey effort conducted within the study area by showing the track logs and data points collected throughout using a GPS. This map also shows the most relevant previous riparian vegetation mapping surveys conducted across the study area.

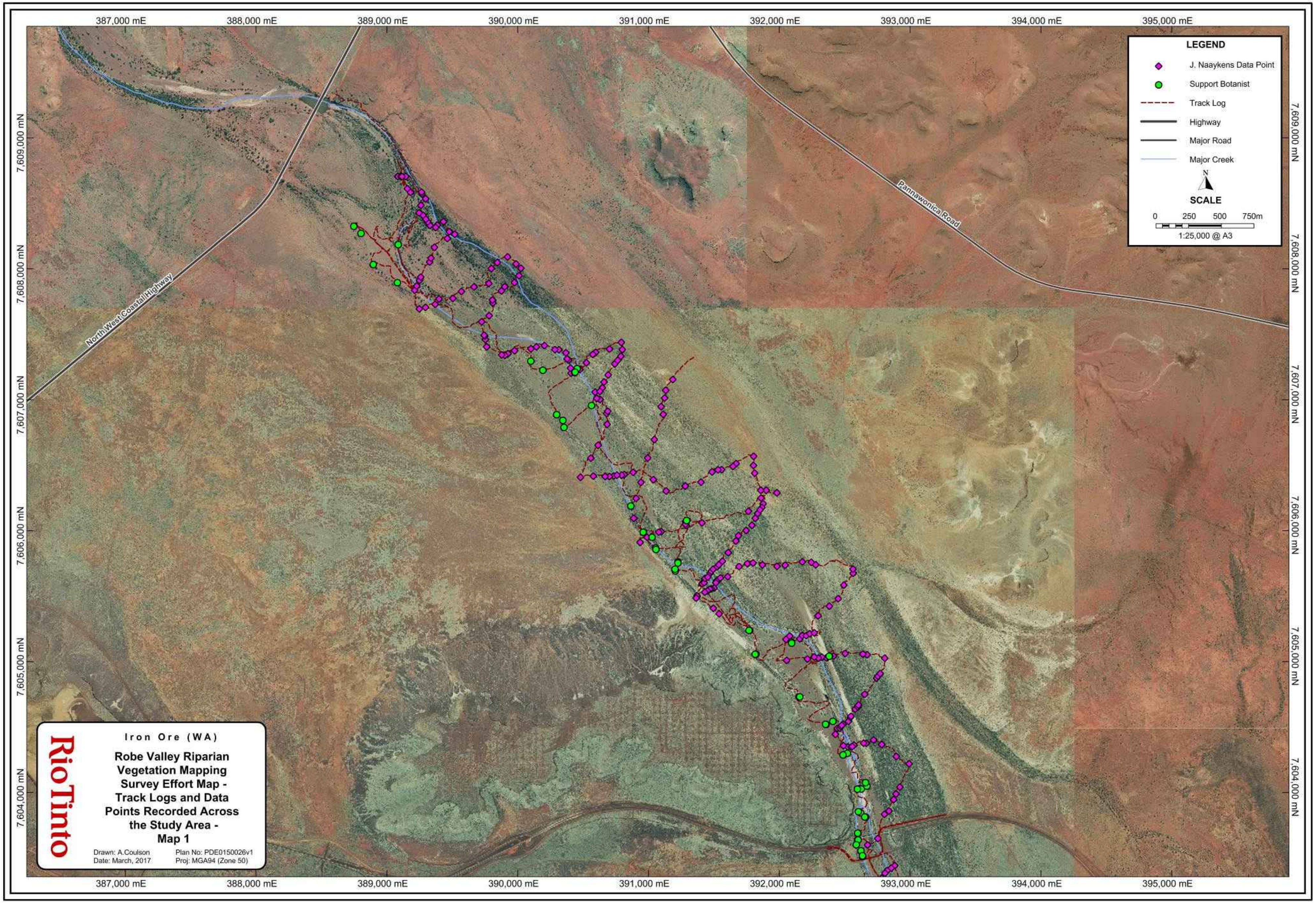

Figure 3-2: Survey effort Map 1 of 7

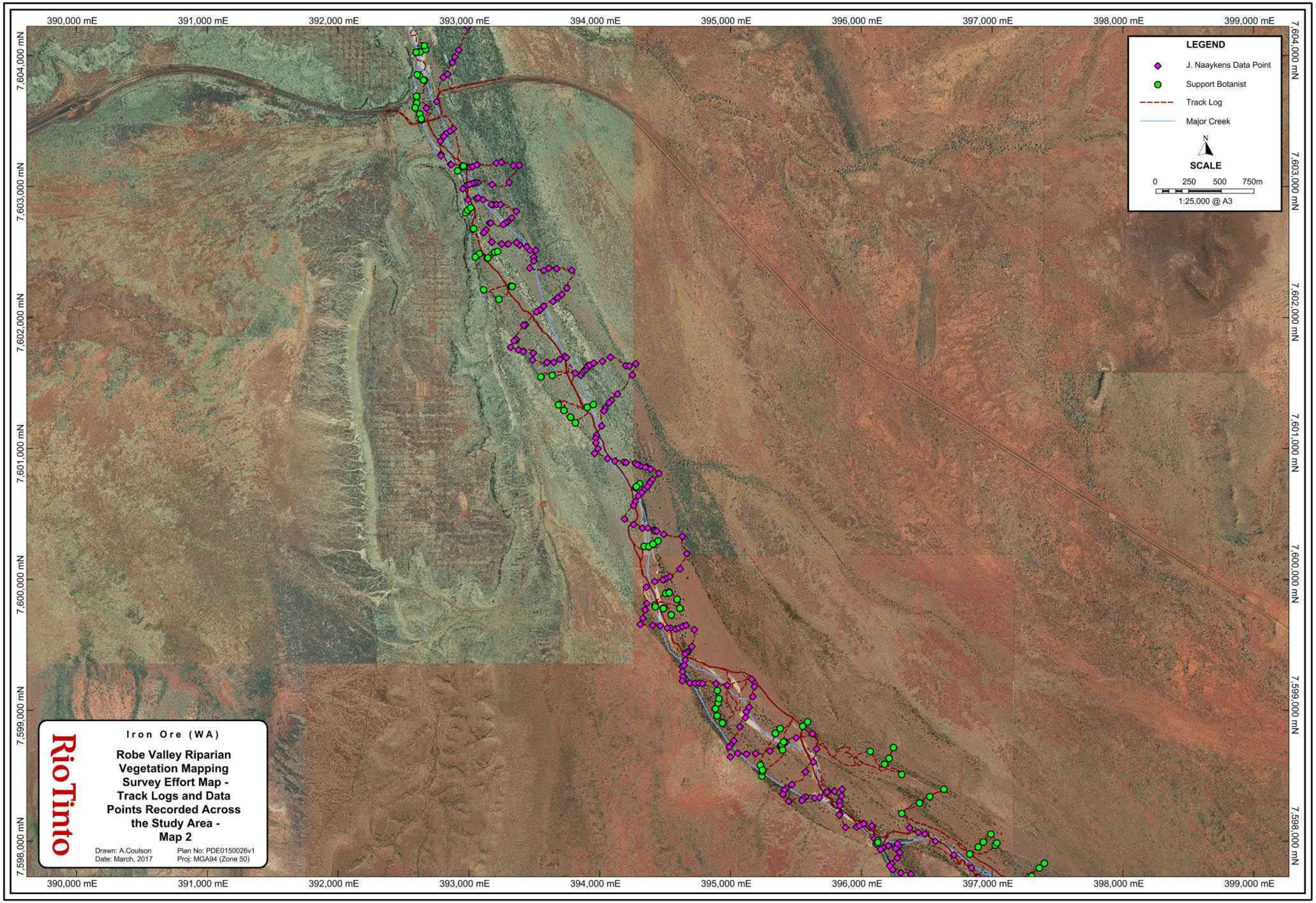

Figure 3-3: Survey effort Map 2 of 7

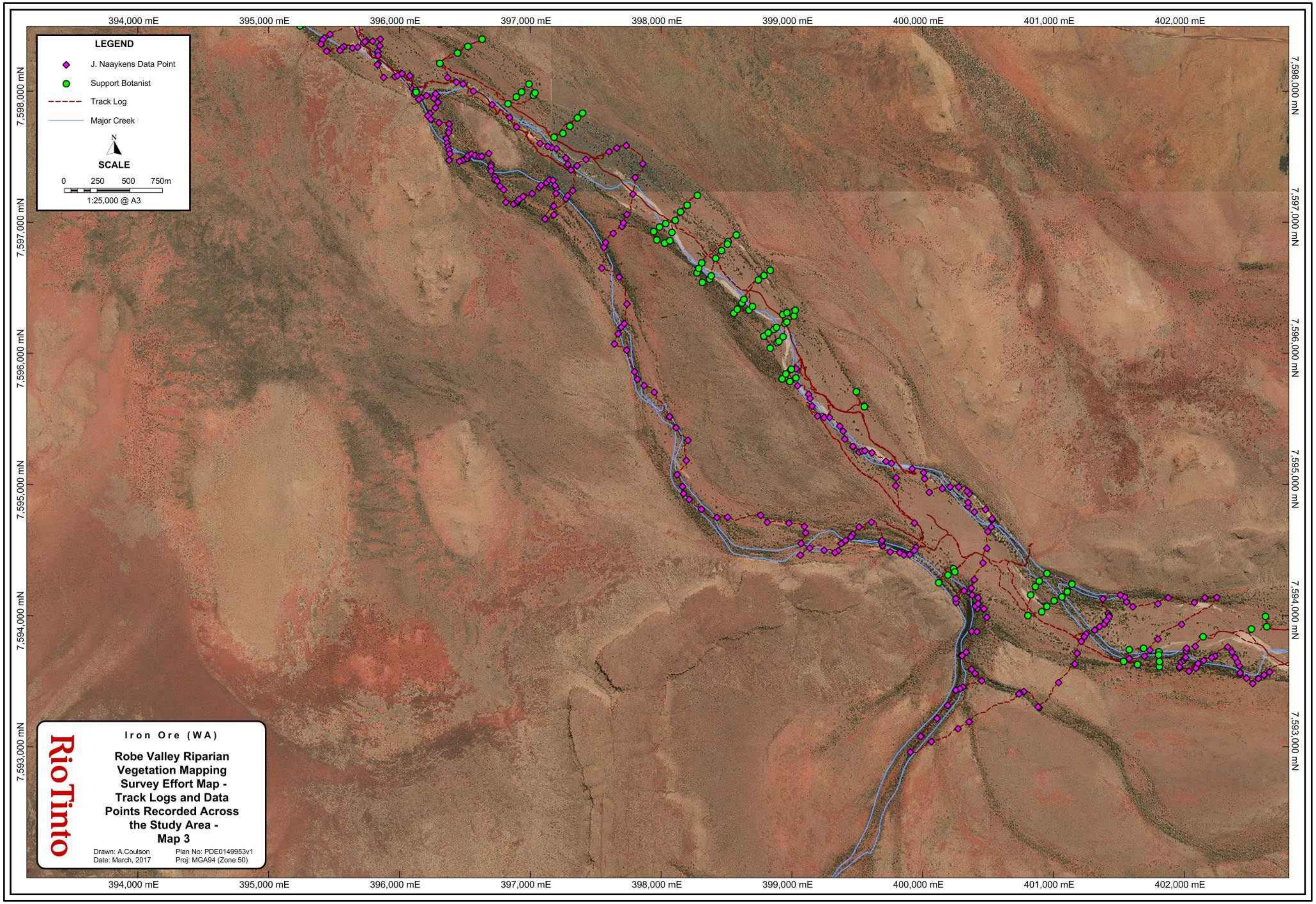

Figure 3-4: Survey effort map 3 of 7

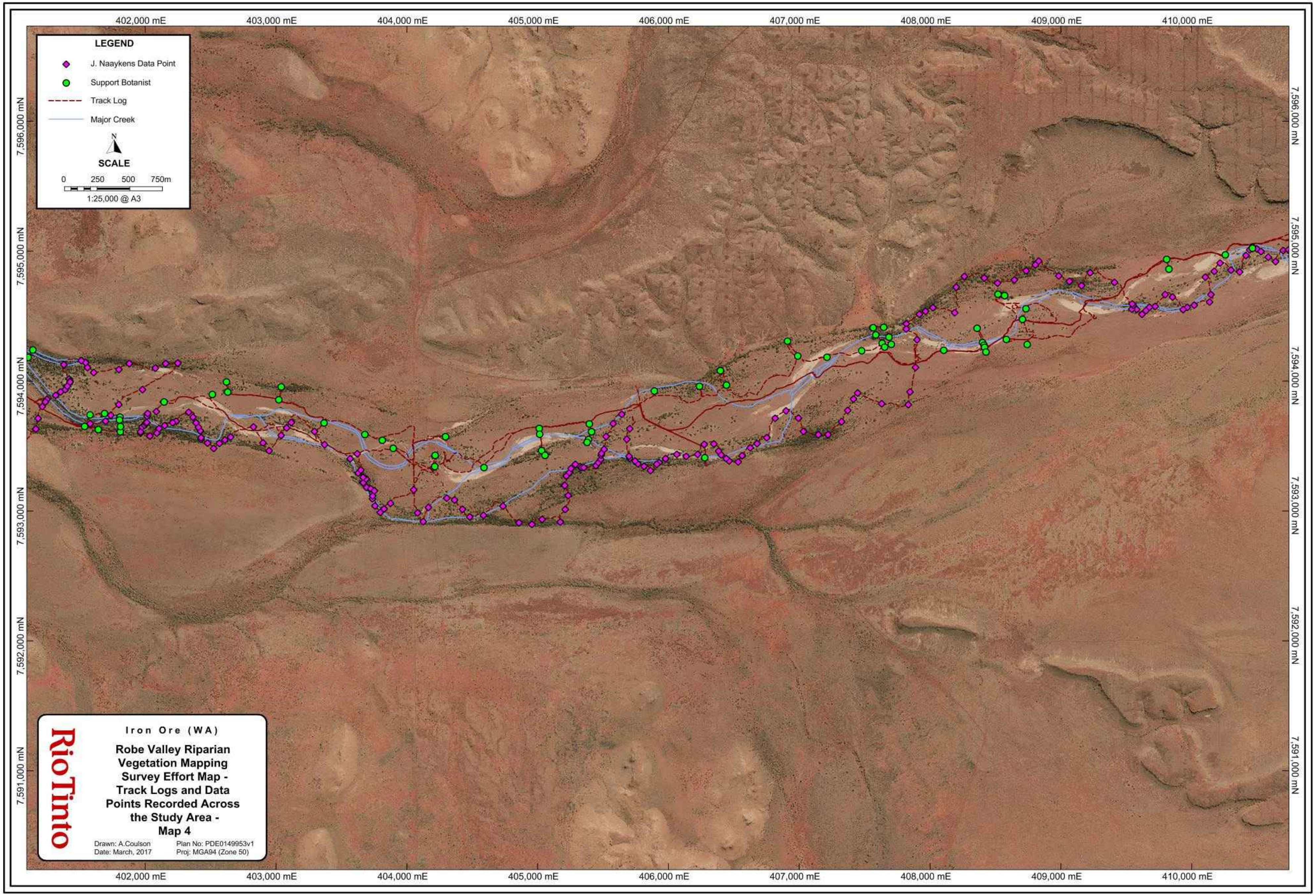

Figure 3-5: Survey effort Map 4 of 7

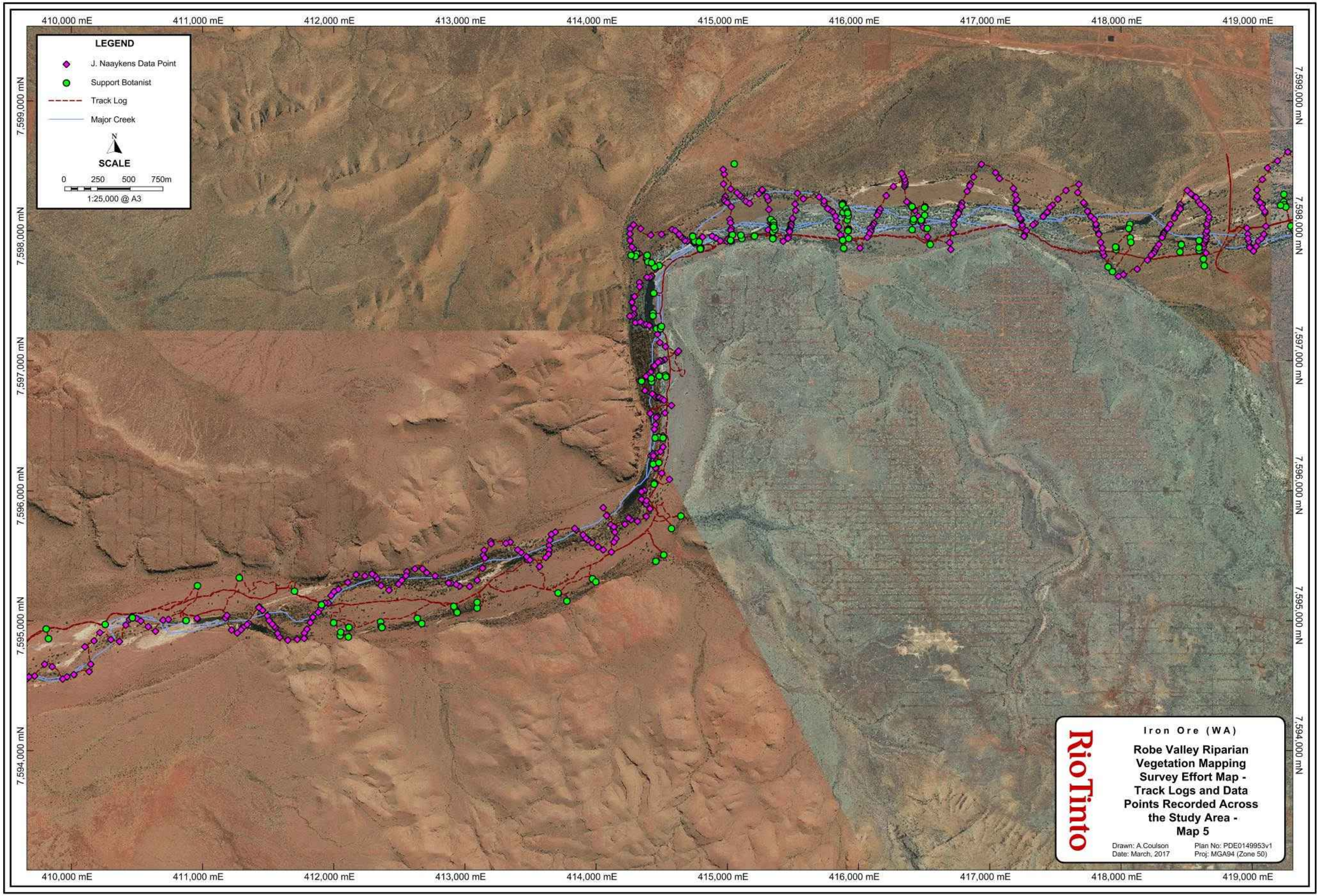

Figure 3-6: Survey effort Map 5 of 7

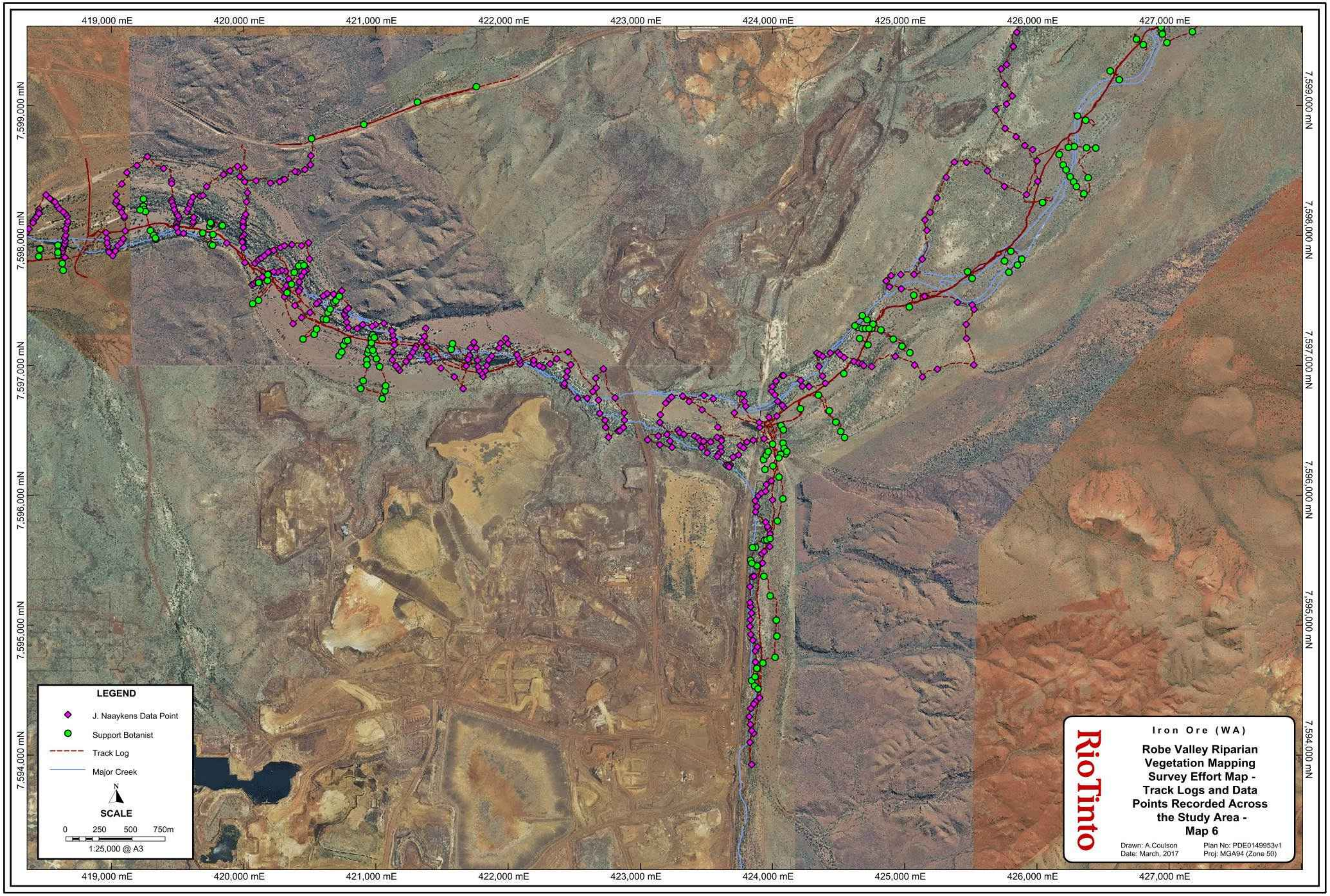

Figure 3-7: Survey effort Map 6 of 7

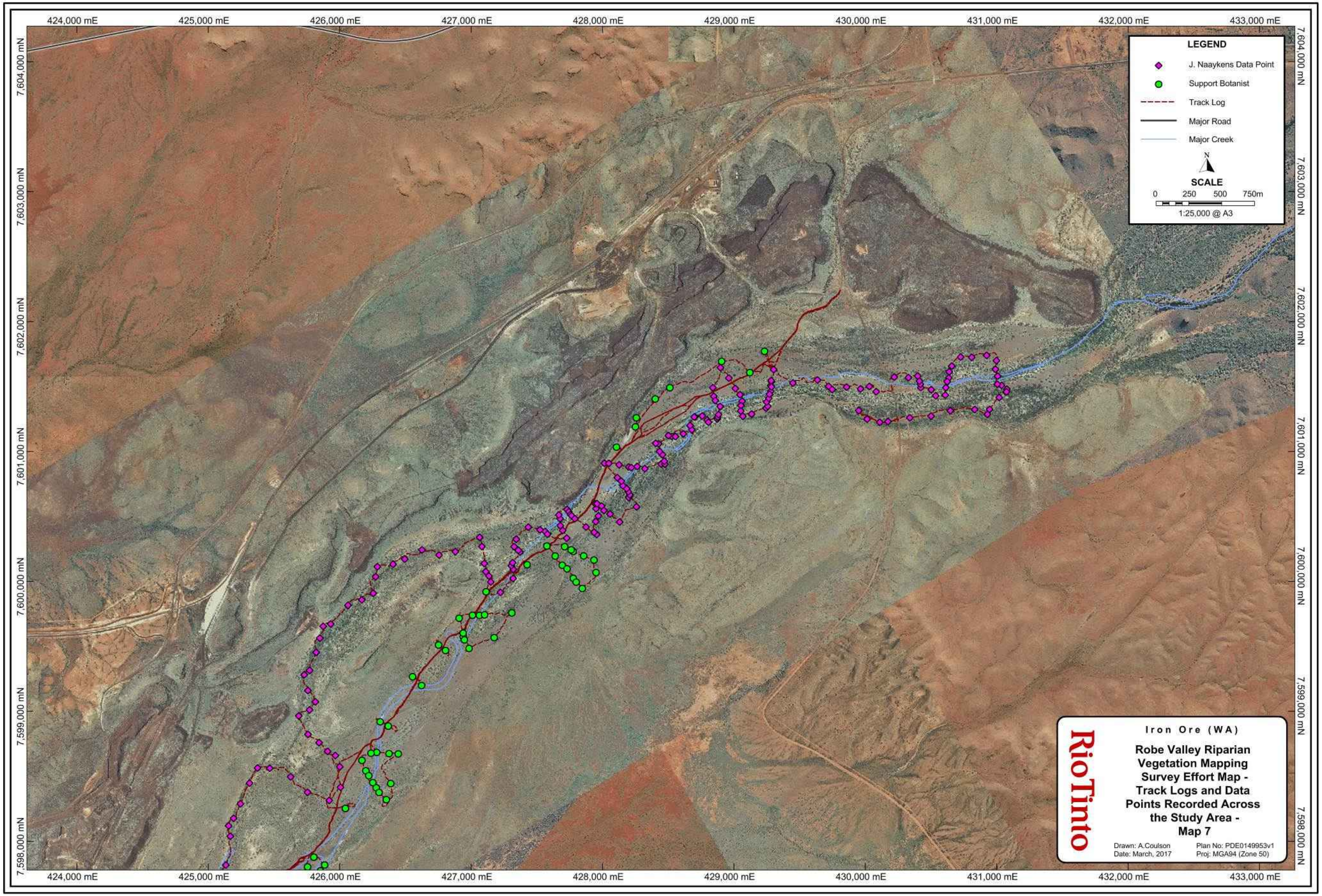

Figure 3-8: Survey effort Map 7 of 7

3.1.4 Post Field Work Vegetation Mapping

Classification and mapping of OPV communities across the study area

Following field acquisition, data was entered within Microsoft Excel and uploaded to a GIS (Mapinfo Pro, Encom Discovery 2011). This GIS data was initially analysed to gain a broad scale understanding of the distribution of OPV within the study area. Once general distribution patterns were established and considered in relation to the location of different river reaches, adjacent topographical features and broad patterns of river morphology, all data relating to OPV were used to identify and classify 6 different OPV community types across the study area;

1. a “Mature” *Melaleuca argentea* (**MA**) dominated closed forest.
2. a “Mature” MA dominated open forest.
3. a variable “Mature” (to “Semi-mature”) woodland co-dominated by MA and *E. camaldulensis*
4. a variable “Young” to “Semi-mature” low woodland (to tall shrubland) of MA and *Eucalyptus* pp.
5. a “Young” shrubland (to open shrubland) of MA *and E. camaldulensis* saplings
6. a “Young” (to “Semi-mature”) low open forest of *MA* (low trees to saplings).

These six communities were split on their structural and compositional characteristics and by their degree of “Maturity” (inferred from recorded size class ranges). Therefore; the inferred degree of structural/compositional stability and inherent significance is able to be reasonably attributed to each. Using the complete OPV dataset and commonly accepted data point correlation and extrapolation techniques, the spatial boundaries of all OPV communities encountered in the study were mapped at a fine scale. Correlation and extrapolation techniques generally involve the correlation of vegetation data with aerial photo signatures and the subsequent extrapolation of that data across the extent of the relevant aerial signature. These polygons were mapped to represent areas where the cover/abundance of *M. argentea* was deemed to comprise a significant component of the resident community’s structure and therefore represent a co-dominant/dominant structural component as opposed to merely an associated species.

Factors used in the process of allocating various patches of OPV encountered in the field to one of the six OPV communities included the following.

1. the variability/range of the inferred age structure recorded (inferred based on trunk size classes) within a mapped vegetation patch.
2. the maximum inferred *M. argentea* size for each representative vegetation patch.
3. the general structure and composition (particularly the presence absence of key mesic indicator species) of the vegetation within which the *M. argentea* populations occurred.
4. the distribution of each community in relation to key morphological features of the river (e.g. fringing pools, fringing scoured channels, outer banks, high flow channels etc.).

Once all occurrences of these OPV communities were mapped; for the purpose of presentation within this study, certain communities were amalgamated to produce a simpler complete vegetation model. Of the 6 community types from the preceding list; the 6th was combined with the 3rd type, and the 5th combined with the 4th type. The “Young” (to “Semi-mature”) low open forest of MA (Type 6) was combined with the variable mature woodland (Type 3) due to its generally close spatial association with mature communities alongside large relatively permanent pools. Amalgamation of this community with the other more transient and less significant “Young to Semi-Mature” structured communities is considered incongruent from sensitivity, significance and spatial standpoints, despite the some similarities in age and physical structure.

The amalgamation of types 4 and 5 was an obviously complimentary choice and determined sound from all relevant standpoints.

Mapping FPV communities present within the study area

Following the OPV mapping process; the remaining wooded riparian associations (generally representing FPV) co-occurring with and often surrounding the OPV were refined based on targeted mapping notes, photo points, and interpretation of community and species specific aerial photo signatures.

The key task of this final mapping component was to establish, and spatially delineate FPV communities with a tree strata either dominated by *Eucalyptus camaldulensis* or co-dominated by *E. camaldulensis* and *E. victrix* (FPV), but which does not contain *Melaleuca argentea* as a co-dominant species. *Eucalyptus camaldulensis* is widely considered to be the more groundwater dependent of the riparian eucalypts which commonly occur in the study area. While *Eucalyptus victrix* is generally considered to be a facultative phreatophytic species, it is also recognised that this species is less reliant on groundwater access than *E. camaldulensis*, and more easily able to survive solely on vadose soil water sources. For this reason, mapping the distribution of *E. camaldulensis* (outside of OPV) is an important secondary step in the process of mapping varying degrees of community related groundwater dependence.

E. camaldulensis distribution mapping essentially either requires regular field notes on the presence/absence and abundance of *E. camaldulensis* in the field, or relies on some presence absence field data to help enable accurate interpretation of species specific aerial photo signatures. Within the Robe River; it was noted that canopy and stem related visual cues which often allow relatively confident differentiation between these two species were not clearly aiding this differentiation process during the field survey. For this reason, aerial photo interpretation was the key tool used for mapping the distribution of *E. camaldulensis*, and *E. victrix* in this study. This process was aided significantly by the use of recent high resolution (0.5 m) true colour DMSI imagery. High resolution 4-band aerial imagery enabled individuals/populations of *Eucalyptus camaldulensis* to be identified on GIS and therefore accurately mapped as either representing dominant or co-dominant vegetation communities. In order of relative usefulness in the Robe river locality; Individuals or groups of *Eucalyptus camaldulensis* within the riparian environment were distinguished on aerial photography from *E. victrix* on the basis of:

1. the generally darker green canopy colour signature of *E. camaldulensis*;
2. the generally denser canopy cover signature of *E. camaldulensis*;
3. the generally dissimilar branch signature of *E. camaldulensis* canopy architecture; and
4. the generally larger (spatial extent) canopy footprint of *E. camaldulensis*.

The available aerial photography was considered to be of a quality suitable for the application of the above described visual assessment and was found to be robust when ground-truthed using field data. Some more obvious and presentable examples of the aerial signature of *E. camaldulensis* trees from Weeli Wolli Creek are provided below in Plate 3-3. The examples presented in Plate 3-3 were generally chosen due to their location on an open floodplain, where canopy density is reduced and as such surrounding canopy species don't inhibit the display of the above described characters, thus making them easier for the reader to appreciate/visualise. Plate 3-4 shows examples of key eucalypt aerial signatures from the Robe River

All vegetation types mapped as part of this study, were described using Aplins' (1979) framework for "Vegetation Structural Classes" (Specht 1970). This framework is presented in Appendix 1, along with vegetation condition scale used in this study (Trudgen 1988). As such all communities (**Table 4-1**) established as part of this study are generally considered to represent sub-associations. Community descriptions were created by identifying dominants (where present) for all relevant strata available, rather than restricted to the three traditional strata, such that they represent relatively detailed vegetation descriptions, approximately equivalent to level 5 mapping within the National Vegetation Information System (**NVIS**) (DoE 2014b).

Given the Stage 1 status of this study; some vegetation types mapped and described as part of this study are potentially more accurately classified as associations, or are lacking some of the structural/compositional differentiation which comes from sampling over multiple phases (as part of a detailed survey (EPA 2016b)). Furthermore; some of the non-core riparian communities of the high-flow and terrace riparian habitats are yet to be properly described and delineated throughout the study area. Given the focus of this study is on delineating groundwater dependent ecosystems the reduced level of detail provided for such communities is considered relatively inconsequential and of low significance when considering potential impacts.

Plate 3-3: Aerial photos showing examples of *Eucalyptus camaldulensis* canopies (inside orange polygon) on high resolution aerial photography (Weeli Wolli Creek)

Note: Beyond the more obvious shrub features, the majority of the remaining eucalypt canopies present in these plates are considered to be *E. victrix* as indicated by the relatively obvious white branch and trunk colouration, open branching habit and lighter foliage colour.

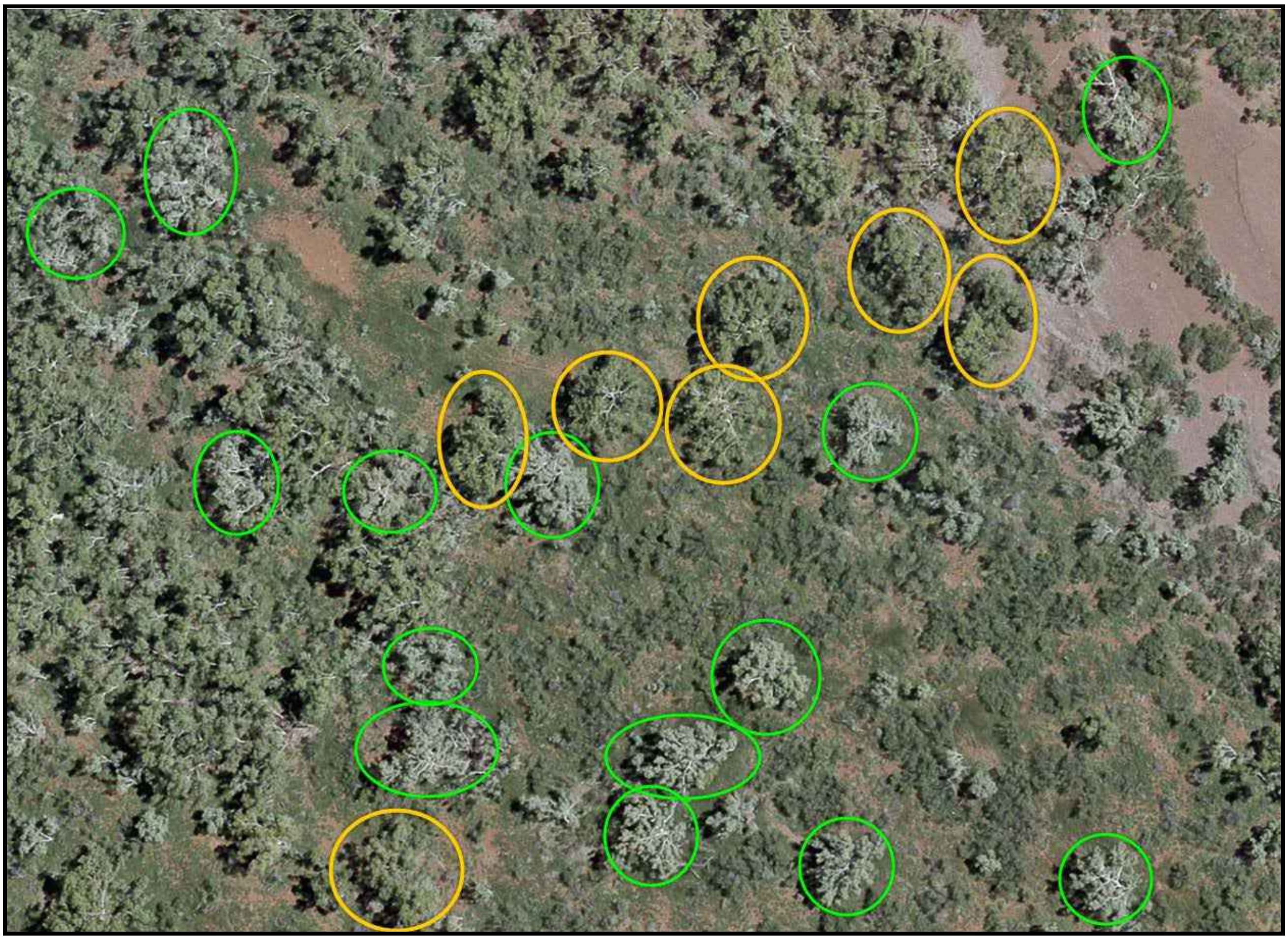

Plate 3-4: Aerial photos showing examples of Eucalyptus camaldulensis canopies (inside orange polygons), and E. victrix (inside green polygons), on high resolution aerial photography within the Robe River (April 2017)

3.2 SIGNIFICANCE FRAMEWORK USED TO ASSESS THE LOCAL SIGNIFICANCE OF RIPARIAN COMMUNITES MAPPED WITHIN THE STUDY AREA

For the purpose of incorporating a sense of "quantification" to the process of attributing significance to riparian communities within the study area, the following "framework for Significance" was developed in Rio Tinto 2015 and adapted in this study as a means of providing a more systematic qualitative assessment of significance:

Key steps for considering the relevant factors/attributes are:

1. Part one - consider the number and magnitude of ecological values associated with or provided by a biological feature.
2. Part two - determine the distribution and therefore degree to which it is restricted in the environment, the degree of representation (the degree to which a vegetation unit is represented by other communities outside of the study area), and potential rarity of this feature within local, sub-regional, and regional scales.
3. Part three – consider the condition of the biological feature, and its inherent resilience to perturbation.

Once determined, the combined consideration of parts one and two result in the determination of an initial significance rating. The inherent sensitivity or resilience of a feature to perturbation will tend to increase or decrease the likelihood of impact, as well as the consequences of the impact. In addition, the current condition of the feature at the time of consideration will have an influence on its significance. In order to incorporate sensitivity/resilience and locally known potential anthropogenic impacts into the resultant significance, it is proposed that for this study, a final “Resultant Local Significance rating” will be determined via part three of the framework and used to attribute an alternative and more locally measured significance to the biological features being assessed.

In addition to the considering physical and biological condition of a feature; this final significance will incorporate some consideration of the inherent risks and potential consequences of development on this feature into the attributed resultant significance. The result of this framework is that ultimately the final resultant local Significance will in turn provide a more measured guidance to management and mitigation as development is undertaken or continued.

3.3 LIMITATIONS OF THIS STUDY

Overarching

- For the most part the study area was easily accessed.
- Base flow in the Robe River was anecdotally much reduced preceding (for at least 1-2 years prior) and at the time of the first survey. Rainfall/seasonal conditions and flowering/fruiting conditions were sub-optimal. However because the GDE focus of this study determined that key interests surrounded the distribution of perennial species this was not generally a limiting factor. Instead the sub-optimal seasonal conditions allowed relatively unrestricted vehicular access and traverse patterns to be conducted throughout the river bed. In addition; the unusually low water levels enabled collection of information on the spatial distribution of low to moderate degrees of hydrological stress within obligate phreatophytes across the study area.
- The vast majority of the field work required for the Robe River riparian vegetation mapping project was successfully completed and reported upon herein. However; some of the planned outer reaches of Robe River and Jimmawarrada Creek remain to be assessed with the methodology adopted in this study. Only those information requirements needed in the short term have been completed and included in this Stage 1 report. This includes the complete differentiation and mapping of some of the Floodplain/Terrace communities which lie in the outer riparian zones of the Robe River. Further to this; a 25 cm pixel aerial photo was requested for the complete study area in October of 2016, but at the time of production of this report had not yet been flown and processed due to mechanical breakdowns and weather limitations. Given the species specific, and community specific identification advantages of this orthophoto, it was planned to be used as an important tool in this project for providing the highest confidence mapping of OPV and FPV communities within the study area. This aerial photo is planned to be used once all additional field work is complete and the entire dataset can be validated using this tool as part of Stage 2.

Desktop and Field Data Acquisition Tools

- Size classes attributed to *M. argentea* populations are a visual estimate and potentially inaccurate in some cases.
- As previously experienced limitations in the correlation between NDVI cover anomalies and OPV were again apparent for the mature OPV woodland communities. This essentially determined that such communities (mainly the C1A and C1b vegetation type) were much harder to distinguish at a desktop level from that of more common mature *Eucalyptus* spp. FPV communities. In these instances; true colour aerial photo signatures and relatively comprehensive creek coverage was relied upon to minimise false negative recordings.

Ground Truthing and Vegetation Mapping Field Work

- The amount of standing water in the creek at the time of survey only restricted movement across creek in a few situations; consequently ground truthing traverse patterns were not hindered.

- Not all species of interest were in optimal condition at the time of the survey. However this did not significantly hinder the acquisition of field data and as mentioned above, for obligate phreatophytic species this enabled the collection of additional useful data. For the most part key eucalypt species were not regularly fruiting/flowering at the time of survey. This did hinder quick differentiation between riparian Eucalypts, however, given that the study area was >60 km in length, it was not feasible to differentiate between these species often enough in the field to provide meaningful differentiation at the scale of the mapping produced. As a result high resolution aerial photo signatures of *E. camaldulensis* and *E. victrix* was inevitably the key tool for mapping the distribution patterns of these two key riparian eucalypt species. However; some field data for ground-truthing aerial photo signatures was required, and where fruit was not available the following technique was used.
- Where riparian eucalypt fruit/flowers were not available, hand lenses were used to determine the identification of the resident eucalypts within a number of representative patches of vegetation via leaf anatomy. *E. camaldulensis* typically possesses true oil glands within the endoplasmic reticulum of its leaves, whereas *E. victrix* does not. Combined with the distinctive differences in lateral vein architecture of the two species (broad/sparse and wavy in *E. camaldulensis*, and tight/uniform and straight in *E. victrix*) ID's were considered accurate in all occasions rather than potentially inaccurate in certain conditions without hand lens techniques.
- Flora and vegetation data collected as part of this study came from a single phase of work and as such were not seasonally sampled.

<u>Post Field Work Vegetation Mapping Process</u>

- Data quantity and resolution was more than adequate for the scope of the targeted assessment.
- Coverage was more than adequate for the scope of the targeted assessment.

Mapping errors have been significantly minimised through extensive ground-truthing and 4-band aerial photo interpretations. The degree of ground-truthing effort conducted for the included groundwater dependent communities, and particularly the OPV communities, is such that the mapping is considered to be significantly more accurate than vegetation mapping typically undertaken within riparian areas.

4 RESULTS

4.1 VEGETATION MAPPING

Table 4-1 below presents the resultant vegetation types described as part of the GDE focused vegetation mapping process. A list of the associated species recorded in each is included in Appendix 2. Representative photos of the riparian vegetation types mapped as part of this study are presented in Appendix 3. For each vegetation type mapped, multiple photos are provided in Appendix 3 to provide some indication of the degree of variation which was observed in each. In an effort to provide a more simplified vegetation model which facilitates easier and broader comprehension of the distribution of groundwater dependent and mesic riparian communities within the study area, a number of the vegetation types presented in Table 4-1 were strategically amalgamated to produce the following riparian vegetation summary maps presented in Figures 4-1 to 4-4. Within Table 4-1, a column has been added to delineate which of the detailed vegetation types were amalgamated to form the summary map vegetation types presented in Figures 4-1 to 4-4. These figures are essentially for the purpose of viewing the distribution of potentially GDV at a larger scale and therefore over larger swathes of the river. These maps should be used when a simpler, broader scale perspective of riparian vegetation within the Robe River is preferred. Maps presenting the resultant vegetation mapping for the complete suite of Stage 1 vegetation types (i.e. without amalgamation of similar communities) are presented in Figures 4-5 to 4-13. These figures present the full degree of mapping detail resulting from stage 1 of the riparian mapping project within the Robe River. As a result Figures 4-5 to 4-13 are most appropriate when considering the distribution and extent of riparian vegetation at the finer scale.

4.1.1 Vegetation Coding

As detailed in the methods, the same coding regime as Rio Tinto (2015) was attributed to vegetation types identified in this study. To help equate the resultant vegetation types to the most recent and relevant local vegetation mapping in the sub-region, the equivalent Astron (2015/2016) veg code for each vegetation type in this study is provided in Table 4-1. The original codes and the hierarchy of significance which they were defined to convey in Rio Tinto (2015) have been maintained as much as possible while still allowing them to reflect the compositional findings and resultant vegetation structure identified in the study area. The most important differences between the coding of these two studies, while minor, relate to the C1AA end of the coding spectrum (communities with an overstorey dominated by obligate phreatophytes) and to the C4-C6 (differing shrublands) end of the coding spectrum. In addition; codes relating to *E. camaldulensis* dominated woodlands/open-forests were required to be integrated due to their delineation in this study and absence in Rio Tinto (2015).

4.2 GROUNDWATER DEPENDENT VEGETATION COMMUNITIES MAPPED

As part of the vegetation mapping process six key types of groundwater dependent vegetation were identified. Listed in order of relative hydrological sensitivity, these are:

1. OPV-A: Vegetation dominated by mature Obligate Phreatophytes
2. OPV-B: Vegetation co-dominated by mature Obligate Phreatophytes

3. OPV-C: Vegetation co-dominated by immature Obligate Phreatophytes
4. FPV-A: Vegetation dominated by *Eucalyptus camaldulensis* (the most hydrologically sensitive Local Facultative Phreatophyte) and at times supporting *Sesbania formosa*
5. FPV-B: Vegetation co-dominated by *Eucalyptus camaldulensis*
6. FPV-C: Vegetation dominated by *Eucalyptus victrix* (the second most hydrologically sensitive local Facultative phreatophyte)

These GDE types are generally relevant to the local Pilbara environment; however the structural concepts and physiological scales which they describe can be applied more widely. It should be noted that the applied differentiation (i.e. A, B, and C) within each accepted hydrological strategy (i.e. Obligate, Facultative etc.) is not widely known or accepted. However; the varying degrees of groundwater availability inferred by the degrees of phreatophyte structural dominance (and maturity) which they intend to classify, are entirely relevant and a useful way of classifying groundwater dependence.

Table 4-1: Vegetation descriptions and GDE summary info for all riparian vegetation types mapped in the study area.

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
PO	Minimal Vegetation	Pool - GDE	**Tree Strata: N/A** **Shrub Strata: N/A** **Lower Strata:** Fringed by variable Sedgeland to open sedgeland of *Typha domingensis*, Cyperaceae spp., *Schoenoplectus* spp., *Schoenus* spp., along with *Stemodia grossa* and other small mesic shrubs	Uncommon but Scattered along the low flow channel and often spatially correlated with topographic pinch points along the river channel	Good to Poor	N/A
C1AAa	Mature MA dominated Closed Forest	OPV	**Tree Strata:** *Melaleuca argentea* closed forest **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, *Melaleuca glomerata* and *Acacia ampliceps* scattered shrubs **Lower Strata:** *Cyperus vaginatus* open sedgeland over *Stemodia grossa* scattered to low open shrubland, amongst scattered pools.	Scattered along low points in the river bed, where groundwater appeared shallow, often up against steep massive bank formations	Excellent to Very Good	Similar to EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016)
C1AAb	Mature MA dominated Open Forest	OPV	**Tree Strata:** *Melaleuca argentea* (plus scattered *Eucalyptus camaldulensis*) open forest (to closed forest in places). **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, and *Acacia ampliceps* scattered shrubs (to open shrubland in places) **Lower Strata:** *Cyperus vaginatus* very open sedgeland (to open sedgeland) over *Stemodia grossa* scattered low shrubs	Scattered along low points in the river bed, and near mesa features where groundwater appeared shallow	Excellent to Very Good	MaEcCv (Astron 2016) or Similar to EcMaCvCspp (Astron 2015)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C1A	Mature MA and EC dominated Open forest to Low Woodland	OPV	**Tree Strata:** *Melaleuca argentea* & *Eucalyptus camaldulensis* subsp. *refulgens* (plus scattered *Sesbania formosa*) Low open forest (to woodland in places) **Shrub Strata:** *Melaleuca argentea*, *Petalostylis labicheoides*, *Acacia trachycarpa*, *Acacia ampliceps* and *Melaleuca glomerata* open shrubland (to shrubland in places) **Lower Strata:** Scattered sedges/shrubs of *Cyperus vaginatus*, *Stemodia grossa* and at times; **Cenchrus ciliaris*, **Cenchrus setiger*, **Setaria verticillata* very open tussock grassland	Consistently fringing low flow channels or scattered around permanent water features where groundwater appeared shallow	Excellent to Very Good	EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016)
C1b	Semi-Mature MA and EC dominated Low Woodland	OPV	**Tree Strata:** *Melaleuca argentea*, *Eucalyptus camaldulensis* subsp. *refulgens* variable low woodland (to low open woodland) (also includes low open forests of *M. argentea* & *E. camaldulensis* saplings fringing pools **Shrub Strata:** *Melaleuca argentea*, *Petalostylis labicheoides*, *Acacia trachycarpa*, and *Melaleuca glomerata* variable open shrubland to shrubland **Lower Strata:** *Cyperus vaginatus* scattered sedges, over *Stemodia grossa* scattered low shrubs.	Scattered along low flow or secondary channels of the main river bed, including some high flow channels	Excellent to Very Good	Similar to EcMaCvCspp (Astron 2015) or similar to MaEcCv (Astron 2016)
C2AA	Large Mesic EC dominated Open Forest representations	FPV-A	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens* open forest (to low open forest with scattered *Eucalyptus victrix* and at times *Sesbania formosa*) **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, *Melaleuca glomerata* and *Acacia ampliceps* tall shrubland (to tall open shrubland in places) **Lower Strata:** *Cyperus vaginatus* scattered sedges and in places **Cenchrus ciliaris*, **Cenchrus setiger* (**Setaria verticillata*) very open tussock grassland	Scattered along secondary channels and banks of the main river bed, including some high flow channels	Very Good to Good	Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C2A	EC dominated Open Forest	FPV-A	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens* open forest (to low open forest with scattered *Eucalyptus victrix* and at times *Sesbania formosa*) **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, *Melaleuca glomerata* and *Acacia ampliceps* tall shrubland (to tall open shrubland in places) **Lower Strata:** *Cyperus vaginatus* scattered sedges and in places **Cenchrus ciliaris*, **Cenchrus setiger*, **Setaria verticillata* very open tussock grassland	Consistently Scattered along low flow channels, secondary channels and banks of the main river bed	Very Good to Good	Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)
C2B	EC & EV co-dominated Open Forest	FPV-B	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *E. victrix* open forest (to woodland in places) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* and *Melaleuca glomerata* tall open shrubland (to tall shrubland in places) **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* (**Setaria verticillata*) very open (to open) tussock grassland with scattered sedges of *Cyperus vaginatus*	Scattered throughout the bed, but often along secondary channels and banks of the main river bed, including high flow channels.	Good to Poor	Similar to EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)
C2A-B	EC dominated Woodlands	FPV-A	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens* woodland (to open forest in places) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*, *Gossypium robinsonii*) tall open shrubland (plus *Melaleuca glomerata* in some areas) **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (plus scattered *Cyperus vaginatus* and *Stemodia grossa* and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the bed, but often along secondary channels and banks of the main river bed, including high flow channels	Good	EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C2B-B	EC & EV co-dominated Woodland	FPV-B	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *Eucalyptus victrix* woodland (to low woodland) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*, *Gossypium robinsonii*) tall open shrubland (plus *Melaleuca glomerata* in some areas) **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (plus scattered *Cyperus vaginatus* and *Stemodia grossa* and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the bed, often along secondary channels and banks of the main river bed, including tributaries & high flow channels	Good to Poor	EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)
C2C	EV Dominated Woodland	FPV-C	**Tree Strata:** *Eucalyptus victrix* woodland (to low woodland with scattered *E. camaldulensis*) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall open shrubland (to scattered tall shrubs in places) **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the bed, often along secondary channels and banks of the main river bed, including tributaries & high flow channels	Good to Poor	EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016)
C3A	EC & EV co-dominated Open woodland	FPV-B	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *Eucalyptus victrix* open woodland (to scattered trees in places) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland) **Lower Strata:** Gravel beds at times colonised by **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (at times including a very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the drier, often elevated sections of the main river bed, and associated tributaries	Good to Poor	EcEvCspp (Astron 2015) or similar to EcEvAtrApyPlTw (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C3B	EV Dominated Open Woodland	FPV-C	**Tree Strata:** *Eucalyptus victrix* low open woodland (to scattered trees in places) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland) **Lower Strata:** Gravel beds at times colonised by **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (at times including a very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the drier, often elevated sections of the main river bed, and associated tributaries.	Good	EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016)
C4	Shrublands	Vadophytic	**Tree Strata:** N/A **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland) **Lower Strata:** Gravel beds generally dominated by scattered mixed grasses and herbs; but at times colonised by **Cenchrus ciliaris*, **C. setiger* very open (to open) tussock grassland and *Triodia epactia* very open hummock grassland	Scattered throughout the main river bed and terraces; often associated with periodically scoured bed formations	Good to Very Good	Similar to AtrEs & AtTeCc (Astron 2015) or AtrPl (Astron 2016)
C5	Beds with minimal vegetation	Vadophytic	**Tree Strata:** Expansive open gravel beds with isolated trees **Shrub Strata:** Isolated to scattered tall shrubs of *Acacia trachycarpa*, *Petalostylis labicheoides* **Lower Strata:** Variable; Scattered herbs of *Euphorbia schultzii*	Scour zones present throughout river bed, in low flow channels and preferential flow zones where scouring is high.	Excellent	AtrEs (Astron 2015) or Es (Astron 2016*)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C6	Shrublands	Vadophytic / Xerophytic	**Tree Strata:** N/A **Shrub Strata:** Variable; Tall shrubland (to tall open shrubland) of *Acacia trachycarpa*, *A. pyrifolia* & *Petalostylis labicheoides* (dominating riparian fringes); *A. bivenosa*, *A. inaequilatera*, *A. synchronicia* & *A. ancistrocarpa* with scattered *Corymbia hamersleyana* low trees (dominating terraces) **Lower Strata:** Variable grasslands: **Cenchrus ciliaris*, **Cenchrus setiger* open tussock grassland and *Triodia epactia* (*T. wiseana*) very open hummock grassland (fringing riparian zones); *T. wiseana* (*T. epactia*) open hummock grassland (on terraces)	Distributed throughout the river terrace and high flow channel zones.	Good to Very Good	Similar to AtTeCc & ChAsppTwTe (Astron 2015) or ChAsppGOrGsppPlSsTeTw & ChPlAbGOrTw (Astron 2016)

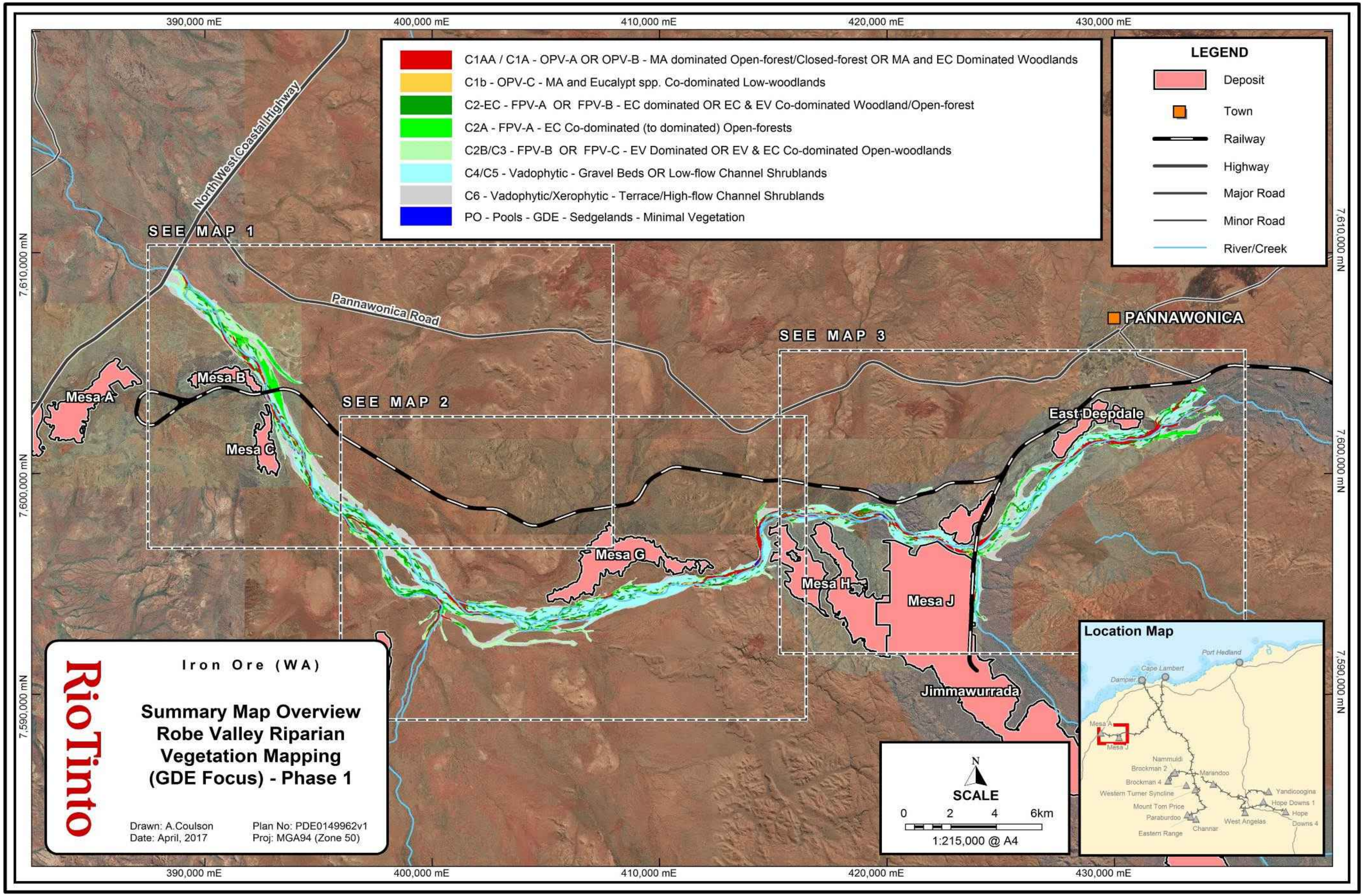

Figure 4-1: Overview map showing the layout of the 3 Riparian Vegetation Summary Maps

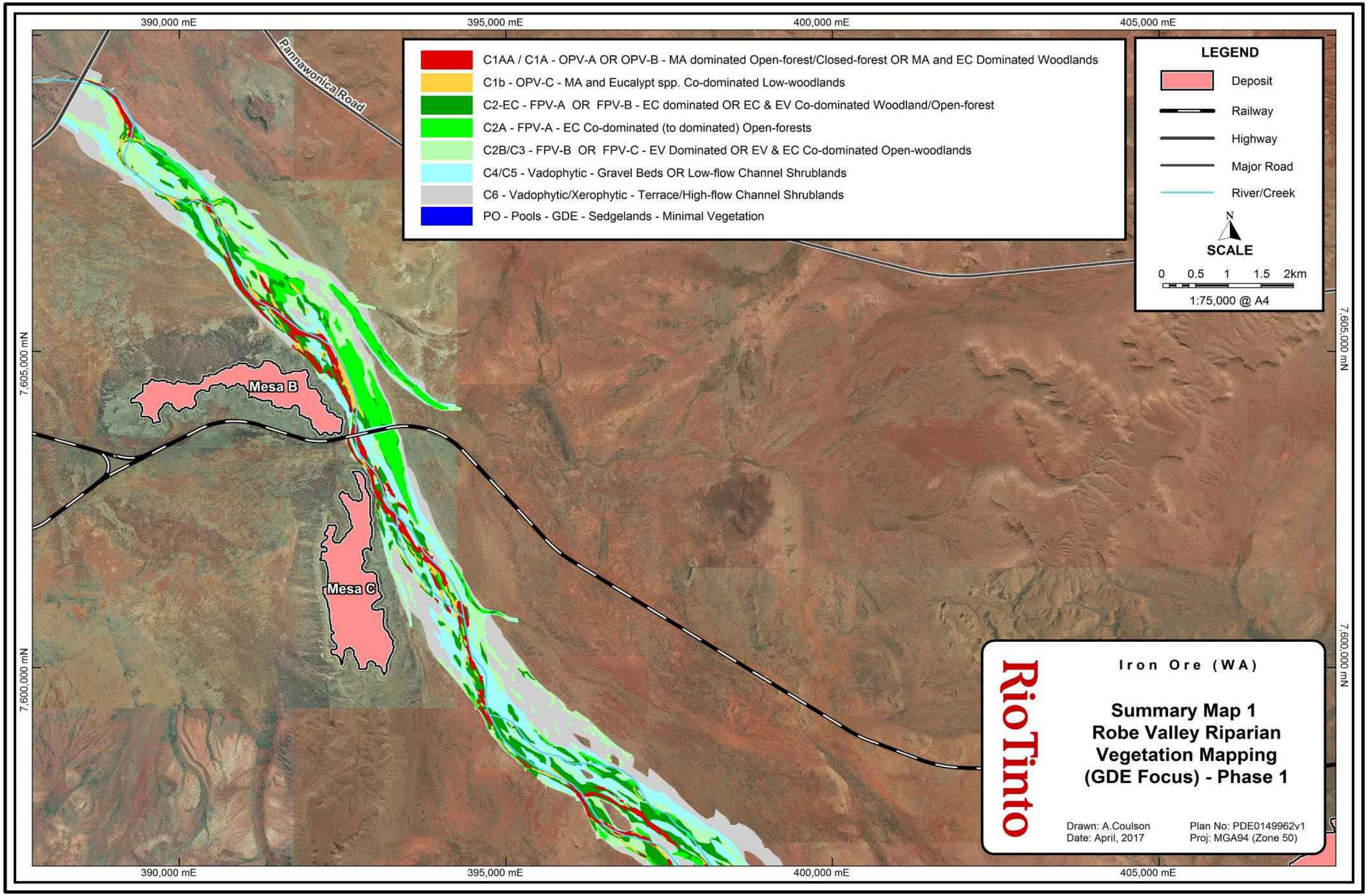

Figure 4-2: Robe Valley Riparian Vegetation summary; Map 1 of 3

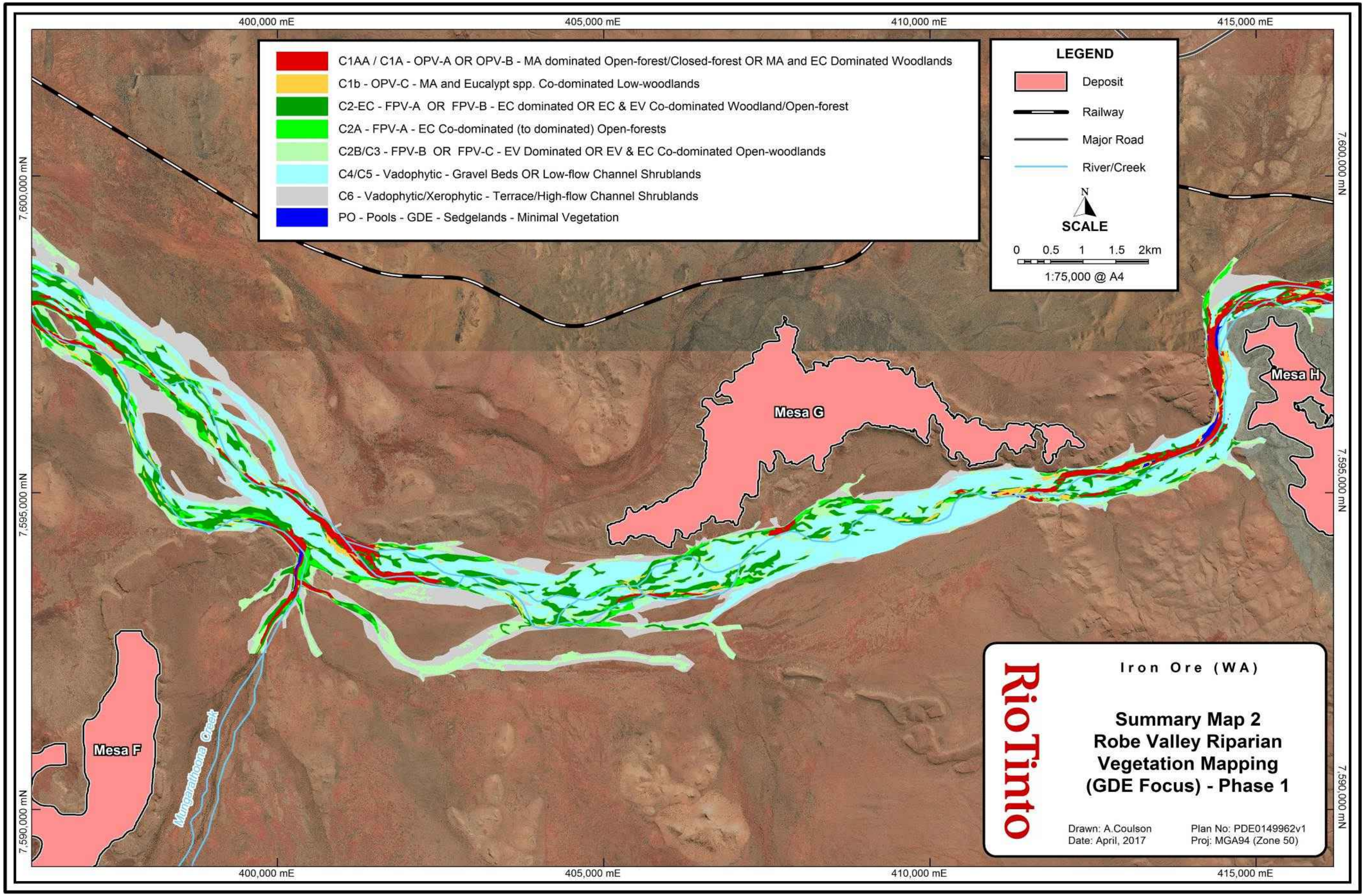

Figure 4-3: Robe Valley Riparian Vegetation summary; Map 2 of 3

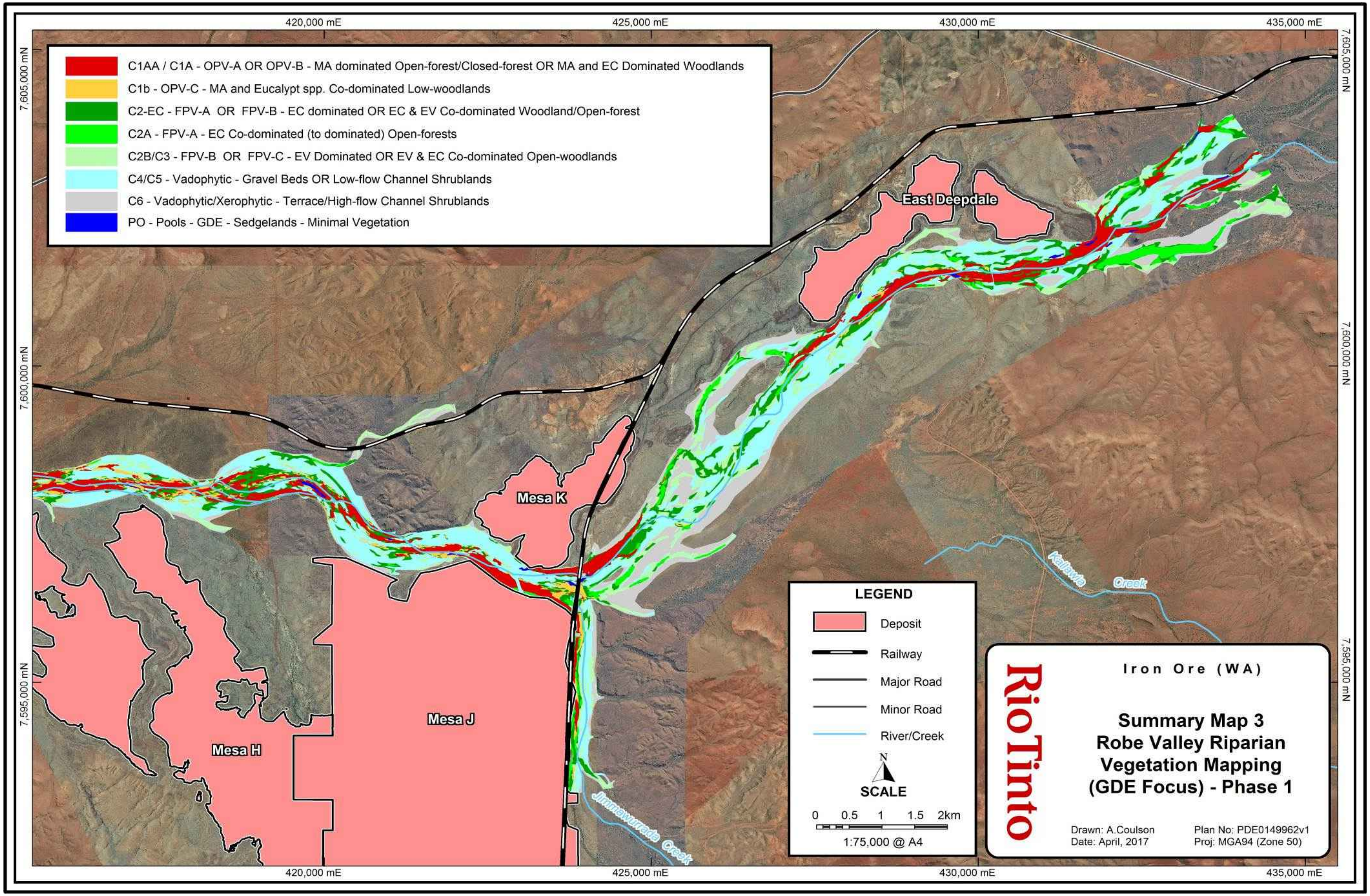

Figure 4-4: Robe Valley Riparian Vegetation summary; Map 3 of 3

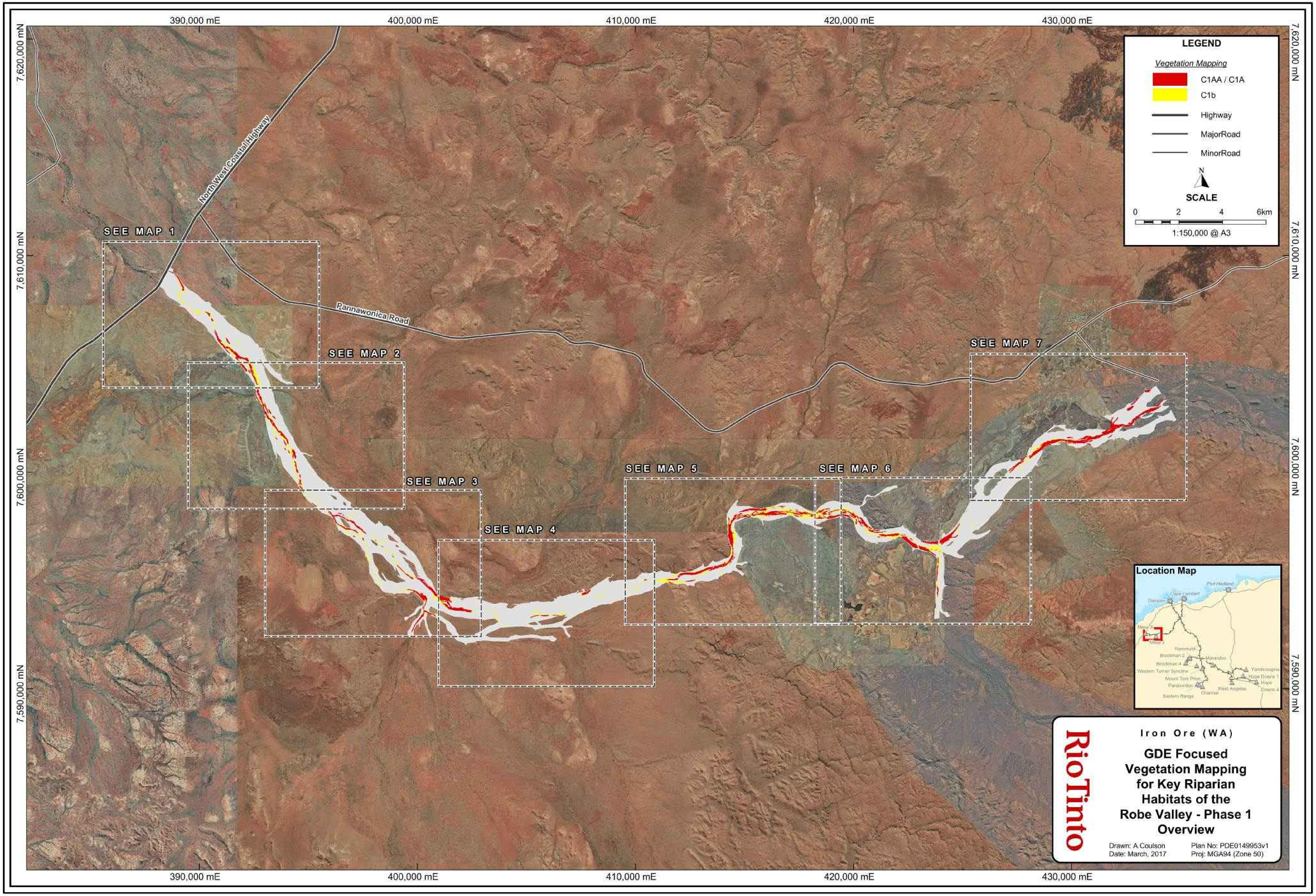

Figure 4-5: Overview map showing the layout of the 7 maps showing the results of the Robe River riparian vegetation mapping project.

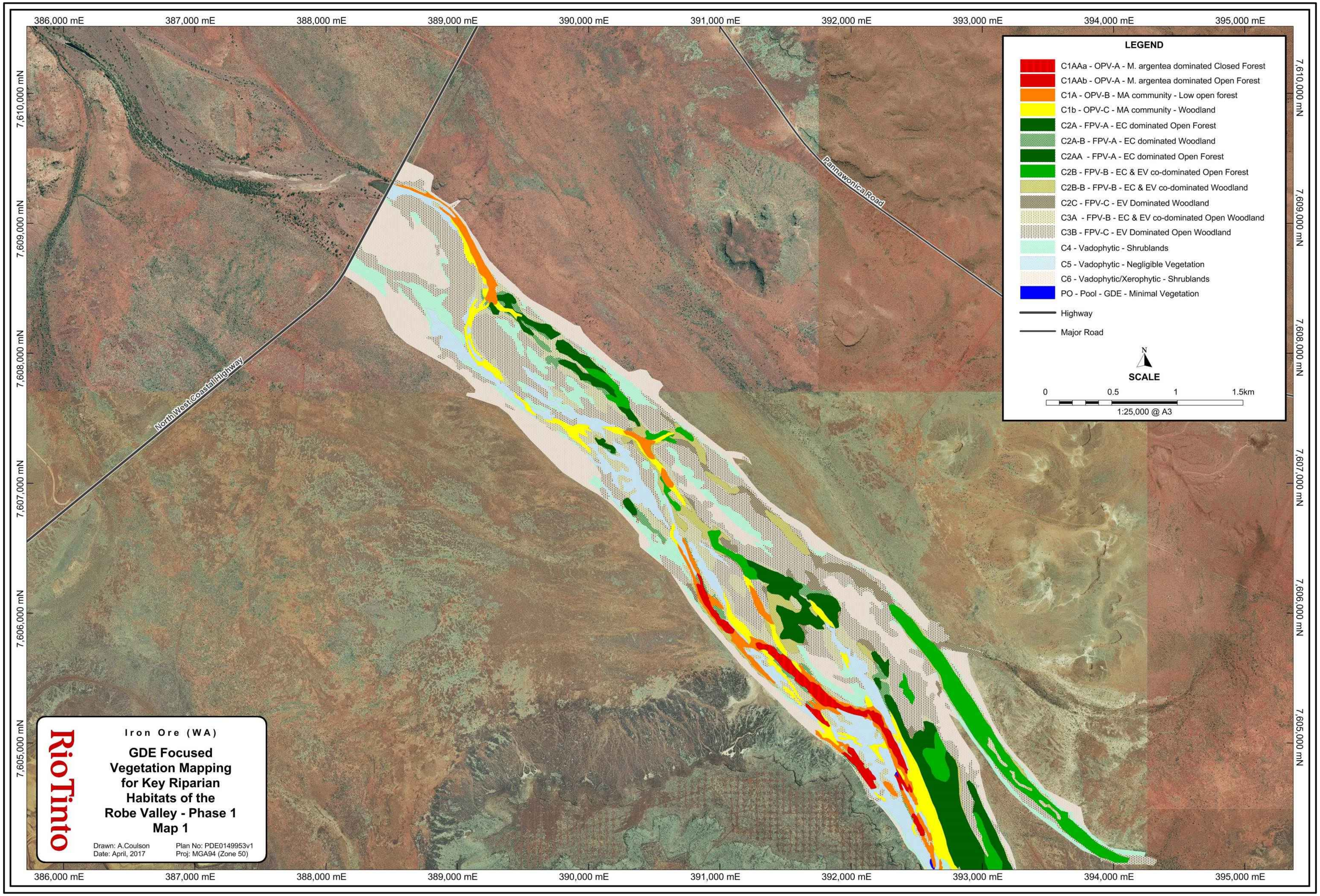

Figure 4-6: **Results of the Robe River riparian vegetation mapping project; Map 1 of 7**

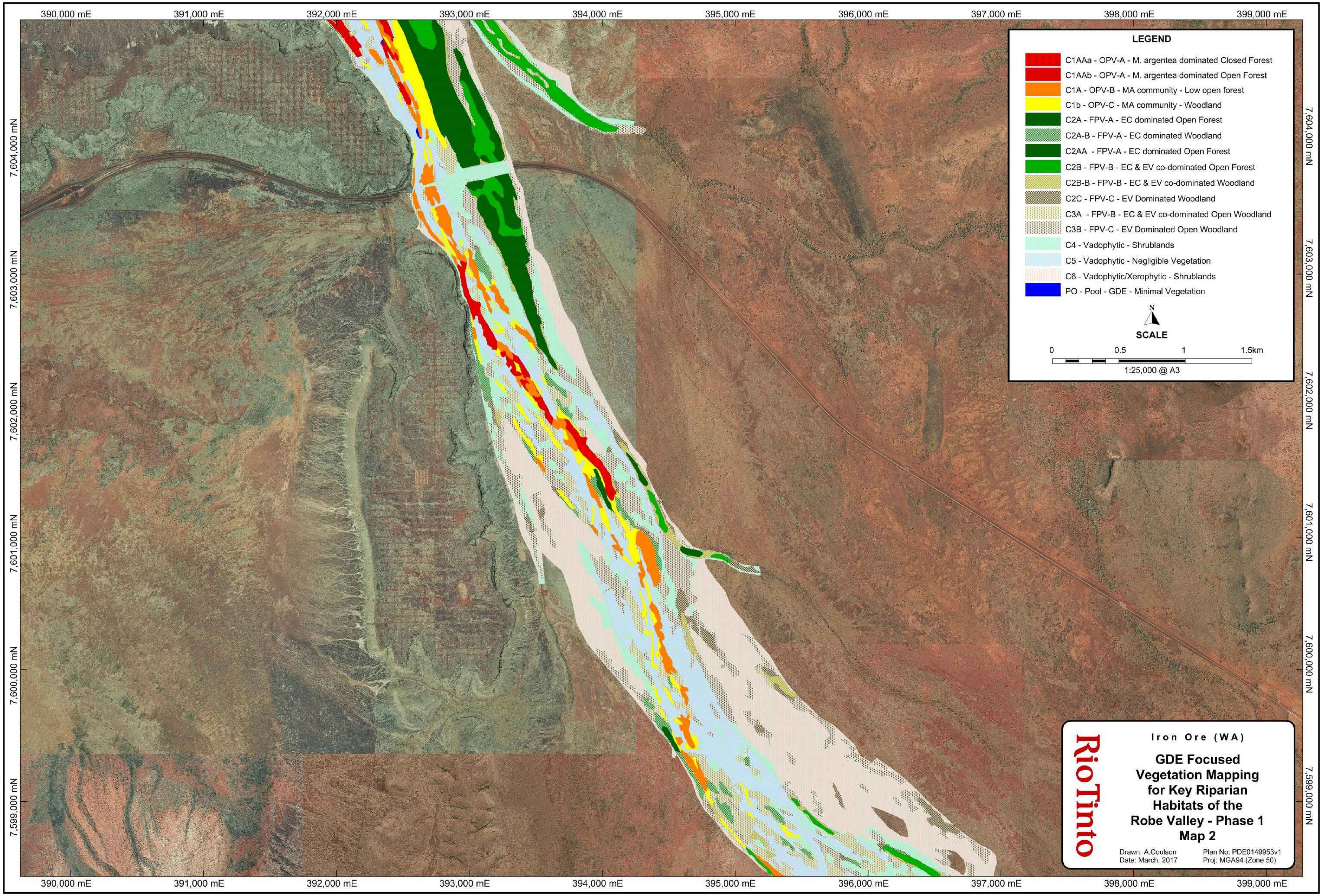

Figure 4-7: **Results of the Robe River riparian vegetation mapping project; Map 2 of 7**

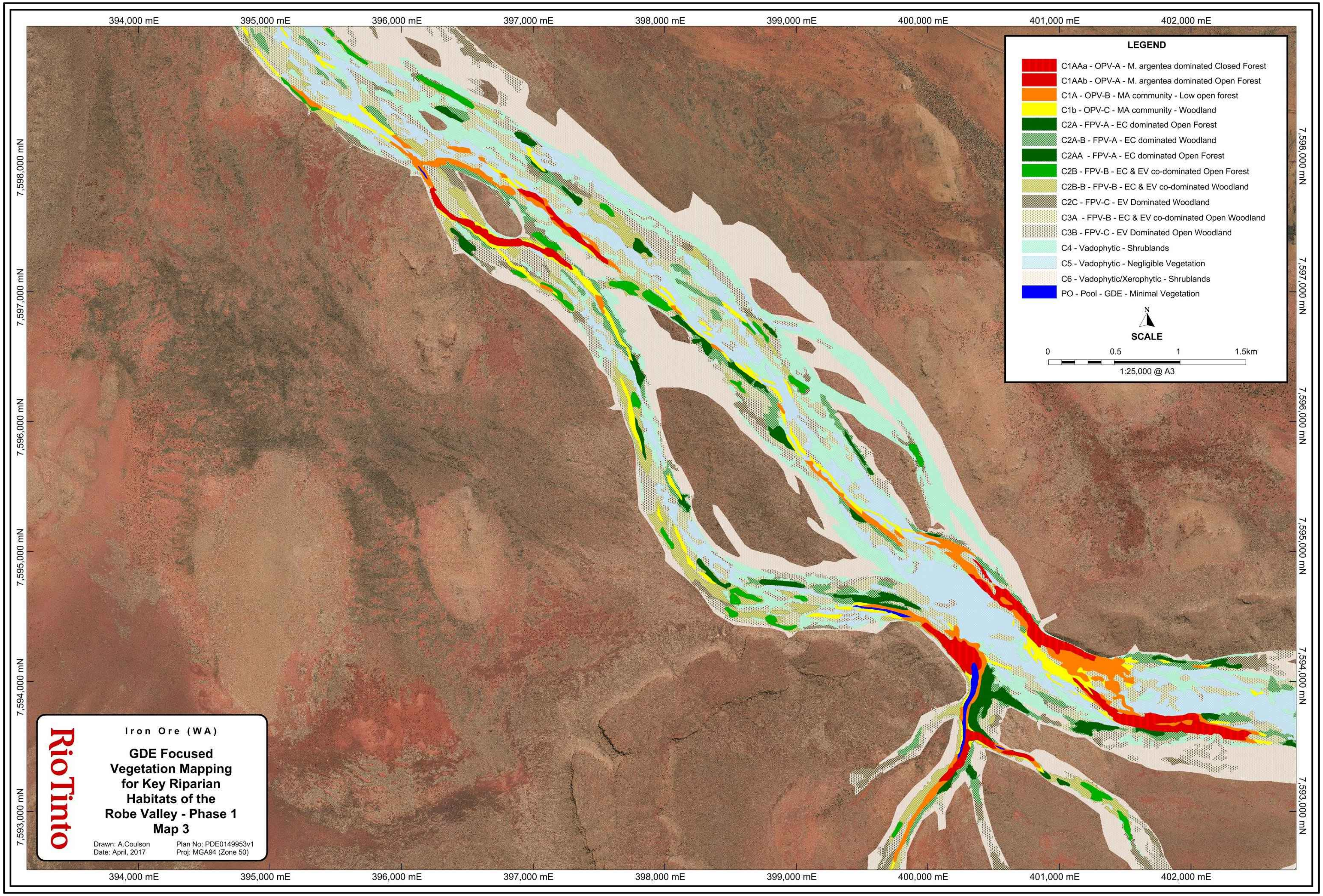

Figure 4-8: **Results of the Robe River riparian vegetation mapping project; Map 3 of 7**

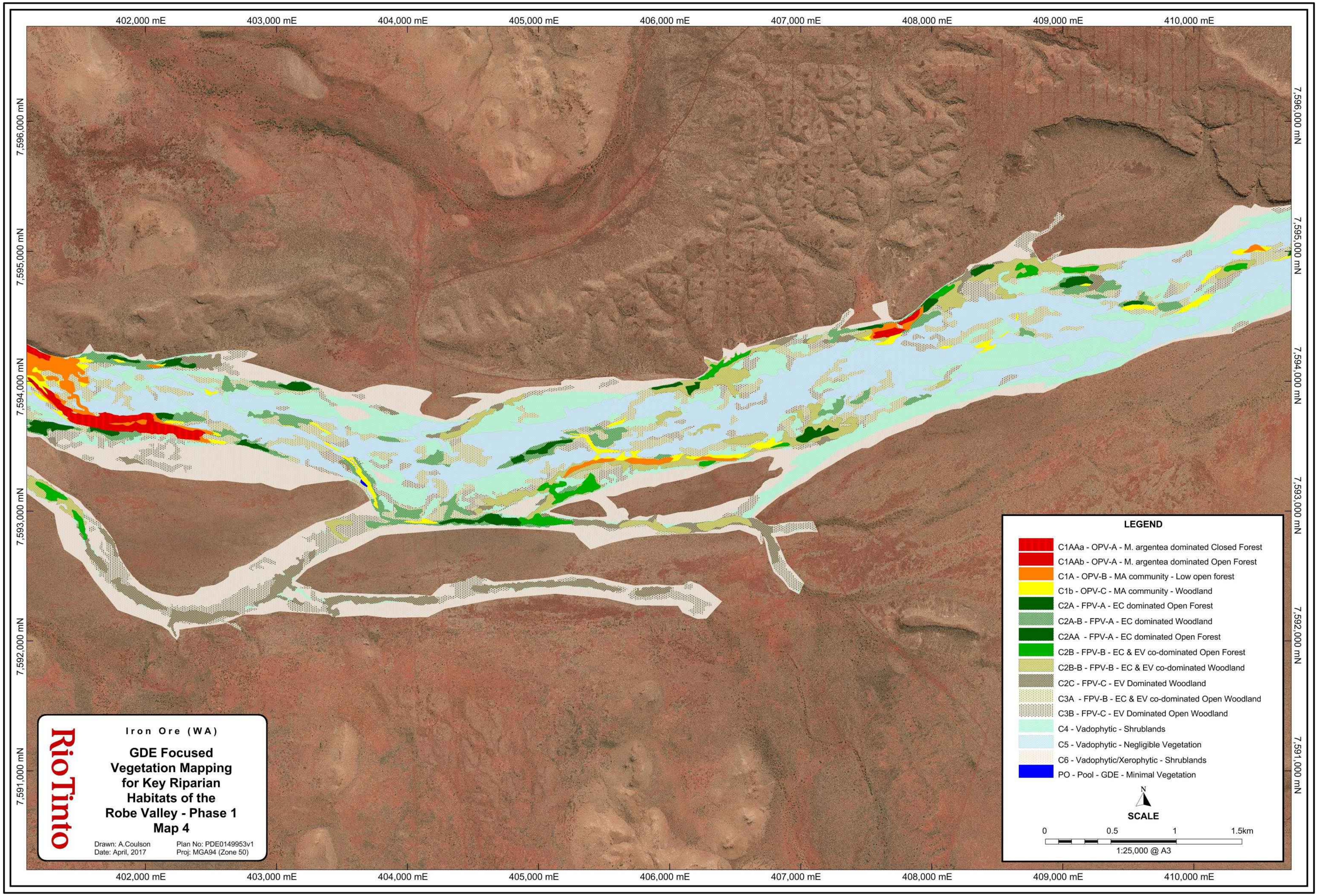

Figure 4-9: **Results of the Robe River riparian vegetation mapping project; Map 4 of 7**

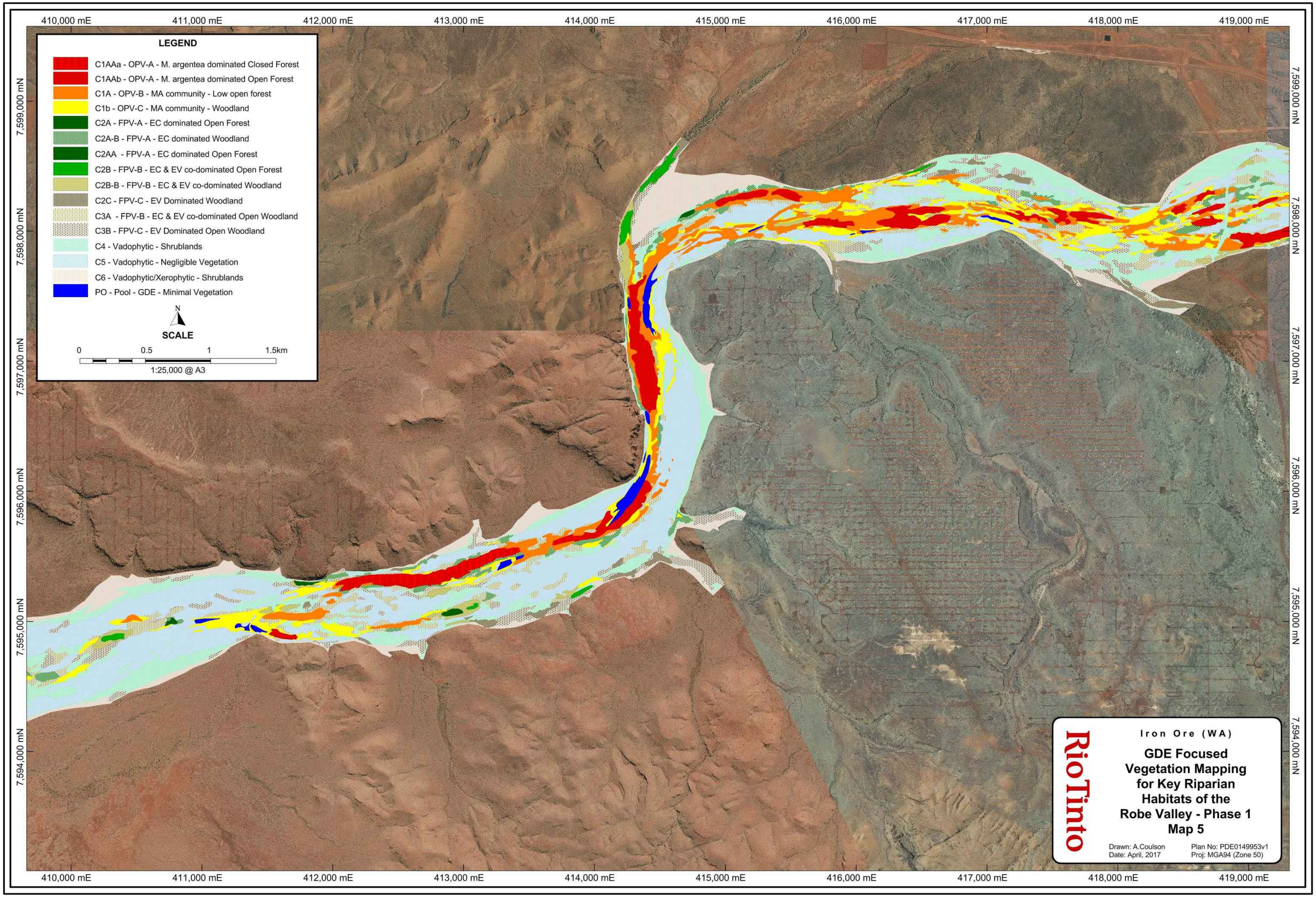

Figure 4-10: **Results of the Robe River riparian vegetation mapping project; Map 5 of 7**

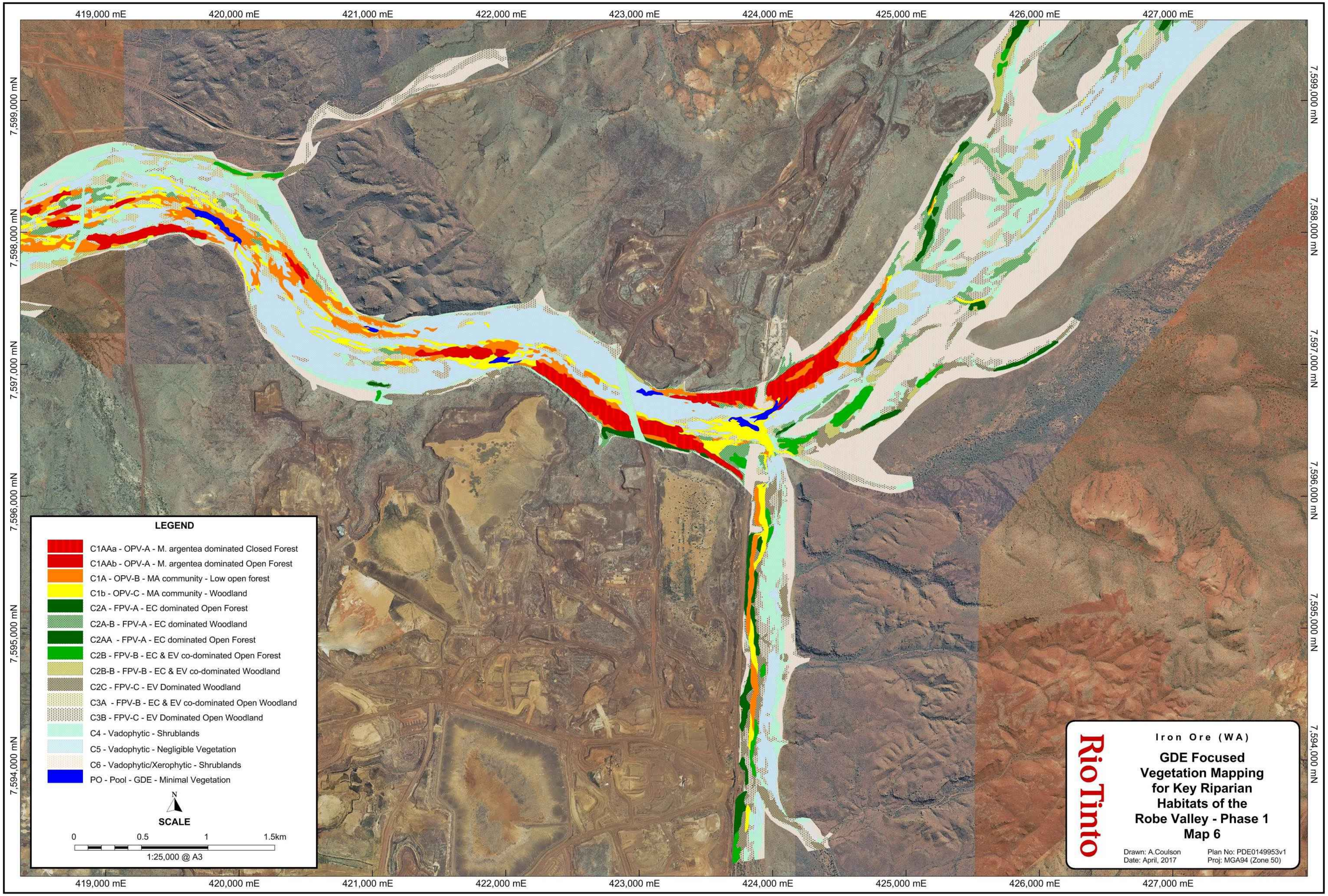

Figure 4-11: **Results of the Robe River riparian vegetation mapping project; Map 6 of 7**

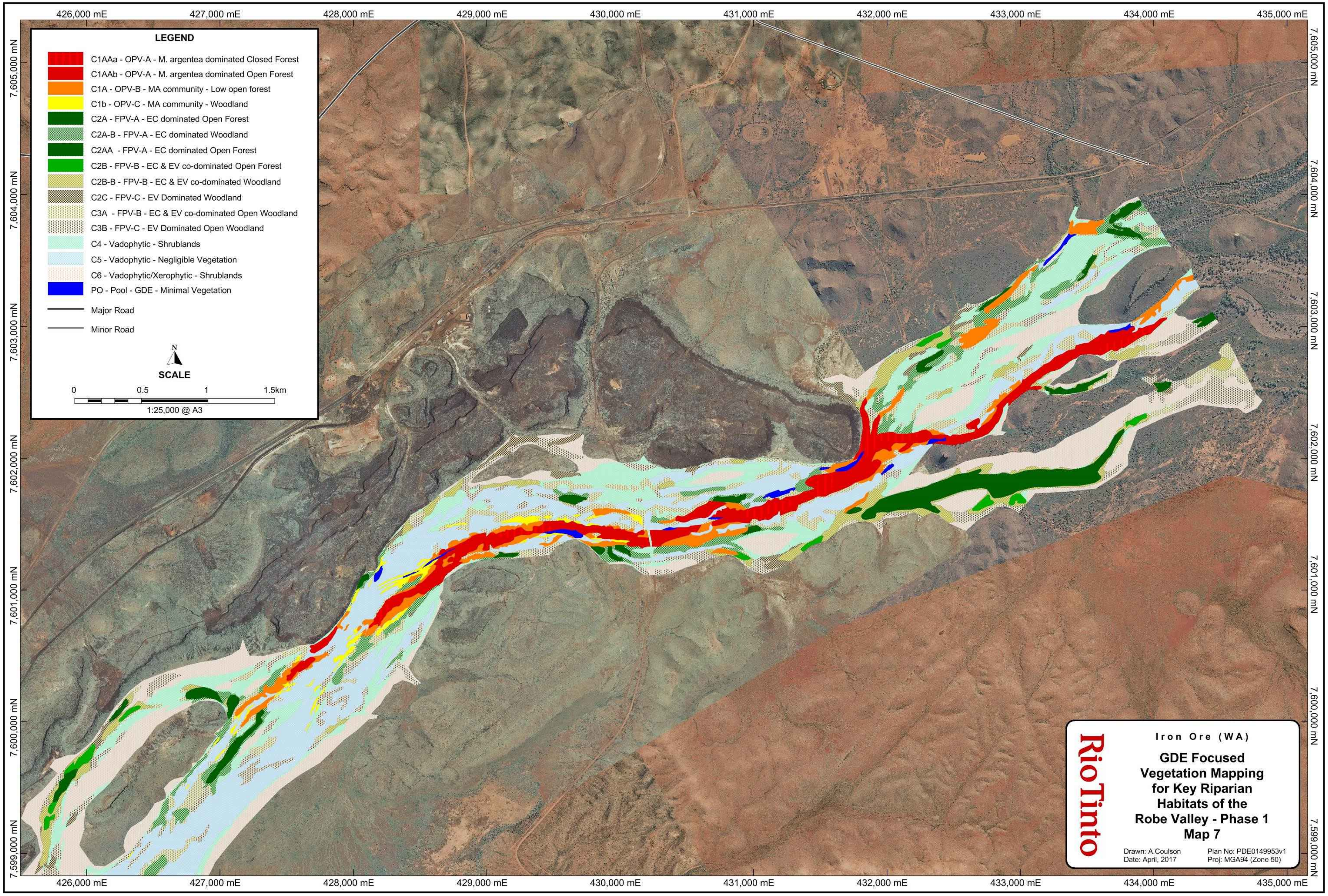

Figure 4-12: **Results of the Robe River riparian vegetation mapping project; Map 7 of 7**

Legend

Style	Veg Code	GDE type & GDE / Community Summary Info	Style	Veg Code	GDE type & GDE / Community Summary Info
	PO	Pool - GDE Minimal Vegetation		**C2A-B**	FPV-A EC domimonated Woodland
	C1AAa	OPV-A MA dominated Closed Forest		**C2B-B**	FPV-B EC & EV co-dominated Woodland
	C1AAb	OPV-A MA dominated Open Forest		**C2C**	FPV-C EV Dominated Woodland
	C1A`	OPV-B MA community - Low open forest		**C3A**	FPV-B EC & EV co-dominated Open woodland
	C1b	OPV-C MA community - Woodland		**C3B**	FPV-C EV Dominated Open Woodland
	C2AA	FPV-A EC domimonated Open Forest		**C4**	Vadophytic Shrublands
	C2A	FPV-A EC domimonated Open Forest		**C5**	Vadophytic Negligible vegetation
	C2B	FPV-B EC & EV co-dominated Open Forest		**C6**	Vadophytic/Xerophytic Shrublands

GDE = Groundwater Dependent Ecosystem, OPV = Obligate Phreatophytic Vegetation,
FPV = Facultative Phreatophytic Vegetation, EC = Eucalyptus camaldulensis, EV = Eucalyptus victrix
MA = Melaleuca argentea

Figure 4-13: Detailed Legend for Figures 4-6 to 4-12.

4.3 SIGNIFICANCE OF THE RIPARIAN VEGETATION COMMUNITIES IN THE STUDY AREA

The extremely large distances traversed during the field survey enabled a relatively comprehensive understanding of the structure, composition and distribution of riparian communities throughout the study area. Through this process a thorough appreciation of the ecological values and significance held by vegetation communities within the Robe River was also attained. From this combined experience a number of communities of note, significance or elevated hydrological sensitivity were identified.

The permanent and semi-permanent pools of the Robe River are considered to be a restricted landform and habitat; in particular those with high species diversity and low disturbance from weed invasion, trampling and grazing. At the time of survey; the river was exceptionally dry and the remaining relatively permanent pools had been subject to greater than normal trampling and disturbance pressure from cattle. Vegetation surrounding these pools was typically dominated by dense *Melaleuca argentea* open forests, accompanied by scattered (and at times co-dominant) *Eucalyptus camaldulensis* subsp. *refulgens* over mixed sedge, grass and herbaceous species, and is described by vegetation associations C1AAa, C1AAb & C1A. This landform and associated vegetation often occurred on the edges of the Robe River, often close to breakaways and rock walls, where either adjacent (often porous) lithologies help maintain shallow water tables, or shallow water tables were coinciding with the main low-flow channel of the river. Patches of closed *Melaleuca argentea* forest (C1AAa) were often in association with such landforms. At the time of the survey; the more significant of these communities, namely the C1AAa & C1AAb vegetation types, were relatively dry, so the understorey appeared relatively devoid of the accompanying mesic species diversity thought to be normally supported.

The C1AAb and C1A communities were the most widespread of the more significant riparian OPV communities, with the C1AA vegetation types generally occurring where shallow water tables supported a wider more expansive lateral extent to the resident OPV communities. In areas where the zone of suitable conditions for OPV was much narrower and such vegetation was often more tightly restricted to low flow channel banks, the C1A community was common and relatively dominant.

Quite extensive, and relatively significant representations of the C1AA OPV vegetation types were mapped and noted to occur adjacent to and upstream of the East Deepdale deposits, adjacent to Yeera Bluff, immediately upstream and downstream of the confluence with Jimmawurrada creek, immediately upstream of the eastern tip of Mesa G, immediately upstream and downstream of the confluence with Mungarathoona creek (multiple occurrences), and immediately downstream of Mesa B. These areas were significant owing to the density and maturity of their canopies, the associated mesic species diversity, supported faunal assemblages, and mesic community diversity occupying the fringing ecotones (as a result of decreasing water availability).

The results of the field work and vegetation mapping exercise were used to contribute to an assessment of the significance of each of the communities mapped to occur within the study area. The significance value attributed to each community is derived from consideration of the factors deemed to be relevant when considering vegetation significance, and which are presented in Section 2.3. To do this in a relatively systematic qualitative manner the significance values attributed within this study followed a local significance framework developed in Rio Tinto 2015, adapted within this study and presented in Section 3.2.

This Framework incorporates an assessment of the ecological values provided, the distribution or degree to which it is represented in the environment (local, sub-regional, regional), the condition, and the sensitivity to change of each community mapped within the study area.

The resultant local significance framework attributed to each riparian vegetation unit is initially assigned to one of the following significance ratings (Table 4-3).

Table 4-2: Ten tier "Significance Rating" scale adapted for this study

(1) Very High	(2) Moderate
(3) High+	(4) Minor-Moderate
(5) High	(6) Minor +
(7) Moderate-High	(8) Minor
(9) Moderate+	(10) Low

It should be noted that this scale assumes the most common and widespread of the vegetation-types/habitats within a study area are considered to fall outside this scale such that the Low rating is attributed to vegetation of slightly elevated significance when compared to the remaining "common" vegetation units.

The results of the significance assessment are presented in Table 4-3 below. It should be noted that Table 4-3 does not provide an indication of conservation significance, rather provides a relative ranking in the locality for the context of this study.

Table 4-3: Significance ratings attributed to each community mapped in the study area and the associated factors contributing to assigned significance ratings.

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C1AAa	Mature Melaleuca argentea dominated Closed Forest	OPV-A	Mature mesic Forest habitat, with a canopy dominated by Obligate Phreatophytes.	**Locally and Sub-regionally restricted and relatively rare/uncommon.** The rocky rangeland river variant of this community is genuinely uncommon and restricted within the Hamersley sub-region. Larger areal extent representations of this community are substantially restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion **Potentially significant from Biological and cultural standpoints.** The representations present in the study area are at times relatively large and possess relatively wide lateral extents within the River Channel. Some degree of impact has already been suffered by these communities due to the construction of mining related infrastructure and minimal degrees of surplus water discharge.	**High**	**Excellent to Very Good**	**Very High**	**High (+)**
			Perennial groundwater availability, with scattered perennial pools also associated.					
			High mesic flora species diversity.					
			Cryptic and Conservation significant fauna habitat (likely to include the Pilbara olive python (POP), Northern Quoll (NQ), and potentially the Ghost Bat and Pilbara Leaf Nosed Bat (PLNB).					
C1AAb	Mature Melaleuca argentea dominated Open Forest	OPV-A	Cryptic and conservation significant flora species habitat (e.g. Livistona alfredii).					
			High subsurface aquatic invertebrate diversity.					
			High local avifauna and bat species diversity.					
			Some reduced value from direct impacts (e.g. rail line footings) and cumulative impact. Some vegetation augmentation from surplus water discharge (mainly in the Mesa J vicinity).					
			Unique representation of a relatively upland positioned River System of the Pilbara.					
C1A	Mature M. argentea and *Eucalyptus camaldulensis* dominated Open Forest to Low Woodland	OPV-B	Relatively mature mesic woodland habitat	**Locally and somewhat Sub-regionally restricted and significant** The rocky rangeland river variant of this community is uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion	**Moderate-high**	**Excellent to Very Good**	**High**	**High**
			Perennial groundwater availability, with some scattered semi-permanent pools also associated.					
			Above average to High mesic flora species diversity.					
			Cryptic and Conservation significant fauna habitat (likely to include the POP, NQ, and potentially the Ghost Bat, and PLNB).					
			Cryptic and conservation significant flora species habitat (e.g. Livistona alfredii).					
			High subsurface aquatic invertebrate diversity.					

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C1A (continued)			High local avifauna and bat species diversity.	**Potentially significant from Biological and cultural standpoints.** The representations present in the study area are at times relatively large and possess relatively wide lateral extents within the River Channel. Some degree of impact has already been suffered by these communities due to the construction of mining related infrastructure and minimal degrees of surplus water discharge.				
			Some reduced value from direct and indirect impacts.					
			Some reduced value from direct impacts (e.g. tracks & rail line footings) and cumulative impact. Some vegetation augmentation from surplus water discharge (mainly in the Mesa J vicinity).					
			Above average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.					
			Potential for elevated sedge diversity, and possibly including or conservation significant species.					
PO	Minimal Vegetation	Pool - GDE	Perennial water availability	**Locally to Sub-regionally restricted**	**Moderate-High**	**Good to Poor**	**High**	**High**
			Above average mesic flora species diversity; particularly sedge and emergent macrophyte species					
			Cryptic and Conservation significant fauna habitat (likely to include the POP, NQ, and potentially the Ghost Bat, and PNLB), particularly migratory bird species.	**Habitat is considered significant from Both Biological, Cultural and Social standpoints**				
			Cryptic flora species habitat. Elevated sedge diversity, and possibly including cryptic and conservation significant sedge species grasses and herbs.	**The representations mapped and present in the study area are all considered relatively Permanent (to Semi-permanent) and at times relatively substantial in size.**				
			High subsurface aquatic invertebrate diversity.					
			High local avifauna diversity and important refuge habitat.					
			High local and sub-regional aquatic fauna diversity (particularly fish assemblages).					
			Some reduced value from direct impacts.					
			supports highly productive algal communities linked to productivity of surrounding ecosystems.					
C1b	Young to Semi-Mature Melaleuca argentea and Eucalyptus camaldulensis dominated Low Woodland	OPV-C	Young to semi-mature mesic woodland habitat	**Locally restricted and somewhat uncommon**	**Moderate to High**	**Excellent to Very Good**	**Moderate to High** (Generally High, but due to likely transient nature; rating is reduced)	**Moderate** (At times: Moderate to High; due to close proximity to High sig'n communities)
			At least semi-permanent to permanent groundwater availability, with surface water expressions not uncommon.	The rocky rangeland river variant of this community is somewhat uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion.				
			Relatively High mesic flora species diversity.					
			At times relevant as cryptic and Conservation significant fauna habitat (potential to include the POP, NQ, and potentially the Ghost Bat, and PLNB).					
			Cryptic flora species habitat, and some potential as habitat for conservation significant flora (e.g. Livistona alfredii).					
			High subsurface aquatic invertebrate diversity.					

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C1b (continued)			Relatively High local avifauna and bat species diversity. Some reduced value from direct and indirect impacts. Some reduced value from direct impacts (e.g. tracks & rail line footings) and cumulative impact. Some reduced value due to the interpreted likely transient nature of this type of community within relevant zones of a Pilbara ephemeral river system.	The representations present in the study area are at times relatively large and possess relatively wide lateral extents within the river channel. Some degree of impact has already been suffered by these communities due to the construction of mining related infrastructure and minimal degrees of surplus water discharge.				
C2AA	Large Mesic Eucalyptus camaldulensis dominated Open Forest representations	FPV-A	Mature to Semi-Mature mesic open-forest habitat. Apparent; at least semi-permanent to permanent groundwater availability. Relatively high to Above average mesic flora species diversity. Cryptic and Mesic Fauna habitat (May include the POP). Cryptic flora species habitat. Potentially possesses Above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts. May represent a higher risk GDE due to Mesic indicators. Above average to high quality representation of Riverine Eucalypt forests.	**This community represents the more mesic and Larger areal extent representations of the C2A community. Given the size, structure and composition of this community, it is considered to be Locally and potentially sub-regionally restricted.** The rocky rangeland creek variant of this community is somewhat uncommon within the Hamersley sub-region, and relatively restricted to Larger River and creek systems.	**Moderate (+)** (Moderate to High for largest representations)	**Very Good to Good** (at times poor due to moisture attracting grazing disturbance)	**Moderate to High**	**Moderate (+)**
C2A	Eucalyptus camaldulensis dominated Open Forest	FPV-A	Mature to Semi-Mature mesic open-forest habitat. Apparent; at least semi-permanent groundwater availability. Above average mesic flora species diversity. Cryptic and Mesic Fauna habitat (May include the POP). Cryptic flora species habitat. Above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts. Above average representation of Riverine Eucalypt forests.	**Somewhat locally restricted but not uncommon** The rocky rangeland creek variant of this community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.	**Moderate**	**Very Good to Good**	**Moderate to high**	**Moderate**

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C2B	Eucalyptus camaldulensis & Eucalyptus victrix co-dominated Open Forest	FPV-B	Mature somewhat mesic woodland/open-forest habitat. Apparent; at least semi-permanent groundwater availability. Elevated mesic flora species diversity. Cryptic and Mesic Fauna habitat (Some potential for Conservation significant fauna). Cryptic flora species habitat (may include Stylidium Weeli Wolli). Above average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Some reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt forests.	**Somewhat locally restricted but not uncommon** The rocky rangeland river variant of this community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.	**Minor-Moderate**	**Very Good to Good** (+ regularly Poor)	**Moderate (+)**	**Moderate**
C2A-B	Eucalyptus camaldulensis dominated Woodlands	FPV-A	Mature somewhat mesic woodland habitat. Apparent; at least semi-permanent to permanent groundwater proximity. Elevated mesic flora species diversity. Cryptic and Mesic Fauna habitat (Some potential for Conservation significant fauna). Cryptic flora species habitat (may include Stylidium Weeli Wolli). Above average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Some reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor-Moderate**	**Very Good to Good** (+ regularly Poor)	**Moderate**	**Minor-Moderate**
C2B-B	Eucalyptus camaldulensis & Eucalyptus victrix co-dominated Woodland	FPV-B	Mature somewhat mesic woodland habitat. Apparent; at least semi-permanent to permanent groundwater proximity. Elevated mesic flora species diversity. Cryptic and Mesic Fauna habitat (Some potential for Conservation significant fauna). Cryptic flora species habitat (may include Stylidium Weeli Wolli). Above average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor (+)**	**Good to Poor**	**Moderate**	**Minor-Moderate**

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C2C	Eucalyptus victrix dominated Woodland	FPV-C	Mature somewhat mesic woodland habitat. Generally ephemeral water availability, with indications that groundwater may be accessed but accessibility is moderately variable. Elevated to average Mesic flora species diversity. Mesic Fauna habitat. Elevated subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor**	**Good to Poor**	**Low-Moderate**	**Minor**
C3A	Eucalyptus camaldulensis & Eucalyptus victrix co-dominated Open Woodland	FPV-B	Mature somewhat mesic open woodland habitat. Apparent; at least regular to intermittent groundwater proximity. Elevated subsurface aquatic invertebrate diversity. Mesic flora species present. Mesic Fauna habitat. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor (+)**	**Good to Poor**	**Low (+)**	**Minor (+)**
C3B	Eucalyptus victrix dominated Open Woodland	FPV-C	Mature open woodland habitat. Generally ephemeral water availability, with indications that groundwater may be accessed but accessibility is highly variable. Mesic flora species present. Mesic Fauna habitat. Elevated subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Common and not locally restricted**	**Minor**	**Good**	**Low (+)**	**Minor**

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C4	River bed Shrublands	Vadophytic with isolated facultative phreatophytes	Riparian habitat with ephemeral water availability. Mesic Fauna habitat. Elevated to average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Some to at times significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Some increased value from discharge enhancement.	**Relatively common but somewhat restricted.** This community is relatively common within the western half of the Hamersley sub-region, but riparian representations are restricted to larger creek/river systems.	**Minor**	**Very Good to Good** (& regularly Poor)	**Low**	**Minor**
C5	Scoured Beds with minimal vegetation	Vadophytic with isolated facultative phreatophytes	Ephemeral water availability. Mesic Fauna habitat. Potentially elevated subsurface aquatic invertebrate diversity. Some reduced value from direct impacts. High potential for reversion to pre-impact condition due to fluvial processes in effect. Large repository of coarse alluvial sediments important for aquatic invertebrate habitats.	**Minimal vegetation; habitat relatively common but somewhat restricted.**	**Low**	**Excellent to Very Good**		**Low**
C6	Floodplain Shrublands	Vadophytic / Xerophytic	Ephemeral water availability (Perennial in some areas at present). Slightly elevated mesic flora species diversity. Mesic Fauna habitat. Elevated local avifauna diversity. At times significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.	**Common and not locally restricted**	**Low**	**Very Good to Good (and regularly Poor)**	**Very Low**	**Low**

4.4 GDE SENSITIVITY AND RISK MAPPING

For the purpose of mapping the spatial distribution of risk within the study area each community mapped was attributed a risk rating. This process firstly involved providing an interpretation of the degree of sensitivity (or vulnerability) to hydrological change held by each community. Secondly; using this degree of sensitivity/vulnerability; produce a rating of the risk that "measurable" impact/change to a community could result from a significant degree of hydrological change. A significant degree of hydrological change may be in multiple forms, including;

- a 2-3m drop in the average groundwater height within the alluvial's immediately adjacent to features of value;
- a discernible (statistically significant) reduction in catchment reporting to the river, and
- a physical obstruction to river flow significantly changing flow patterns.

A "measurable" 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. Such arid habitats exhibit extremes in climate and therefore local vegetation inherently possess numerous adaptive traits to facilitate their persistence. As a result, significant impacts are best defined as those changes which are able to be distinguished from the natural variability in effect at the locality. For this reason it is important to be able to distinguish anthropogenic impacts from the inherent degree of natural variation and associated riparian changes. This baseline (or natural) riparian vegetation change is generally restricted to changes in health and at times structure, but less often leading to vegetation compositional changes. As a result "measurable" impact is restricted to that level of riparian change which includes both health changes as well as at least one of either compositional (loss or addition of dominant species) or structural change in resident vegetation.

Conceptually, a significant degree of hydrological change may be best viewed as a magnitude equal to or greater than that hydrological variability experienced naturally at least every 1 to 2 decades. However at this stage, the magnitude of hydrological change, or the definition of a "measurable" impact is not the important factor. What is most important to understand is that an interpretation of sensitivity has been combined with additional influential environmental factors to attribute a risk rating. Thus; once the magnitude of potential hydrological change can be measured the risk rating can be used as a factor by which to multiply the magnitude of hydrological change to in–turn give an idea of the potential size of the resulting ecological perturbation.

To interpret this sensitivity and therefore attribute a final risk rating; the following factors were considered:

(1) Water use strategy (i.e. obligate phreatophyte, facultative, etc.) and associated groundwater dependence associated;
(2) Obligate phreatophyte age structure (maturity);
(3) Obligate phreatophyte structural dominance;
(4) Distribution within the bed profile;
(5) Vegetation cover (i.e. stand density);
(6) Proximity to surface water; and
(7) Inherent Significance; broadly as a measure of degree of restriction, and magnitude of associated values.

Once all of these factors were considered a risk rating was attributed, and this rating was attributed from a 10 tier scale of risk rating such that the following ratings presented in Table 4-4 were available. In situations where, almost no risk was perceived to be present, a rating of Negligible was determined as the relevant rating to be attributed.

Table 4-4: Ten tier "Risk Rating" scale adapted for this study

(1) Very High	(2) Moderate
(3) High+	(4) Low-Moderate
(5) High	(6) Low+
(7) Moderate-High	(8) Low
(9) Moderate+	(10) Very Low

The final Residual risk ratings (similar to "Importance" ratings applied in SKM (2001) attributed to each community are presented in Table 4-5 The spatial risk mapping created from this risk assessment process is presented in Figures 4-14 to 4-17.

Table 4-5: Risk ratings attributed to each community mapped in the study area and the associated GDE classification and sensitivity rating associated with each.

<table>
<tr><th>Veg Code</th><th>Broad Vegetation Type
(MA= Melaleuca argentea, EC= Eucalyptus camaldulensis, EV= Eucalyptus victrix)</th><th>GDE Classification</th><th>Initial sensitivity rating</th><th>Residual Risk (or importance) Attributed</th></tr>
<tr><td>C1AAa</td><td>Mature MA dominated Closed Forest</td><td>OPV-A</td><td>Very High</td><td rowspan="2">Very High</td></tr>
<tr><td>C1AAb</td><td>Mature MA dominated Open Forest</td><td>OPV-A</td><td>Very High</td></tr>
<tr><td>C1A</td><td>Mature MA and EC dominated Open forest to Low Woodland</td><td>OPV-B</td><td>High to High (+)</td><td rowspan="2">High</td></tr>
<tr><td>PO</td><td>Minimal Vegetation</td><td>Pool - GDE</td><td>High</td></tr>
<tr><td>C1b</td><td>MA and EC dominated Low Woodland</td><td>OPV-C</td><td>High</td><td rowspan="2">Moderate-High</td></tr>
<tr><td>C2AA</td><td>Large Mesic EC dominated Open Forest representations</td><td>FPV-A</td><td>Moderate to High</td></tr>
<tr><td>C2A</td><td>EC dominated Open Forest</td><td>FPV-A</td><td>Moderate to High</td><td rowspan="3">Moderate (+)</td></tr>
<tr><td>C2B</td><td>EC & EV co-dominated Open Forest</td><td>FPV-B</td><td>Moderate (+)</td></tr>
<tr><td>C2A-B</td><td>EC dominated Woodlands</td><td>FPV-A</td><td>Moderate</td></tr>
<tr><td>C2B-B</td><td>EC & EV co-dominated Woodland</td><td>FPV-B</td><td>Moderate</td><td>Moderate</td></tr>
<tr><td>C2C</td><td>EV Dominated Woodland</td><td>FPV-C</td><td>Low to Moderate</td><td rowspan="2">Low-Moderate</td></tr>
<tr><td>C3A</td><td>EC & EV co-dominated Open Woodland</td><td>FPV-B</td><td>Low (+)</td></tr>
<tr><td>C3B</td><td>EV Dominated Open Woodland</td><td>FPV-C</td><td>Low (+)</td><td rowspan="2">Low</td></tr>
<tr><td>C4</td><td>Shrublands</td><td>Vadophytic</td><td>Low</td></tr>
<tr><td>C5</td><td>Beds with minimal vegetation</td><td>Vadophytic</td><td>Negligible</td><td rowspan="2">Very Low</td></tr>
<tr><td>C6</td><td>Shrublands</td><td>Vadophytic / Xerophytic</td><td>Very Low</td></tr>
</table>

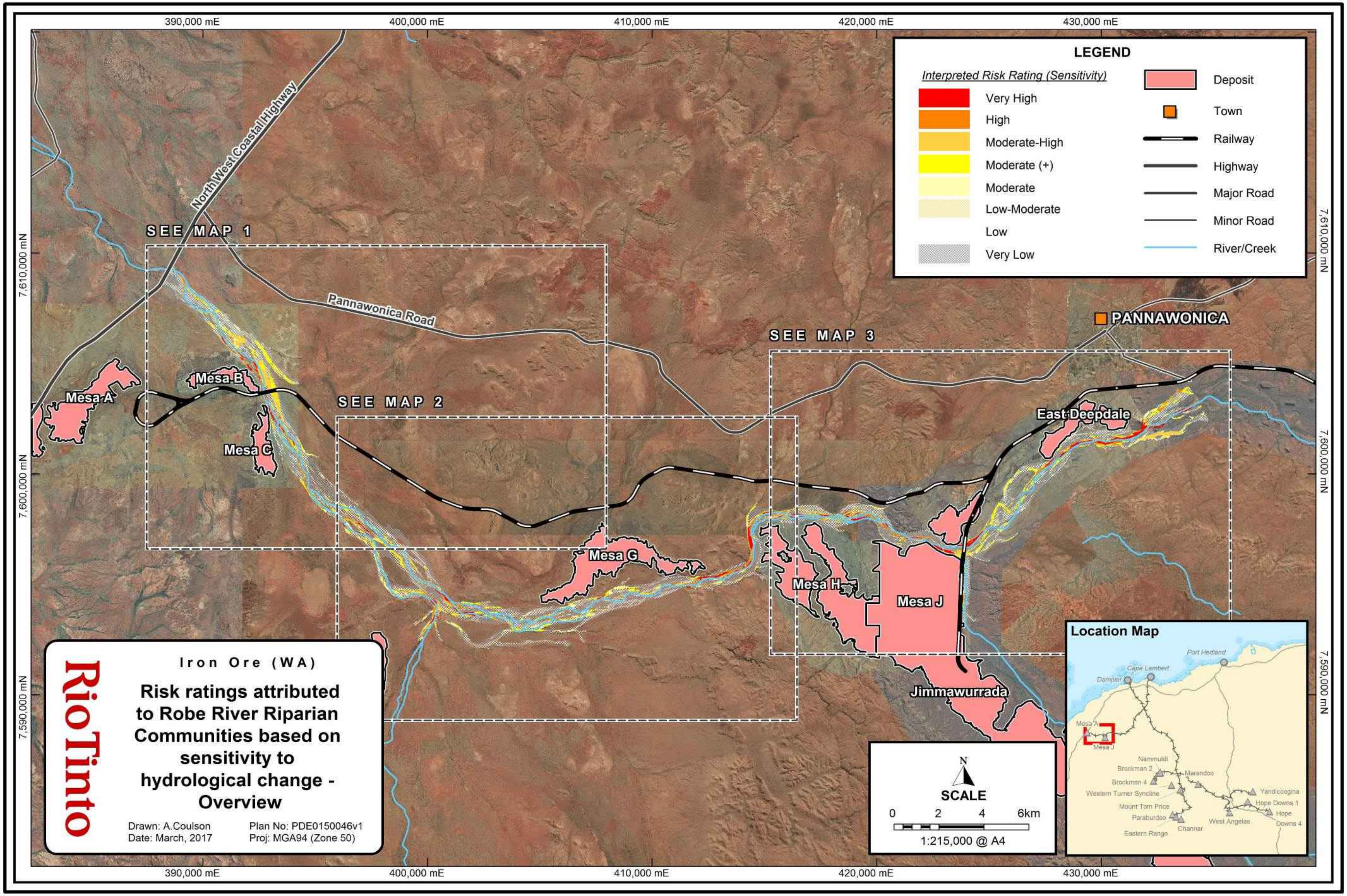

Figure 4-14: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Overview Map

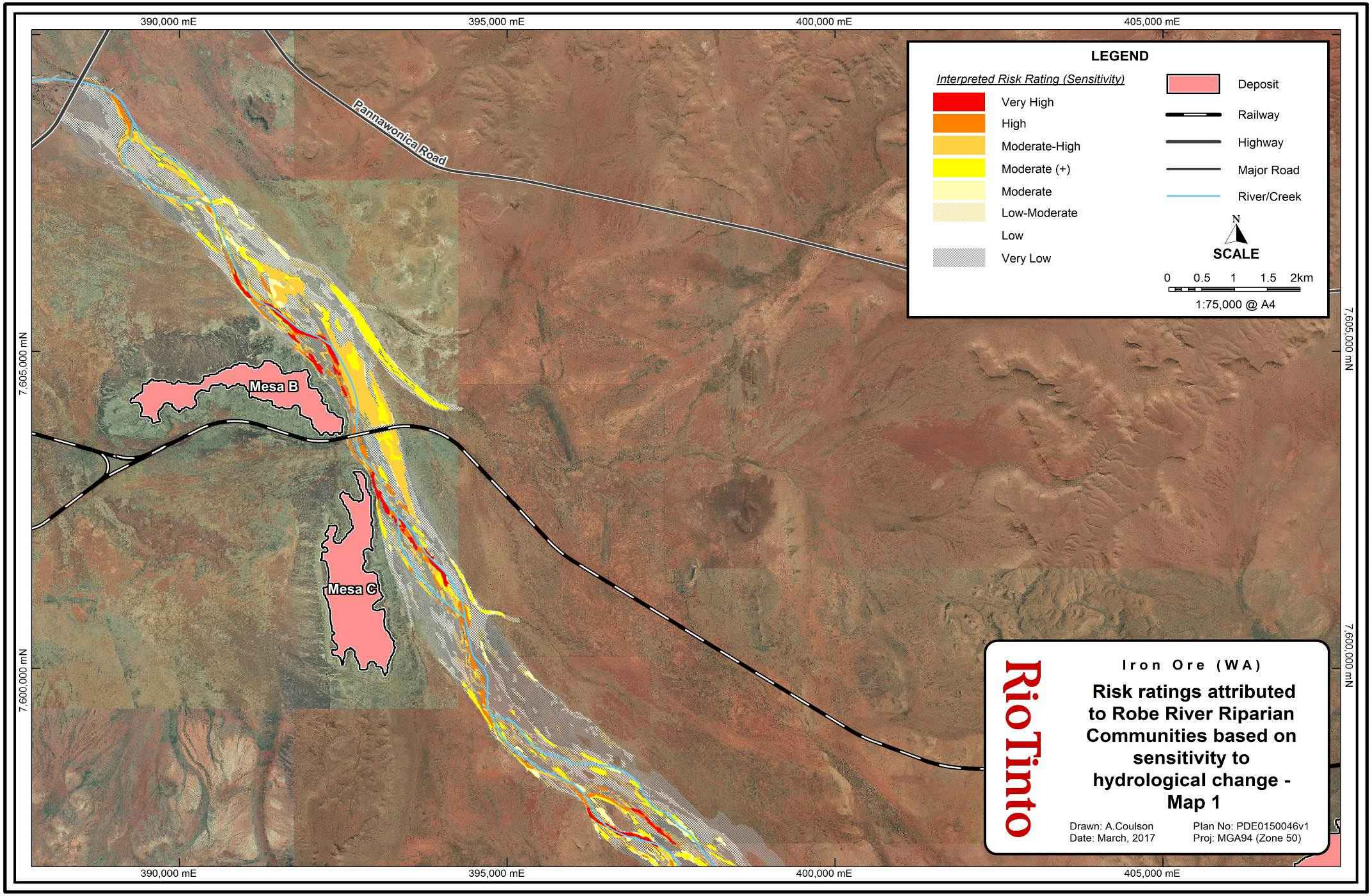

Figure 4-15: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Mesas B and C

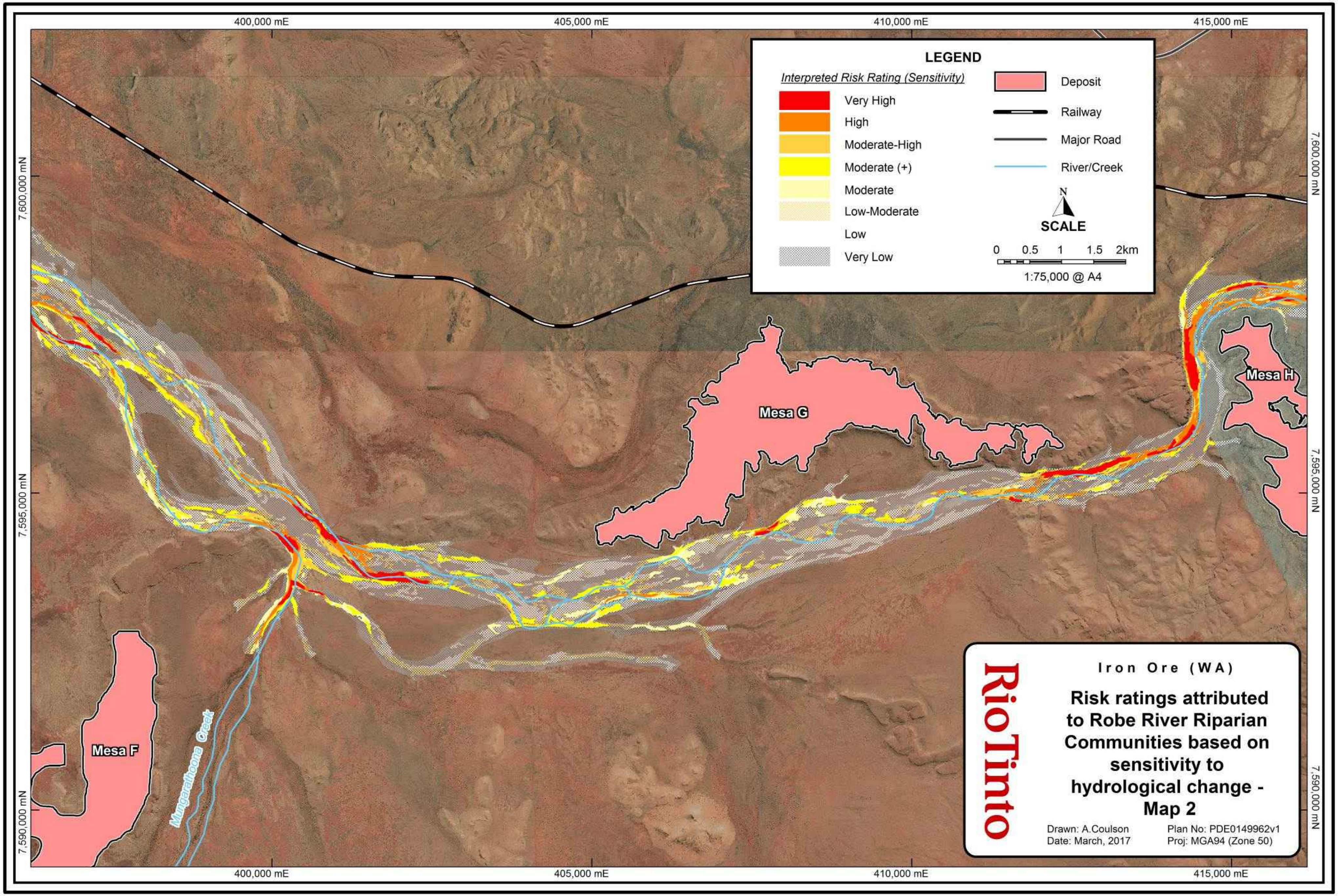

Figure 4-16: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Mesa F to H.

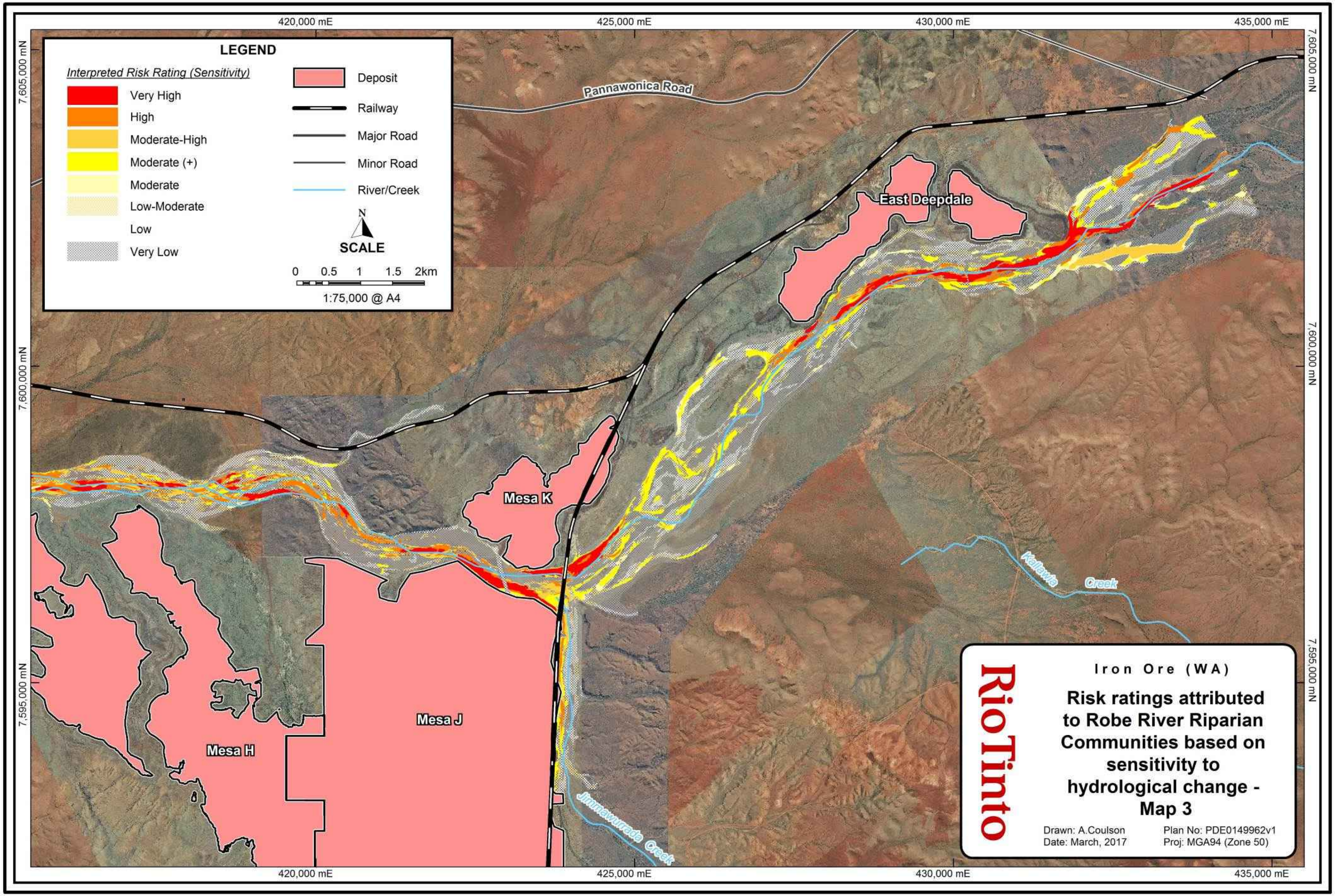

Figure 4-17: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Mesa H to East Deepdale.

5 DISCUSSION

Within the study area; in general, GDV in the form of OPV was relatively common and somewhat consistently longitudinally (i.e. parallel to the river flow) distributed throughout. Local OPV is sensitive to hydrological change and has therefore been categorised as a High Risk type of GDE (as defined by the 10 tier risk rating scale presented in Table 4-4), as it possesses a core dominant species which is obligately dependent on groundwater access.

With regard to the more mature types of OPV identified; distributions were less consistent longitudinally, but such communities were still relatively common throughout the study area. Lateral (i.e. perpendicular to the river flow) distribution patterns of OPV (particularly the distribution of reaches possessing multiple large and laterally broad OPV representations) within the river profile did show stronger spatial correlation to various topographical, drainage and geological features in the landscape. Such features include; large structurally controlled formations (e.g. mesas) in close proximity to the river, river sections strongly confined by outcropping formations with cliffs / bluffs, and confluences with major creek systems. The distribution of mature OPV with tree strata solely dominated by obligate phreatophytes (*Melaleuca argentea*), and represented by vegetation types C1AAa & C1AAb were also more restricted and strongly correlated with such features. This observed association was considered to indicate that through these areas, groundwater was likely shallow and consistently accessible such that these areas also supported surface water expressions and OPV of much broader lateral extent.

Experience with large riparian systems elsewhere in the Pilbara suggests strong correlation between the distribution of mature OPV and alluvial bed intersection/interactions with underlying porous lithologies such as channel iron deposits. Despite this, it is not yet clear what is driving the distribution of clustering among larger, broader, and structurally mature OPV representations within the Robe River. It is plausible that the distribution of such communities may be significantly influenced by these landscape features, but their degree of influence and interaction with other sub-surface and local to catchment scale hydrological factors is highly variable and relatively unknown.

Based on the results, it was noted that occurrences of the mature C1A OPV community were regularly distributed throughout the study area, even occurring in areas where large and obvious landscape features (Mesas etc., with potential to influence groundwater proximity) were relatively absent. This is thought to be important, as it potentially provides evidence supporting the concept that the Robe River is representative of a River Base-flow System (RBS) type of GDE (Clifton and Evans 2001, Boulton and Hancock 2006), where resident communities are likely supported by a degree of groundwater base-flow throughout the local alluvial aquifer. While RBSs are generally perceived to be represented by rivers with perennial to near perennial surface flows, they can also be represented by sub-surface flow which maintain intermittent pools such as those present on the Robe River. Based on DoW gauging at Yarraloola; periods of zero flow along the Robe River occur less than 25% of the time (Streamtec 2016). In addition to this; pool velocity measurements conducted regularly as part of the long term ecological research project on the Robe River (Dobbs & Davies 2009) show that low flows (throughput) are often maintained in a significant proportion of the permanent pools every year. Other local evidence for a relatively sustained sub-surface groundwater flow within certain zones of the Robe is evident within the results of work conducted by Dobbs & Davies (2009), and includes:

- Abnormally low dry season turbidity levels within monitored permanent pools of the Robe River, suggesting relatively consistent sub-surface throughput is potentially reducing sediment loads;

- Observed relatively high levels of algal productivity, and likely nutrient enrichment within local river pools (ecologia & Streamtec 1992);

- Similar elevated nitrogen levels recorded in defined “ramp up” and “ramp down” periods (i.e. increasingly wet or increasingly dry periods) suggest nitrogen levels are less linked to rainfall induced flows and more likely to be a result of hyporheic exchanges and resultant nitrogen subsidies;

- The highest (while still relatively consistent) nitrogen levels are recorded in the largest, potentially most groundwater influenced pools; which could suggest that elevated nitrogen levels are likely to be subsidised by groundwater influx and associated hyporheic exchange processes (however may also be influenced by grazing inputs) .

- Monitored permanent pools commonly recorded as having a small flow velocity at 0.6m depth during dry season monitoring rounds thus indicating common throughput (i.e. supports the understanding that these are the result of base-flow).

Work conducted by Rio Tinto (2017) as part of the H3 Hydrogeological assessments for Mesa C and Mesa H, while not yet definitive, also indicates that base-flow through the alluvial aquifers is likely to have a significant influence on groundwater levels in the Robe River channel. This conclusion is also supported by work conducted by WRM (2016) and Aquaterra (2005).

In general, it is likely that GDEs which rely on river base-flow, have the potential to support more extensive OPV than GDEs that rely on more static type aquifers. Furthermore it is plausible that through continuing inputs; base-flow type GDEs are likely to be more resilient to the influence of changes experienced in “reach” to “local” scale aquifers due to “catchment” and “landscape” scale aquifer influences which are also being exerted on the base-flow delivered at the local and reach scales. Work by (Boulton and Hancock 2006) exploring the functional dependency of river base-flow systems on groundwater at the channel reach, catchment and landscape (regional) scales outlines how this upper catchment scale influence has the potential to minimise or even offset the influence of local scale changes.

In two key sections of the study area, the distribution of OPV showed sharp reductions in abundance, and at times only supported small scatterings of immature, more transient OPV (broadly represented by the C1b vegetation type). These two sections are located within the river reaches broadly running parallel and adjacent to Mesa G, and the reach located between the K and East Deepdale Mesas. For these reaches it is thought that sub-surface alluvial material depths and a reduced influence of sub-surface lithology is likely maintaining deeper groundwater and reduced water accessibility to biota. Importantly, the maintenance of at least minimal amounts of OPV in these reaches also potentially supports the inference that the system is likely base-flow driven.

As detailed above, there is evidence to suggest that rather that possessing more static primarily geomorphologically driven groundwater formations under the Robe River, the groundwater levels below are likely to also be significantly influenced by a catchment scale base-flow of groundwater.

Based on the results of the “H3 Hydrogeological Risk Assessment” for Mesa H (Rio Tinto 2017); the Robe River is considered an ephemeral river, which carries a significant underflow in its alluvial bed. In combination with the evidence sourced from work by Dobbs & Davies (2009), this suggests that; at least the vast majority of the river which falls within the current study area is likely to represent a river base flow type GDE which supports significant amounts of terrestrial GDV.

With the Robe River considered as likely to represent a river base flow type system; it is considered that the abundance and distribution of GDV mapped to occur within this system is largely dependent on the interaction of this base-flow and associated catchment scale inputs with local hydrogeology. Furthermore given the likely influence of base-flow; the influence of dewatering of adjacent local-scale aquifers (in some cases not considered to possess basement hydraulic connectivity with river alluvials) on groundwater proximity within the river channel, may be minimal or at least significantly reduced. However there are a number of unknowns; particularly in relation to basement hydraulic connectivity with alluvial’s, and to a lesser degree in relation to the influence of base-flow.

6 CONCLUSIONS

With climatic influences broadly driving water levels in the Robe River to their lowest level in 26 years, and the potential for further anthropogenic changes to vegetation supported by the river a more holistic assessment of the significant riparian values of the Robe River was undertaken.

Broadly speaking the key aims of the study were to;

- Gather high confidence spatial data on the distribution structure, maturity/immaturity and temporal stability of resident OPVs (and to a lesser extent FPV) within the study area.

- Provide detailed mapping best positioned to assess significance and hydrological sensitivity of all potentially groundwater dependent vegetation throughout the study area (to support impact assessments and cumulative impact assessments)

- Provide spatial mapping of the interpreted risk associated with the significance and inherent sensitivity of these communities to potential hydrological change.

As a result of the degree of survey effort maintained throughout the study area, the field methodology employed, and the lack of significant limitations to the study outputs the study successfully achieved the key aims of the study. In addition, beyond the outputs presented herein; the level of detail recorded and the riparian knowledge accumulated through this study will directly continue to add significant additional value to the monitoring and management of significant riparian communities of the Robe Valley in the short to longer term. From these aims the following key learnings were made:

- GDEs in the form of OPV were relatively common and somewhat consistently longitudinally distributed throughout the study area.

- The more mature types of OPV (C1A vegetation type) were less consistent longitudinally, but still relatively common throughout the study area.

- Lateral distribution patterns of OPV, (particularly the distribution of reaches possessing multiple large and laterally broad representations) within the river profile, showed greater spatial correlation to geomorphological features in the landscape than longitudinal distributions.

- OPV with tree strata solely dominated by obligate phreatophytes (vegetation types C1AAa & C1AAb) and often more laterally broad in spatial extent; were relatively restricted and further correlated with larger geomorphological and geologically controlled features, demonstrating that in such areas, groundwater was quite shallow and consistently accessible.

From the resultant risk mapping produced as part of this study, it can inevitably be seen that the potential risk posed to GDEs in the study area by hydrological change in the alluvial aquifer is relatively extensive. However it is important to keep the risk mapping and attributed risk ratings in context. The risk attributed is not directly related to any proposed impacts related to current development proposal, but is rather a hypothetical risk if significant hydrological change were to eventuate for whatever reason. Furthermore; the Risk ratings were developed through a process of classifying dependence and inferred hydrological sensitivity on qualitative indicators (and some coarse quantitative indicators) of degrees of dependency on groundwater. In addition, it was recognised that the complexity of the natural environment determines that the potential for hydrological changes to be realised in the riparian zone is influenced by many overlapping factors. Factors which occur at the reach, catchment and regional scale, such that only a proportion of the predicted reach to local scale hydrological response may be realised.

While there is evidence to suggest that GDV present in the Robe River is to a degree likely supported by a sub-surface flow (consistent with a river base flow system), and as a result the influence of dewatering of smaller scale local aquifers, may be significantly reduced; at this stage there are still unknowns at a macro scale.

It is clear from the results of this study that a significant amount of groundwater dependent vegetation resides within the study area; importantly such communities are not restricted to those river reaches directly adjacent to mineral resources of the Robe Valley. In addition, there is a high potential that the influence of catchment scale base-flow has the ability to minimise low to moderate scale anthropogenic impacts on local hydrology/GDEs. Furthermore, in light of the magnitude of climatic influence inherently associated with and acting upon GDE's within arid Pilbara environments; the potential for broader scale anthropogenic impact on such communities is significantly reduced.

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8 APPENDICES

Appendix 1: Vegetation structure and condition scale used for vegetation description and mapping formulated within this study.

Vegetation Structure and Condition Scale

Vegetation Structural Classes*

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 / bunch grassland / sedgeland / herbland	Tussock grassland / bunch grassland / sedgeland / herbland	Open tussock grassland / bunch grassland / sedgeland / herbland	Very open tussock grassland / bunch grassland / sedgeland / herbland	Scattered tussock grasses / bunch grasses / sedges / herbs

* Based on 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.

Vegetation Condition Scale*

E = Excellent (=Pristine of BushForever) Pristine or nearly so; no obvious signs of damage caused by the activities of European man.
VG = Very Good (= Excellent of BushForever) Some relatively slight signs of damage caused by the activities of European man. For example, some signs of damage to tree trunks caused by repeated fire, the presence of some relatively non-aggressive weeds such as **Sonchus oleraceus* or **Cucumis* spp., or occasional vehicle tracks.
G = Good (= Very Good of BushForever) More obvious signs of damage caused by the activities of European man, including some obvious impact on the vegetation structure such as that caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive ones such as **Cenchrus* spp.
P = Poor (= Good of BushForever) Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of activities of European man, such as grazing, partial clearing (chaining) or frequent fires. Weeds as above, probably plus some more aggressive ones such as **Cenchrus* spp.
VP = Very Poor (= Degraded of BushForever) Severely impacted by grazing, very frequent fires, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species including very aggressive species such as **Prosopis* spp.
D = Completely Degraded (= Completely Degraded of BushForever) Areas that are completely or almost completely without native species in the structure of their vegetation; ie. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.

* Based on Trudgen M.E. (1988). A Report on the Flora and Vegetation of the Port Kennedy Area. Unpublished report prepared for Bowman Bishaw and Associates, West Perth.

Appendix 2: Associated species recorded in each mapped vegetation type.

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
PO	*Minimal Vegetation*	*OPV*	*Acacia ampliceps, Acacia trachycarpa, Achyranthes aspera, Aeschynomene indica, Alternanthera denticulata, Alternanthera nodiflora, Ammannia baccifera, Argemone ochroleuca* subsp. *Ochroleuca*, Boerhavia repleta, Cenchrus ciliaris*, Cenchrus setiger*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Corchorus tridens, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cymbopogon ambiguus, Cynodon dactylon*, Cyperus bulbosus, Cyperus iria, Cyperus vaginatus, Eriachne benthamii, Eriachne flaccida, Eleocharis dulcis, Eleocharis geniculata, Eucalyptus camaldulensis, Euphorbia australis, Flueggea virosa subsp. melanthesoides, Gomphrena cunninghamii, Gossypium robinsonii, Helichrysum luteoalbum, Hybanthus aurantiacus, Ipomoea muelleri, Juncus kraussii, Lactuca serriola*, Lobelia arnhemiaca, Marsilea hirsuta, Melaleuca glomerata, Melaleuca argentea, Nicotiana occidentalis subsp. occidentalis, Passiflora foetida* var. *hispida*, Petalostylis labicheoides, Phyllanthus reticulatus, Pluchea rubelliflora, Portulaca oleracea, Ptilotus gomphrenoides, Rhynchosia minima, Rostellularia adscendens* var. *clementii, Schoenoplectus subulatus, Schenkia clementii, Sesbania cannabina, Setaria verticillata*, Sonchus oleraceus*, Sporobolus australasicus, Stemodia grossa, Trachymene oleracea* subsp. *Oleracea, Trianthema pilosum, Trianthema triquetrum, Typha domingensis, Utricularia australis, Vigna lanceolata* var. *lanceolata,* and *Zaleya galericulata.*	*N/A*
C1AAa	*Mature MA dominated Closed Forest*	*OPV-A*	*Abutilon sp. Dioicum (A.A. Mitchell PRP 1618), Acacia ampliceps, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Achyranthes aspera, Aerva javanica*, Aeschynomene indica, Alternanthera denticulata, Alternanthera nodiflora, Amaranthus cuspidifolius, Ammannia baccifera, Argemone ochroleuca* subsp. *Ochroleuca*, Boerhavia coccinea, Boerhavia repleta, Bulbostylis barbata, Capparis spinosa* var. *nummularia, Carissa lanceolata, Cenchrus ciliaris*, Cenchrus setiger*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Corchorus tridens, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cucumis variabilis, Cymbopogon ambiguus, Cynodon dactylon*, Cyperus bulbosus, Cyperus iria, Cyperus vaginatus, Datura leichhardtii*, Echinochloa colona*, Eriachne benthamii, Eriachne flaccida, Euphorbia australis, Euphorbia hirta*, Ficus aculeata, Fimbristylis dichotoma, Flueggea virosa* subsp. *melanthesoides, Gomphrena cunninghamii, Gossypium robinsonii, Helichrysum luteoalbum, Hibiscus austrinus, Hybanthus aurantiacus, Ipomoea muelleri, Juncus kraussii, Lactuca serriola*, Lobelia arnhemiaca, Livistona alfredii, Malvastrum americanum*, Marsilea hirsuta, Melaleuca glomerata, Nicotiana occidentalis* subsp. *occidentalis, Passiflora foetida* var. *hispida*, Petalostylis labicheoides, Phoenix dactylifera*, Phyllanthus maderaspatensis, Phyllanthus reticulatus,* and *Pluchea rubelliflora, Portulaca oleracea, Ptilotus gomphrenoides, Rhynchosia minima, Rostellularia adscendens* var. *clementii,*	*Similar to EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
			Schenkia clementii, Sesbania cannabina, Setaria verticillata, Solanum diversiflorum, Sonchus oleraceus*, Sporobolus australasicus, Stemodia grossa, Tinospora smilacina, Trachymene oleracea* subsp. *Oleracea, Trianthema pilosum, Trianthema triquetrum, Trichodesma zeylanicum var. zeylanicum, Typha domingensis, Vigna lanceolata var. lanceolata,* and *Zaleya galericulata.*	
C1AAb	*Mature MA dominated Open Forest*	*OPV-A*	*Acacia ampliceps, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Alternanthera nana, Amaranthus undulatus, Amaranthus cuspidifolius, Ammannia baccifera, Argemone ochroleuca* subsp. *ochroleuca*, Boerhavia coccinea, Capparis spinosa* var. *nummularia, Cenchrus ciliaris*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cucumis variabilis, Cymbopogon ambiguus, Cyperus bulbosus, Cyperus iria, Cyperus vaginatus, Cynodon dactylon*, Echinochloa colona*, Eriachne benthamii, Eriachne flaccida, Euphorbia australis, Ficus aculeata, Fimbristylis dichotoma, Flueggea virosa* subsp. *melanthesoides, Gomphrena cunninghamii, Cyperus vaginatus, Eucalyptus victrix, Goodenia lamprosperma, Gossypium robinsonii, Ipomoea muelleri, Juncus kraussii, Livistona alfredii, Notoleptopus decaisnei, Passiflora foetida* subsp. *hispida*, Petalostylis labicheoides, Phyllanthus reticulatus, Pluchea rubelliflora, Portulaca oleracea, Ptilotus gomphrenoides, Rhynchosia minima, Rhynchosia bungarensis, Rostellularia adscendens* var. *clementii, Schenkia clementii, Sesbania cannabina, Solanum diversiflorum, Sporobolus australasicus, Stemodia grossa, Tinospora smilacina, Sesbania formosa, Sonchus oleraceus*, Tephrosia rosea* var. *Fortescue Creeks (M.I.H. Brooker 2186), Vigna lanceolata, Waltheria indica,* and **Vachellia farnesiana.*	*MaEcCv (Astron 2016*) or Similar to EcMaCvCspp (Astron 2015)*
C1A	*Mature MA and EC dominated Open forest to Low Woodland*	*OPV-B*	*Acacia ampliceps, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Alternanthera nana, Amaranthus undulatus, Amaranthus cuspidifolius, Argemone ochroleuca* subsp. *ochroleuca*, Boerhavia coccinea, Capparis spinosa* var. *nummularia, Cenchrus ciliaris*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cymbopogon ambiguus, Cyperus iria, Cyperus vaginatus, Echinochloa colona*, Euphorbia australis, Gomphrena cunninghamii, Cyperus vaginatus, Eucalyptus victrix, Goodenia lamprosperma, Gossypium robinsonii, Ipomoea muelleri, Juncus kraussii, Notoleptopus decaisnei, Passiflora foetida* subsp. *hispida*, Petalostylis labicheoides, Pluchea rubelliflora, Ptilotus gomphrenoides, Rhynchosia minima, Schenkia clementii, Sesbania cannabina, Sesbania formosa, Sporobolus australasicus, Stemodia grossa, Tinospora smilacina, Sonchus oleraceus*, Tephrosia rosea* var. *Fortescue Creeks (M.I.H. Brooker 2186), Vigna lanceolata, Waltheria indica,* and **Vachellia farnesiana.*	*EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
C1b	*MA and EC dominated Low Woodland*	*OPV-C*	*Acacia ampliceps, Acacia colei var. ileocarpa, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Alternanthera nana, Argemone ochroleuca* subsp. *ochroleuca*, Capparis spinosa* var. *nummularia, Cenchrus ciliaris*, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Cucumis melo, Cymbopogon ambiguus, Cynodon dactylon*, Cyperus vaginatus, Echinochloa colona*, Eucalyptus victrix, Ficus aculeata, Flueggea virosa* subsp. *melanthesoides, Gossypium robinsonii, Ipomoea muelleri, Juncus kraussii, Passiflora foetida* subsp. *hispida*, Petalostylis labicheoides, Rhynchosia bungarensis, Sesbania formosa, Sesbania cannabina, Sonchus oleraceus*, Tephrosia rosea* var. *Fortescue Creeks (M.I.H. Brooker 2186) , Vachellia farnesiana*,* and *Vigna lanceolata.*	*Similar to EcMaCvCspp (Astron 2015) or similar to MaEcCv (Astron 2016*)*
C2AA	*Large Mesic EC dominated Open Forest representations*	*FPV-A*	*Acacia ampliceps, Acacia bivenosa, Acacia colei var. colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia maitlandii, Acacia pyrifolia* var. *pyrifolia, Acacia tumida* var. *pilbarensis, Argemone ochroleuca* var. *ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea var. neglecta, Cucumis variabilis, Cucumis melo, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Ipomoea muelleri, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Senna notabilis, Sesbania cannabina, Sesbania formosa, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks* (M.I.H. Brooker 2186), *Trachymene oleracea* subsp. *Oleracea, Triodia epactia, Typha domingensis, Vachellia farnesiana** and *Vigna lanceolata* var. *lanceolata.*	*Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2A	*EC dominated Open Forest*	*FPV-A*	*Acacia ampliceps, Acacia bivenosa, Acacia colei* var. *colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia trachycarpa, Argemone ochroleuca var. ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cucumis variabilis, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Sesbania formosa, Sesbania cannabina, Stemodia grossa, Trachymene oleracea* subsp. *Oleracea, Typha domingensis,* and *Vigna lanceolata* var. *lanceolata.*	*Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2B	EC & EV co-dominated Open Forest	FPV-B	*Acacia ampliceps, Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*Similar to EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
C2A-B	EC dominated Woodlands	FPV-A	*Acacia bivenosa, Acacia colei* var. *colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia trachycarpa, Argemone ochroleuca* var. *ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cucumis variabilis, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Sesbania cannabina, Stemodia grossa, Trachymene oleracea* subsp. *Oleracea, Typha domingensis,* and *Vigna lanceolata* var. *lanceolata.*	*EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2B-B	EC & EV co-dominated Woodland	FPV-B	*Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca argentea, Melaleuca glomerata, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2C	EV Dominated Woodland	FPV-C	*Acacia pyrifolia* var. *pyrifolia, Acacia bivenosa, Acacia maitlandii, Acacia pyrifolia* var. *pyrifolia, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea* var. *neglecta, Gossypium robinsonii, Hybanthus aurantiacus, Ipomoea muelleri, Rhynchosia minima, Senna notabilis, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks* (M.I.H. Brooker 2186)*, Triodia epactia, Triumfetta appendiculata, Vachellia farnesiana**, and *Waltheria indica.*	*EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016*)*
C3A	EC & EV co-dominated Open woodland	FPV-B	*Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca argentea, Melaleuca glomerata, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*EcEvCspp (Astron 2015) or similar to EcEvAtrApyPlTw (Astron 2016*)*
C3B	EV Dominated Open Woodland	FPV-C	*Acacia pyrifolia* var. *pyrifolia, Acacia bivenosa, Acacia maitlandii, Acacia pyrifolia* var. *pyrifolia, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea* var. *neglecta, Gossypium robinsonii, Hybanthus aurantiacus, Ipomoea muelleri, Rhynchosia minima, Senna notabilis, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks (M.I.H. Brooker 2186), Triodia epactia, Triumfetta appendiculata, Vachellia farnesiana**, and *Waltheria indica*	*EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
C4	Shrublands	Vadophytic	*Acacia bivenosa, Acacia pyrifolia* var. *pyrifolia, Abutilon otocarpum, Acacia ancistrocarpa, Aerva javanica*, Argemone ochroleuca* subsp. *Ochroleuca*, Boerhavia coccinea, Cenchrus ciliaris*, Crotalaria cunninghamii, Eriachne pulchella* subsp. *dominii, Euphorbia schultzii, Gomphrena cunninghamii, Gossypium australe, Ipomoea muelleri, Notoleptopus decaisnei* var. *Orbicularis (A.B. Craig 428), Ptilotus astrolasius* var. *astrolasius, Ptilotus nobilis, Senna notabilis , Triodia epactia, Tephrosia rosea* var. *Fortescue Creeks (M.I.H Brooker 2186), Trachymene oleracea* subsp. *Oleracea*, and *Triodia wiseana.*	*Similar to AtrEs & AtTeCc (Astron 2015) or AtrPl (Astron 2016*)*
C5	Beds with minimal vegetation	Vadophytic	*Acacia trachycarpa, Argemone ochroleuca* subsp. *ochroleuca*, Boerhavia coccinea, Eriachne pulchella* subsp. *dominii, Gomphrena cunninghamii, Hybanthus aurantiacus, Ipomoea muelleri, Ipomoea muelleri, Ptilotus incanus, Ptilotus nobilis, Rhynchosia minima, Senna notabilis, Trichodesma zeylanicum* var. *zeylanicum*, and *Trachymene oleracea* subsp. *Oleracea.*	*AtrEs (Astron 2015) or Es (Astron 2016*)*
C6	Shrublands	Vadophytic / Xerophytic	*Acacia ancistrocarpa, Acacia bivenosa, Acacia inaequilatera, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Acacia colei* var. *ileocarpa, Acacia inaequilatera, Acacia maitlandii, Acacia monticola, Acacia pyrifolia* var. *pyrifolia, Acacia synchronicia, Acacia trachycarpa* x *tumida* var. *pilbarensis, Acacia tumida* var. *pilbarensis, Acacia wanyu, Abutilon otocarpum, Aerva javanica*, Boerhavia coccinea, Bonamia erecta, Cajanus cinereus, Cenchrus ciliaris*, Corchorus lasiocarpus* subsp. *parvus, Crotalaria cunninghamii, Cymbopogon ambiguous, Grevillea pyramidalis* subsp. *leucadendron, Gossypium australe, Gossypium robinsonii, Hybanthus aurantiacus, Indigofera monophylla, Jasminum didymum* subsp. *lineare, Malvastrum americanum*, Notoleptopus decaisnei* var. *Orbicularis* (A.B. Craig 428), *Pentalepis trichodesmoides, Rhynchosia minima, Senna artemisioides* subsp. *oligophylla, Senna notabilis*, and *Trichodesma zeylanicum* var. *zeylanicum.*	*Similar to AtTeCc & ChAsppTwTe (Astron 2015) or ChAsppGOrGsppPlSsTe Tw & ChPlAbGOrTw (Astron 2016*)*

Appendix 3: Representative photographs of the key riparian vegetation units mapped to occur within the study area

New Veg code	Vegetation Type and Description	Representative Photos
PO	Minimal Vegetation	

New Veg code	Vegetation Type and Description	Representative Photos
		

New Veg code	Vegetation Type and Description	Representative Photos
C1AAa	Mature MA dominated Closed Forest	

New Veg code	Vegetation Type and Description	Representative Photos
		   

New Veg code	Vegetation Type and Description	Representative Photos
C1AAb	Mature MA dominated Open Forest	   

New Veg code	Vegetation Type and Description	Representative Photos
		   

New Veg code	Vegetation Type and Description	Representative Photos
C1A	Mature MA and EC dominated Open forest to Low Woodland	   

New Veg code	Vegetation Type and Description	Representative Photos
		   

New Veg code	Vegetation Type and Description	Representative Photos
C1b	MA and EC dominated Low Woodland	   

New Veg code	**Vegetation Type and Description**	**Representative Photos**
		   

New Veg code	Vegetation Type and Description	Representative Photos
C2AA	Large Mesic EC dominated Open Forest representations	

New Veg code	Vegetation Type and Description	Representative Photos	
			
C2A	EC dominated Open Forest		

New Veg code	Vegetation Type and Description	Representative Photos
		

New Veg code	Vegetation Type and Description	Representative Photos
C2B	EC & EV co-dominated Open Forest	   

New Veg code	**Vegetation Type and Description**	**Representative Photos**
		 
C2A-B	EC dominated Woodlands	 

New Veg code	Vegetation Type and Description	Representative Photos
		   

New Veg code	Vegetation Type and Description	Representative Photos
C2B-B	EC & EV co-dominated Woodland	

New Veg code	Vegetation Type and Description	Representative Photos
		 
C2C	EV Dominated Woodland	 

New Veg code	Vegetation Type and Description	Representative Photos
		 
C3A	EC & EV co-dominated Open woodland	 

New Veg code	Vegetation Type and Description	Representative Photos
		   

New Veg code	Vegetation Type and Description	Representative Photos
C3B	EV Dominated Open Woodland	   

New Veg code	Vegetation Type and Description	Representative Photos
C4	Shrublands	

New Veg code	Vegetation Type and Description	Representative Photos
C5	Beds with minimal vegetation	

New Veg code	Vegetation Type and Description	Representative Photos
C6	Shrublands	   

New Veg code	Vegetation Type and Description	Representative Photos