Iron Valley Groundwater Dependent Ecosystem Investigation
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Abbreviations

Abbreviation	Definition
AQ2	AQ2 Pty Ltd
AWT	Above watertable mining
BC Iron	BC Iron Limited
BHPBIO	BHP Billiton Iron Ore Limited
BWT	Below watertable mining
Consult.	Specialist GDV consultant
DBH	Diameter at Breast Height
Ec	*Eucalyptus camaldulensis*
Ev	*Eucalyptus victrix*
GDE	Groundwater Dependent Ecosystem
GDV	Groundwater Dependent Vegetation
GIS	Geographical Information System
GWI	Groundwater Impact
kL/d	Kilolitres per day
Ma	*Melaleuca argentea*
mbgl	Metres below ground level
MC	Marillana Creek
MRL	Mineral Resources Limited
MS	Ministerial Statement
NDVI	Normalised Difference Vegetation Index
NDWI	Normalised Difference Water Index
NIR	Near infrared spectral band
R	Red spectral band
Rio Tinto	Rio Tinto Iron Ore
SWI	Surface Water Impact
SWIR	Short wave infrared spectral band
The Project	The Iron Valley Above Watertable Mining Project
TSF	Tailings Storage Facility
VIS	Visible spectral band
WWC	Weeli Wolli Creek

Executive Summary

The Iron Valley mining project, located approximately 90 kilometres north-west of Newman in the Eastern Pilbara region, is an iron ore mine being developed by Mineral Resources Limited on behalf of BC Iron Limited. As the mine develops, there will be an expected change from mining above the water table to below the water table. Mining below the watertable will require groundwater abstraction for the purpose of mine dewatering and discharge of water into the nearby Weeli Wolli Creek. Groundwater abstraction has the potential to affect the health of groundwater dependent vegetation within a projected drawdown and mounding zone, which extends outwards from the mine to cover significant portions of the Marillana-Weeli Wolli Creek system. This report presents an investigation into the potential impact of groundwater abstraction and discharge on groundwater dependent vegetation near the Iron Valley mine, including a literature review, identification of the groundwater dependent vegetation risk area, risk assessment and consideration of monitoring requirements.

Groundwater dependent vegetation in the vicinity of the Iron Valley mine was identified using a combination of three different methods: visual inspection of aerial imagery, analysis of multispectral satellite (Landsat) imagery, and on-ground reconnaissance. The area targeted for assessment was a circular area with a radius of 10 kilometres, with the centre point located in the approximate centre of the tenement, encompassing the expected area of groundwater drawdown. On-ground reconnaissance was undertaken over a period of three days, from 22 to 24 November 2015. A total of 14 sites were inspected along a 25 kilometre length of the Marillana-Weeli Wolli Creek system, with sites located every 1.5 kilometres to 3 kilometres. Sites were described and rated for a range of qualitative parameters.

Results from on-ground reconnaissance were used to produce maps of groundwater dependent vegetation based on the presence of the key indicator species: the facultative phreatophytes *Eucalyptus victrix* and *Eucalyptus camaldulensis*, and the obligate phreatophyte *Melaleuca argentea*. Maps were cross-checked with aerial imagery and remote sensing maps indicating the likely presence of groundwater dependent vegetation based on the persistence of vegetation 'greenness' and 'wetness'.

A model was devised to assess the risk of a biologically significant decline in groundwater dependent tree health in response to groundwater abstraction and discharge associated with the Iron Valley mining operations. The model incorporated a surface water impact score based on the projected presence of surface water, and a groundwater impact score based on the projected magnitude of drawdown or final depth to the water table of mounding. The model was applied using the groundwater dependent vegetation risk area maps and the results of numerical groundwater and surface water modelling undertaken by AQ2 Pty Ltd. After tallying impact scores, mapped vegetation was assigned to one of four categories of risk: negligible (zero probability of decline), low (< 10% probability of decline), moderate (10% to 50% probability of decline) and high (50% to 100% probability of decline).

The risk model was applied to two scenarios: Iron Valley impacts from dewatering and surplus disposal (referred to as the Base Case), and Iron Valley impacts plus surplus disposal from the proposed expansion of a neighbouring iron ore mine operated by Rio Tinto Iron Ore Pty Ltd (referred to as the Rio Tinto Case). Both scenarios were assessed based on conditions at the end of the mining at Iron Valley in 2025.

The total area containing groundwater dependent vegetation was estimated to be 2,284 hectares within a total assessed area of 31,416 hectares (area within the circle of 10 kilometres from the centre of the tenement). Groundwater dependent vegetation was found to occur along the entire inspected length of the Marillana-Weeli Wolli Creek system, mostly along creek banks and in creek beds but also within floodplain areas up to 1.5 kilometres wide. Of note, compared to the drier

northern (downstream) portion of Weeli Wolli Creek, the southern (upstream) portion of the Marillana-Weeli Wolli Creek system was clearly affected by current discharge from nearby mines. Southern areas were wetter (with pooled and flowing water) and more highly productive, supporting wetland areas and dense stands of *E. victrix*, *E. camaldulensis* and *M. argentea* that are likely to be both discharge and groundwater dependent.

Excluding areas within the Iron Valley tenement boundary (which are likely to be cleared), the area of groundwater dependent vegetation included in the risk assessment was 2,542 hectares. For the Base Case, approximately one quarter of the risk area (591 hectares) was assessed to be at high risk. The high risk area for the Base Case was spread across the area of the main creek bed and across the entire width of the risk area in places from the current Rio Tinto discharge point to approximately six kilometres downstream of the Marillana-Weeli Wolli Creek confluence. High risk for the Base Case was associated with groundwater drawdown from the Iron Valley mine coupled with surface water impacts from the existing Rio Tinto discharge. Surface water impacts from the Iron Valley discharge were assessed to pose a moderate risk immediately downstream of the Iron Valley discharge points, with no risk beyond the projected Iron Valley wetting front where groundwater levels are projected to rise but the water table is expected to remain relatively deep. Similar to the Base Case, approximately one quarter of the risk area (583 hectares) was assessed to be at high risk for the Rio Tinto Case. High risk for the Rio Tinto Case was predominantly associated with the main creek bed from the Rio Tinto discharge point to around 14 kilometres from Marillana-Weeli Wolli Creek confluence, approximately two kilometres beyond the furthest Iron valley discharge point. In this case, high risk was associated with surface water impacts and groundwater mounding in areas where groundwater levels were projected to rise very near the surface.

With regard to cumulative impacts, it appears possible that current and future disposal of water from Rio Tinto's mining operations could mitigate potential negative impacts of drawdown from the Iron Valley Project along the southern (upstream) portion of the Weeli Wolli Creek system. However, the combined discharge from Rio Tinto and Iron Valley in this cumulative scenario may potentially lead to an additional discharge impact along the mid to northern (downstream) portion of the Creek, which could be either positive in some areas and negative in others depending on species, spatial distribution of vegetation in the creek bed and surrounding areas, and tolerance to inundation and waterlogging.

It is difficult to predict with any certainty the long term consequences and recovery potential of groundwater dependent vegetation once groundwater and surface water regimes have stabilised and are back under natural influences. According to AQ2's modelling, groundwater levels and Creek water levels are projected to recover to an equilibrium level relatively quickly (within 10 years) once abstraction and discharge have ceased. Individuals that may have become adapted to shallower groundwater levels, waterlogging or additional soil water in the unsaturated zone may struggle to re-adapt to natural regimes. Overall however, given the prevalence of groundwater dependent vegetation in the area and the apparent good health of upstream and downstream populations, recovery of the ecosystem is expected, particularly if management measures such as staged discharge reduction are implemented.

Given the presence of significant groundwater dependent vegetation in the vicinity of the Project area, it is expected that there will be a monitoring requirement associated with any future approval for groundwater abstraction associated with below water table mining. A potential monitoring program of the type that may be required to meet regulatory requirements was outlined, including suggested monitoring sites, parameters and methods. High resolution satellite image acquisition is also recommended for inclusion in the program.

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1 Introduction

1.1 Background

The Iron Valley Mining Project (the Project) is an iron ore mine located on the Iron Valley Mining tenement (M47/1439), located approximately 90 km north-west of Newman in the Eastern Pilbara region. The registered holder of the Iron Valley tenement is Iron Ore Holdings Ltd, which was recently acquired by BC Iron Limited (BC Iron). The mine is being developed by Mineral Resources Limited (MRL) on behalf of BC Iron. The Project is in the same region as a number of other operating iron ore mines, the closest of which is the Rio Tinto Iron Ore (Rio Tinto) Yandicoogina mine (5 km to the west). The Iron Valley tenement is adjacent to land held by Rio Tinto, BHP Billiton Iron Ore Limited (BHPBIO) and Fortescue Metals Group.

MRL currently holds a licence to abstract 720 mega litres/year of groundwater for mine use associated with the Iron Valley Above Water Table (AWT) Mining Project. Abstraction for AWT mining commenced during the latter half of 2013, and a zone of water table drawdown has been projected to extend outwards from the mine area as a result of abstraction. Water table drawdown may potentially affect the health of groundwater dependent ecosystems (GDEs) containing groundwater dependent vegetation (GDV) within the projected drawdown zone.

Condition 6 of Ministerial Statement (MS) 933 for the Project stipulates a requirement to manage GDEs. In particular, BC Iron must ensure that there are no long term impacts to the health and abundance of the facultative phreatophytic tree species *Eucalyptus victrix* outside the approved disturbance area (Condition 6-1). Annual monitoring is currently being undertaken to maintain compliance with MS 933. The objective of the current monitoring program is to detect impacts of abstraction associated with AWT mining.

As the mine develops, there will be an expected change to mining below the water table (BWT), which will require further abstraction of groundwater for the purpose of mine dewatering and the disposal of surplus water. BC Iron is therefore currently seeking approval for a revised combined project: the Iron Valley BWT Mining Project. The zone of water table drawdown associated with groundwater abstraction for BWT mining has been projected to expand significantly across a much broader area around the mine than for AWT mining, including significant portions of the Marillana-Weeli Wolli Creek system that are likely to support significant GDE communities. Surplus water from the Iron Valley mine is also likely to be discharged directly into the creek, which would add to current discharge into the creek from Yandicoogina mine operated by Rio Tinto. Further volumes of excess water would also be disposed into the creek system should Rio Tinto proceed with development of their Pocket and Billiard Mine.

Significant changes to the hydrological regime around the Project are likely, and it is recognised that a good understanding of the spatial extent of GDV and the risk to GDV health in response to groundwater drawdown and mounding and changes in surface water flow in the Marillana-Weeli Wolli Creek system is required to support the approval process for further groundwater abstraction associated with BWT mining.

1.2 Scope of Work

The scope of work was to complete a desktop investigation and ground based truthing on the potential impact of future groundwater drawdown and discharge on GDV associated with the Iron Valley Mine, including requirements for future monitoring. The major purpose of the investigation is to support BC Iron's application for approval to undertake groundwater abstraction for the purpose of BWT mining.

1.3 Objectives

The major objectives of the investigation were to:

- identify and classify potential GDV in the vicinity of the Project
- assess the potential risk to GDV from groundwater abstraction and discharge associated with BWT mining
- assess potential cumulative impacts of BWT mining in the context of existing and reasonably foreseeable iron ore mines upstream
- identify potentially suitable locations for future monitoring of GDV
- conduct on-ground reconnaissance with regard to the location of GDV and potential monitoring sites
- outline an appropriate GDV monitoring program for the Project.

1.4 This Report

This report outlines the background, methods and results of the investigation. For context, the report includes a brief literature review on GDV and its responses to changes in groundwater and surface water. Readers are referred to other reports for summaries of the environmental setting (Astron 2012), GDV monitoring history (Astron 2014) and the broader impacts of increased groundwater abstraction at Iron Valley (Soilwater Consultants 2015). Following the literature review and background information on groundwater and surface water management for the Iron Valley mine, the report is divided into sections detailing the identification and mapping of GDV, a risk assessment, and future monitoring requirements.

2 Literature Review

2.1 Groundwater Dependent Vegetation

GDV is defined as terrestrial vegetation that is dependent on the presence of groundwater to meet some or all of their water requirements such that vegetation community structure and function is maintained (Orellana et al. 2012). GDV may be dependent on either the surface expression or subsurface presence of groundwater (Eamus, Hatton, et al. 2006). Surface expressions of groundwater occur in the form of base-flow rivers, streams, creeks, springs and some floodplains where groundwater may soak below the surface and become available to plant roots. Subsurface groundwater is accessed by plants via the capillary fringe above the water table, that is, the interface between the unsaturated and saturated zones of the soil profile.

GDV species that utilise groundwater are referred to as phreatophytes, and they may be classified as either obligate or facultative phreatophytes depending on their level of dependence on groundwater.

Obligate phreatophytes are plants that are completely or highly dependent on groundwater. This dependence can be continual, seasonal or episodic. Obligate phreatophytes tend to be associated with surface expressions of groundwater rather than the subsurface presence of groundwater, and they are highly sensitive to large changes in groundwater regime and respond negatively to rapid groundwater drawdown.

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

GDV communities are commonly associated with the riparian zones and floodplains of ephemeral creeks and rivers in arid and semi-arid areas of Australia including the Pilbara. Vegetation in these areas is often broadly categorised as 'riparian vegetation', of which GDV species are an important subset. However, GDV species sometimes occur in other areas of the landscape, as dominant or minor elements of communities, depending on soil type, groundwater depth and species rooting depth.

2.2 Plant Responses to Groundwater Drawdown

The response of GDV to groundwater drawdown is incremental, as described below and summarised in Table 1.

In the initial stages of drawdown, plants begin to lose contact with groundwater and they become increasingly dependent on soil moisture stored in the unsaturated zone to meet their water requirement. Contact with groundwater may be completely lost if the water table is lowered beyond the root zone, leading to complete reliance on the unsaturated zone. Beyond this point, further drawdown has no effect on plants.

As the store of water in the unsaturated zone becomes depleted, plants initiate short-term adaptive physiological responses (within days to weeks) to conserve water, the most important of which is stomatal closure in leaves (Eamus, Hatton, et al. 2006). Stomatal closure occurs to prevent damage to leaf tissues as a result of dehydration, and to prevent failure of the water transport system as a result of cavitation and embolism in xylem vessels (note: stomata are pores in the leaf surface that allow exchange of water vapour, oxygen, carbon dioxide and other gases between the leaf and the atmosphere; xylem vessels are specialised, pipe-like conduits that comprise a plant's water transport system). Stomatal closure restricts water loss but it also reduces the rate of carbon fixation, which in turn leads to a reduction in growth.

If water stress is prolonged, plants may begin to initiate adaptive structural responses (over weeks and months) in an attempt to maintain contact with existing water sources, to explore new sources, or to reduce whole-plant water use in line with reduced water availability. This may include root proliferation and/or the shedding of leaves.

When faced with severe depletion of water, plants keep stomata closed for longer and experience progressively lower xylem water potentials (indicative of water stress) that may approach threshold levels beyond which plant tissues may sustain irreversible damage and the water transport system may collapse, resulting in plant death. Plants suffering from severe water stress over a prolonged period tend to display leaf discolouration, wilting and curling, senescence of fine roots, substantial leaf shedding, branch death, and overall poor canopy condition. At the stand level, severe water stress manifests as reduced leaf area index and altered spectral signatures characterised by reduced 'greenness'.

Prolonged water stress reduces the ability of plants to reproduce and increases the mortality of mature plants, such that individuals begin to die off with no recruitment of new seedlings. Eventually, over many years to decades, original species are replaced by a new suite of species more suited to the drier hydrological regime, which can lead to a marked change in community structure and function.

The timing and magnitude of the events described in Table 1 is highly variable across space and time, and these events depend on the timing and magnitude of groundwater drawdown. It is necessary to note that when followed to the end, this sequence of events represents an extreme, worst-case scenario. At the less severe end of the continuum, a drop in the water table may only cause a structural change to facultative phreatophytic trees, such as reductions in height, leaf area and possibly stand density, but not permanent compositional change involving an irreversible loss of GDV and replacement by new species.

Table 1: Summary of incremental response of groundwater dependent vegetation to groundwater drawdown.

Phase	Change and response	Timing
Groundwater drawdown	Initial decline in water table level ↓	Groundwater drawdown begins
	Root growth to maintain contact with water table ↓	Within weeks and months
	Water table declines below the maximum root zone ↓	Within weeks to years[1]
Soil drying	Plant available soil water in the unsaturated zone becomes depleted ↓	Within weeks to years[2]
	Plant water uptake threshold is exceeded ↓	
Plant response to soil drying	Physiological responses: • stomatal opening reduced • transpiration declines • carbon fixation declines • leaves wilt ↓	Within weeks
	Structural responses: • leaf area declines • branch dieback • root dieback/new growth ↓	Within months
	Plant growth declines ↓	Within months
	Plant recruitment declines ↓	Within a couple of years
	Plant mortality increases ↓	Within several years
	New species invade ↓	Within a decade
	New community structure and function becomes evident	Within several decades

1. Dependent on rate of drawdown and depth of root system.

2. Dependent on depth of unsaturated soil, antecedent soil moisture, replenishment by rainfall, root system extent, competition for soil moisture, and evaporative demand.

2.3 Plant Responses to Groundwater Mounding, Surface Water Inundation and Waterlogging

Negative impacts to GDV can arise as a result of groundwater rise (mounding) or surface water pooling. Groundwater mounding can have a potential negative impact on GDV in situations where the water table rises to such an extent that it envelops a large proportion of the root system. Similarly, negative impacts from surface water can arise where exposed roots and stems are inundated by flowing or pooled surface water and a large proportion of the root system is embedded in soil that has become super saturated (waterlogged), termed the hyporheic zone (the layer of sediment adjacent to a stream through which stream water readily exchanges). Effects are obviously compounded in situations where the hyporheic zone intersects with groundwater mounding because there is no possibility that waterlogged, poorly aerated soils can drain into unsaturated soil layers underneath.

Soil aeration is physiologically important to plants. Oxygen is a key component of a number of physiological processes that take place within the plant including respiration and photosynthesis. Unless there is a rapid exchange of gas between the soil and the air, the oxygen supply soon becomes limiting for plant growth. The rate of exchange between soil and aboveground air decreases with decreasing soil porosity and increasing water content. Flooding of the capillary pore spaces in soil is highly likely to result in roots suffering severe oxygen deficiency due to the fact that soil air is displaced by water. This has major consequences given that transport of oxygen to roots is about 300,000 times greater through air-filled pore spaces than when they are filled with water (Kramer and Boyer 1995). Flooding also forces roots to obtain most of their oxygen from the shoot by diffusion though via complex, tortuous, highly inefficient pathways.

Most woody plants are not adapted to complete immersion in hypoxic, waterlogged soil conditions for extended periods of time. Flooding injuries can have multiple causes and symptoms (Kramer and Boyer 1995), including but not limited to:

- wilting
- development of adventitious roots near the water line
- reduced growth causing epinasty (downward and outward bending of plant parts), leaf chlorosis, and in severe cases death
- disruption of root hormone production and transport to other parts of the plant
- disruption to nutrient metabolism
- disruption to the development of healthy plant tissues such as aerenchyma (air conducting tissues)
- stem hypertrophy (swelling of tissues)
- damage caused by exposure to toxic compounds that may accumulate in flooded soils, such as methane and sulfides
- greater susceptibility to root diseases (for example, *Phytopthora*).

In general, plants that develop adventitious roots can usually survive flooding better than those that do not. It is well known that trees and other plants growing in poorly drained soil often develop shallow root systems concentrated in the better aerated soil surface (Kramer and Boyer 1995), which can have consequences for facultative phreatophytic species that depend on the development of a deep root system for long term survival.

2.4 Major Influencing Factors

The response of GDV to changes in groundwater level and surface water dynamics is predominantly influenced by the following factors: the depth to groundwater, the rate and magnitude of groundwater level change, and exposure to surface water. These factors are discussed below.

2.4.1 Depth to groundwater

There is general acceptance that reliance of GDV on groundwater decreases with increasing depth to the water table (Department of Water 2009). This is based on the fundamental empirical observation of plant growth that root biomass decreases exponentially with increasing depth (Jackson et al. 1996) such that most GDV species are likely to contain the large majority of their root biomass within the top few metres of the soil profile. This is partly related to the plant energy requirement to grow roots at depth and the greater suction required to extract water from depth.

Obligate phreatophytes that are adapted to shallow water tables (less than 2 m depth, for example) and a moderate degree of inundation and waterlogging are typically able to tap the capillary fringe and/or penetrate directly into the saturated zone with a large mass of shallow roots, which enables them to draw a relatively large proportion of their water requirement from groundwater. In contrast, facultative phreatophytes that occur in environments with deeper water tables (greater than 10 m depth, for example) can usually only access the capillary fringe via a relatively small number of roots, such that groundwater comprises only a relatively small proportion of total plant water use. It follows that GDV established over shallow water tables is likely to be much more sensitive to groundwater fluctuations than GDV established over deep water tables.

For Australian systems, evidence suggests that reliance on groundwater by terrestrial vegetation is greatly reduced in areas where the water table exceeds a threshold depth, likely to lie between 7 m and 12 m (Benyon, Theiveyanathan, and Doody 2006; Department of Water 2009; O'Grady, Carter, and Holland 2010; Zolfaghar et al. 2014), with 10 m suggested as a general threshold (Eamus, Froend, et al. 2006). An assessment of water level ranges of dominant riparian species across four Pilbara study sites indicated that the absolute maximum water level range was around 9 m (Loomes 2010). Vegetation may potentially access groundwater when the water table is between 10 m and 20 m depth, although it is thought to be negligible in terms of contribution to total plant water use (Zencich et al. 2002), and beyond 20 m depth, the probability of groundwater as a water source for vegetation is regarded as being low. In the case of groundwater mounding, there is evidence from the riverbanks, creeks and floodplains of Australian systems that although creekside *Eucalyptus* species can be tolerant to repeated flooding, trees tend to use water from unsaturated shallow soil and groundwater and not creek water (Thorburn and Walker 1994).

In general for the Iron Valley Project area, only eucalypts, which have sufficient biomass and longevity to develop roots beyond 20 m depth, are likely to be at any risk from groundwater level change within the 10 m to 20 m depth zone.

2.4.2 Magnitude of groundwater drawdown

From the previous section, it is self-evident that the magnitude of groundwater drawdown is directly related to the magnitude of impact on GDV. The likelihood of impact is clearly very high in situations when drawdown is of sufficient magnitude to lower the water table below the rooting depth of GDV. However, this influence decreases with increasing depth to groundwater pre-drawdown, due to a lesser pre-existing dependence on groundwater of GDV. That is, the lowering of a shallow water table by even a small amount can potentially have large consequences for obligate phreatophytes with shallow root systems that depend on groundwater for a large proportion of their water requirement. On the other hand, further lowering of an already deep water table may not have a large impact on deep-rooted facultative phreatophytes for which groundwater comprises only a small proportion of total plant water use.

Available information on the ability of GDV to adjust to groundwater change suggests that changes of < 2 m can most likely be tolerated, but the consequences to plant health of changes > 2 m are often detrimental (Marcam Environmental 1998; Naumburg et al. 2005; Braimbridge 2010). A change of > 2 m may be considered necessary to result in a risk of impact when groundwater is deeper (for example > 5 m depth), however a more conservative change of > 1 m may be considered to have a risk of impact when groundwater is shallower (for example, < 5 m depth), taking into account the relatively greater vulnerability of GDV that is more highly dependent on groundwater.

2.4.3 Rate of groundwater drawdown

The rate at which vegetation is impacted by drawdown is directly proportional to the rate of groundwater drawdown. Gradual drawdown results in a slower progression of reduced water availability and a greater opportunity for plants to adapt to the altered groundwater regime, whereas rapid drawdown results in the rapid acceleration of negative impacts (Froend et al. 2004). In theory, plant roots can maintain a functional connection with groundwater as long as the rate of water table decline does not exceed potential maximum rate of root growth (Naumburg et al. 2005).

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

2.4.4 Surface water

The GDV that occurs along creeks in the Pilbara is adapted to episodic large rainfall events that can result in fast, high energy stream flows in the creek bed and the pooling of water in floodplains. These accumulations of surface water are usually only temporary, lasting over several days to weeks. Flowing water is rarely a permanent feature and the size and permanency of pools is highly variable. However, the dynamics of surplus water discharge into creeks differ considerably. Discharge occurs as a slow, steady release of water into creek. Flows are very low energy, which can lead to the creation of permanent large pools that engulf the full extent of tree root zones. This may suit some GDV species that are well adapted to long periods of flooding (for example, *Melaleuca argentea*), but harm other species that are not. On the other hand, the steady supply of water from discharge has the potential to recharge soil moisture in the underlying alluvium. This would potentially benefit facultative phreatophytic species (for example *Eucalyptus victrix*) that draw most of their water from the unsaturated zone, as long as they can support roots beyond the hyporheic zone and roots are not flooded by groundwater mounding.

2.4.5 Other factors

The magnitude and extent of GDV response to groundwater drawdown, mounding and surface water pooling is influenced by a range of other secondary factors including:

- rooting depth and spread of individual plants (determines the level of access to groundwater and soil moisture in the unsaturated zone)
- soil texture (determines the maximum amount of soil moisture in the unsaturated zone that can be utilised by plants in the absence of groundwater)
- antecedent soil moisture (determines the actual amount of soil moisture in the unsaturated zone that can be utilised by plants in the absence of groundwater)
- magnitude and frequency of rainfall (determines the extent to which the soil moisture in the unsaturated zone is replenished)
- structural and physiological factors such as transpiration rate, leaf area, and stand density (determined the rate at which soil moisture in the unsaturated zone is depleted)
- evaporative demand (determines the rate at which soil moisture in the unsaturated zone is depleted and the level of plant stress when there is insufficient water to meet plant water requirements).

2.5 Key Species

From previous vegetation surveys and anecdotal knowledge of riparian vegetation that occurs along the Marillana-Weeli Wolli Creek system, three key species with potential groundwater dependence are known to be present in the vicinity of the Project: *Eucalyptus victrix* (coolibah), *E. camaldulensis* (river red gum) and *Melaleuca argentea* (silver cadjeput).

Of note, the Marillana-Weeli Wolli Creek system is also known to support a range of other large woody species that commonly co-occur with *E. victrix* and *E. camaldulensis* in the riparian zone (for example, *Melaleuca glomerata*, *Corymbia candida*, *Acacia coriacea* and *Atalaya hemiglauca*); very little is known about the water use, water sources or rooting depths of these species, and the possibility that some of the larger individuals (> 5 m in height) may also be dependent on groundwater to some degree cannot be discounted.

2.5.1 Eucalyptus victrix

E. victrix is a small to medium tree (5 m to 15 m) with a spreading form that occurs on red loamy or sandy soils and clay loams on floodplains and in low lying areas across the Pilbara and other areas in the north-west of Western Australia (Western Australian Herbarium 1998-2015). Mature *E. victrix* trees commonly support a large dimorphic root system, consisting of prominent tap roots and a network of laterally expansive roots near the soil surface and in the top 1 m to 2 m of the soil profile, which can extend to at least 10 m to 12 m away from the main stem, from which vertical sinker roots can also develop and potentially extend tens of metres to water table depth (Florentine 1999).

E. victrix is regarded as being a facultative phreatophyte that most likely draws the majority of its water requirement from the unsaturated zone, but can use groundwater opportunistically as required. Previous studies have shown that when provided with access to groundwater, *E. victrix* can maintain high leaf water potentials and high rates of tree water use during times of drought (O'Grady et al. 2009; Pfautsch et al. 2011; Pfautsch et al. 2014). However, *E. victrix* also demonstrates a strong ability to regulate water losses when water supplies are limited via regulation of stomatal conductance (Pfautsch et al. 2014) and structural modifications including leaf die-off, crown defoliation and adjustment of leaf area to sapwood area ratio, which enables trees to maintain constant water use despite increasing evaporative demand if sufficient water is available (O'Grady et al. 2009). In general, the water use strategy of *E. victrix* appears to be highly plastic and opportunistic, enabling survival in a wide range of ecohydrological settings (Pfautsch et al. 2014). However, despite being a relatively plastic species, major adjustments to hydraulic architecture in large trees take time such that large changes in hydrology are likely to affect trees growing over historically shallow groundwater to a greater extent than trees that have developed over historically deeper groundwater, as highlighted in a recent study by Pfautsch et al. (2014). From an assessment of water level ranges of Pilbara riparian species, it was found that the mean minimum water level depth of *E. victrix* was greater than that for *E. camaldulensis*, providing some support for the view that *E. victrix* is found in slightly drier areas than *E. camaldulensis* and may not be as responsive to water table fluctuations (Loomes 2010).

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

2.5.2 Eucalyptus camaldulensis

E. camaldulensis is one of the most iconic and broadly distributed *Eucalyptus* species in Australia, and more is known about this species than nearly all others. Across its broad geographic distribution, *E. camaldulensis* populations display high genetic diversity with regard to hydraulic architecture, water relations and salt tolerance, reflecting how different populations have evolved and adapted to local climates and hydrogeological regimes (Colloff 2014). In the Pilbara, *E. camaldulensis* commonly occurs along water courses and river banks, growing in deep alluvial sand and sandy loams (Western Australian Herbarium 1998-2015). It is a small to large tree (5 m to 20 m) with a generally spreading form, but it displays a great diversity in height, form, trunk and leaf morphology (Western Australian Herbarium 1998-2015). Trees in riparian zones exposed to high energy flood events tend to have short, thick stems with irregular crowns or multiple stems diverging from a short trunk. Stems can sprout from epicormic buds in living tissue of the bole or root stock, and new stems can arise from horizontal stems fallen by flood, fire or windstorms. In less dynamic environments, fast-growing trees can grow tall and straight with even form similar to silvicultural plantations.

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

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

Where large *E. camaldulensis* trees are present, groundwater is usually present within the depth of the root zone, and in some environments depth to groundwater is a good predictor of the condition of *E. camaldulensis* stands. Some studies have observed a sharp decline in tree health and stand condition below a threshold depth or around 10 m to 12 m (England et al 2009 cited in Colloff 2014). The ability of *E. camaldulensis* to utilise groundwater has proven useful for lowering water tables and reclamation of saline land in agricultural regions of southern Australia, where water use can be in the order of 300 mm to 550 mm per year (1 mm to 1.5 mm per day) depending on stand density and access to water.

In the Pilbara, riparian communities containing *E. camaldulensis* occupy only a relatively small percentage of the landscape total area, but they are integral to the ecosystem function of riparian systems, providing vital refuge and resources for birds, mammals, reptiles, invertebrates and people in an otherwise dry landscape (Colloff 2014).

2.5.3 *Melaleuca argentea*

M. argentea is a medium size tree up to 20 m in height that normally grows along the banks of creeks, water courses and swamps. It has a predominantly shallow, flat root system, comprised mostly of surface lateral roots that can grow directly into standing or flowing water (Graham 2001; Loomes 2010; Department of Parks and Wildlife 2015).

M. argentea is considered an obligate phreatophyte that typically accesses surface expressions of groundwater or shallow water tables within 3 m of the soil surface. This species exhibits signs of stress and even death if the groundwater table falls by more than 0.5 m to 1 m (Astron, unpublished data), and this species does not appear capable of surviving above water tables deeper than around 5 m (Loomes 2010). Stream water (often linked groundwater discharge) is commonly the most important source of water for this species, which likely plays a key role in influencing the form and ecology of stream channels in northern Australia. Studies have also shown that even in higher rainfall environments in the tropical north of Australia, *M. argentea* remains predominantly reliant on groundwater and river water (O'Grady et al. 2006).

Compared to *E. victrix* and *E. camaldulensis*, the ecophysiology, water relations and water use behaviour of this species has rarely been studied and remain poorly understood.

3 Identification and Mapping of Groundwater Dependent Vegetation

GDV in the vicinity of the Project was identified using a combination of three different methods: visual inspection of available aerial imagery, analysis of multispectral satellite imagery, and on-ground reconnaissance. The area targeted for assessment was an approximately circular area with a radius of 10 km (31,416 ha), with the centre point located in the approximate centre of the tenement. This area encompassed the expected area of groundwater drawdown associated with BWT mining. Of note, actual groundwater dependency has not been confirmed for any vegetation in this study; hence all references to GDV should be regarded as referring to 'potential' GDV.

3.1 Inspection of Aerial Imagery

Available aerial imagery of the assessment area sourced from Google Earth, Landgate and BC Iron was compiled and visually inspected for the presence of GDV. Particularly close attention was paid to identifying individual large trees and clumps of trees in areas of the landscape that were likely to support GDV species, such as along major creeks, drainage lines and surrounding floodplains. Specific patches of vegetation thought to contain GDV were marked in GIS layers and on printed maps for comparison with other methods and to guide on-ground reconnaissance. Of note, the base layer for the maps produced in this report was an aerial image of the Weeli Wolli Creek system captured in 2004, sourced from Landgate.

3.2 Remote Sensing Analysis

A remote sensing analysis was carried out to identify GDV based on vegetation 'greenness' and 'wetness', and the persistence of greenness and wetness over time. Briefly, the analysis utilised freely available data sets from the Landsat satellite, a remote sensing platform that captures imagery across a number of spectral bands including across visible (VIS), near infrared (NIR) and short wave infrared (SWIR) wavelengths.

The capture of wavelengths in the NIR band is an important tool used in vegetation health monitoring primarily because healthy, green leaves strongly reflect NIR wavelengths. At the same time, chlorophyll in plant leaves absorbs red light. Therefore, where leaves are healthy and foliage is dense, there is greater absorption of red light and greater reflection of NIR per unit area. Comparing the NIR and VIS red bands of Landsat imagery provides the Normalised Difference Vegetation Index (NDVI), an index that is widely used for measuring vegetation cover and condition. NDVI is calculated as: $NDVI = (NIR - R) / (NIR + R)$, where NIR is the near infrared spectral band and R is the red spectral band.

The NDVI indicates the 'greenness' of target vegetation and ranges between -1 (snow and ice) to +1 (100% healthy and dense vegetation cover). In this way, NDVI is highly correlated with per cent canopy closure: if there is more reflected light in the NIR wavelengths then the vegetation of interest is likely to be dense. Thus, the difference between NIR and R reflectance from vegetation will reduce as vegetation health, or vegetation cover proportion within a pixel, reduces (Tucker 1979; Jensen et al. 1991; Heute 2012). A decline in live plant cover will therefore be reflected by a decrease in NDVI. Similarly, the 'persistence' of high NDVI values can be used to identify vegetation that remains consistently green and in good condition over time with little fluctuation in response to changes in climate (rainfall and drought), which by inference suggests access to reliable, consistent water sources, including groundwater.

Changes in NDVI are also frequently compared to changes in the Normalised Difference Water Index (NDWI), derived from the NIR and SWIR channels, which is considered to be a good proxy for plant water stress. The SWIR reflectance reflects changes in leaf water content and thus allows for monitoring of the moisture condition of vegetation. NDWI is calculated as: NDWI = (NIR – SWIR) / (NIR + SWIR).

For the analysis, a simplified version of the method of Barron et al. (2014) was used to identify and map GDV within the assessment area from analyses of NDVI and NDWI. The analysis used two Landsat data sets, one from the end of November 1996 following a prolonged dry period (dry), and the other from the end of May 2000 following a relatively wet period (wet). A four layer hyperplane, made up of $NDVI_{wet}$, $NDVI_{dry}$, $NDWI_{wet}$ and $NDWI_{dry}$ was used to perform an unsupervised classification of pixels to identify potential GDV. A k-means cluster analysis was applied to define a number of classes, after which a maximum likelihood algorithm was applied to assign pixel locations to classes. The final classification involved assigning pixels to one of four classes based on the persistence of greenness and wetness: non-drying vegetation, slow-drying vegetation, fast-drying vegetation and 'other' (for which NDVI values were too low to be significant vegetation), with the non-drying vegetation and possibly the slow-drying vegetation laying claim to represent GDV. Further technical details of the analysis are available upon request.

An important point to note about remote sensing analyses referred to in this report is that the scale and resolution of analyses needs to be taken into account when interpreting and extrapolating results. For example, the Landsat satellite captured imagery at a relatively coarse resolution of 30 m x 30 m pixels, which was appropriate for making inferences at the habitat/community scale, but not the individual tree scale.

3.3 On-ground Reconnaissance

On-ground reconnaissance and mapping of GDV was conducted by two senior scientists from Astron with experience in the identification and monitoring of GDV in the eastern Pilbara (R. Archibald and T. Bleby). Reconnaissance was undertaken over a period of three days, from 22 to 24 November 2015. A total of 19 sites were selected for inspection along a 25 km length of the Marillana-Weeli Wolli Creek system, with sites located approximately every 1.5 km to 3 km. These sites were pre-selected from a desktop analysis of aerial imagery prior to the trip. On-ground, 14 of the 19 sites were inspected. Sites 2 and 4 were not inspected because they occurred on tenements where survey work was not permitted. Sites 10 and 19 were determined to be redundant given their similarity to preferred sites nearby. Site 17 was determined not to contain GDV. Site 8 was inspected but only photographs were taken.

Most sites were directly accessible by vehicle via bush tracks and dry creek beds. Where possible, a north-south or east-west cross-section of the creek (up to 1.5 km) was traversed on foot to inspect vegetation in creek beds and on both sides of the floodplain (riparian uplands). The current monitoring transect was also re-assessed at the same time as annual monitoring activities were being undertaken.

Each site was described and rated for a range of qualitative parameters, as listed in Table 2. Field notes, photographs and GPS points of interest (including GDV boundaries) were also recorded at each site. The outline of GDV was transposed onto printed maps and then digitised to produce a GIS layer for electronic production. The mapping process to produce final GDV maps involved the interpolation of GDV boundaries along areas that were not inspected on-ground. On-ground observation of GDV were subsequently cross-checked with aerial imagery and GDV maps from remote sensing, and all three methods were then used in combination to interpolate the presence of GDV in areas that were not ground-truthed.

Table 2: Parameters and ratings used to describe groundwater dependent vegetation (GDV) inspection sites during on-ground reconnaissance. Ev = *Eucalyptus victrix*, Ec = *Eucalyptus camaldulensis*, Ma = *Melaleuca argentea*. DBH = diameter at breast (1.3 m) height.

<table>
<tr><th colspan="2">Parameter</th><th>Term/rating</th><th>Description</th></tr>
<tr><td rowspan="3">GDV indicator species</td><td>Ev</td><td rowspan="3">Present/absent</td><td rowspan="3">Presence/absence of GDV indicator species in any form, including juvenile saplings</td></tr>
<tr><td>Ec</td></tr>
<tr><td>Ma</td></tr>
<tr><td colspan="2" rowspan="3">GDV tree size</td><td>Large</td><td>DBH > 0.5 m; height > 15 m</td></tr>
<tr><td>Medium</td><td>DBH between 0.1 m and 0.5 m; height between 5 m and 15 m</td></tr>
<tr><td>Small</td><td>DBH < 0.1 m; height < 5 m</td></tr>
<tr><td colspan="2" rowspan="3">GDV tree density</td><td>Dense</td><td>> 15 stems per ha</td></tr>
<tr><td>Scattered</td><td>5 to 15 stems per ha</td></tr>
<tr><td>Sparse</td><td>< 5 stems per ha</td></tr>
<tr><td colspan="2" rowspan="3">GDV tree health</td><td>Good</td><td>Majority of trees display dense foliage cover and appear in good visual health</td></tr>
<tr><td>Moderate</td><td>Majority of trees display thinning foliage cover and visual health could be better</td></tr>
<tr><td>Poor</td><td>Majority of trees display sparse foliage and visual health shows signs of decline</td></tr>
<tr><td colspan="2" rowspan="4">Vegetation strata</td><td>Overstorey</td><td>The dominant (tallest) tree canopy</td></tr>
<tr><td>Midstorey</td><td>Vegetation that grows above the understorey but below the dominant tree canopy, including small trees and tall shrubs</td></tr>
<tr><td>Shrubland</td><td>Vegetation that grows above the understorey but is lower than the midstorey, including medium size shrubs</td></tr>
<tr><td>Understorey</td><td>Vegetation that grows at the lowest level below the dominant tree canopy, including low-lying shrubs, grasses and herbs</td></tr>
<tr><td colspan="2" rowspan="5">Surface water</td><td>Flowing</td><td>Flowing water in creek channel</td></tr>
<tr><td>Pooled</td><td>Standing pools of water in creek channel</td></tr>
<tr><td>Dry</td><td>Dry creek bed with no pools or flowing water</td></tr>
<tr><td>High level</td><td>Relatively deep pools/channels of flowing water (> 1 m depth)</td></tr>
<tr><td>Low level</td><td>Relatively shallow pools/channels of flowing water (< 1 m depth)</td></tr>
<tr><td colspan="2" rowspan="3">Distance from discharge</td><td>Close</td><td>< 5 km</td></tr>
<tr><td>Near</td><td>5 km to 10 km</td></tr>
<tr><td>Far</td><td>> 10 km</td></tr>
</table>

3.4 Results and Discussion

GDV in the vicinity of the Project is shown in a series of maps contained in Appendix A (Figure A.1). Mapping notes, site descriptions and relevant GPS points of interest are summarised in tables in Appendix A (Table A.1 and A.2). Site photographs are available upon request. The total area of GDV within the assessed area was 2,284 ha, including the current monitoring transect.

In brief, GDV was found to occur along the entire inspected length of the Marillana-Weeli Wolli Creek system (25 km), which stretched from the south-western corner to the far north of the assessed area (Figure A.1). Potential GDV was found to occur across entire cross-sections of the Creek, with a typical cross-section of the northern portion of Weeli Wolli Creek described as containing scattered large *E. victrix* and *E. camaldulensis* along creek banks and within the open creek bed, and sparse large *E. victrix* over *Acacia* midstorey over native grass and buffel (**Cenchrus ciliaris*) understorey in the riparian uplands (floodplain) on both sides of the main channel (Figure A.1; Table A.1).

The southern portion of the Marillana-Weeli Wolli Creek system was clearly wetter and more highly productive than the drier northern portion of Weeli Wolli Creek, almost certainly as a result of discharge from surrounding mines. The southern portion supported large pools of water and significant stretches of flowing water, which in turn supported wetland areas with dense tall reeds, and dense patches of small to medium sized *E. victrix*, *E. camaldulensis* and *M. argentea* in addition to scattered large *E. victrix* and *E. camaldulensis*. Floodplain areas along the southern portion also tended to support denser stands of mid-storey *Acacia* species than the northern portion of Weeli Wolli Creek. The transition zone between the 'discharge affected' southern portion and the 'discharge unaffected' northern portion of Weeli Wolli Creek was the area around inspection site 6. The presence of discharge affected GDV is a major confounding influence with regard to monitoring for impacts of groundwater drawdown. The nature and magnitude of the effects of discharge on GDV in this portion of the system remains to be determined with certainty. In all likelihood, the discharge is likely to 'protect' much of the vegetation from groundwater drawdown while historical discharge regimes are maintained. A broad scale separation of GDV that has developed in response to discharge versus the pre-existing GDV would be possible via an analysis of Landsat imagery spanning the pre- and post-discharge period.

GDV trees were mostly observed to be in very good health along the entire length of the Creek system, except at inspection site 16 which was downstream from a section of the creek that had been blocked by development. Indications are that this site may have been the recipient of historic discharge that has since ceased, the result of which appears to have been the growth and subsequent decline of a partially 'artificial' GDV community (or 'discharge dependent community').

An area on the western edge of the floodplain at the southern base of a hill near inspection site 12 was found to support a potentially important community of medium to large *E. camaldulensis* trees that may or may not be reliant on groundwater. This patch of forest contained numerous tall, straight, evidently fast-growing trees with diameter at breast height of around 40 cm to 50 cm, and heights of around 20 m. Inspection of historic aerial images suggests that this stand may not be more than 10 to 15 years of age, and it may have enlarged after the commencement of discharge.

For the major Creek system, there was good general agreement between on-ground GDV observations and the remote sensing analysis (Appendix B, Figure B.1), taking into account the coarse pixel size (30 m x 30 m). In particular, there was good correspondence between the mapping of non-drying vegetation from remote sensing (red areas in Figure B.1) and the confirmed presence of large GDV trees along creek banks and within open creek beds. Similarly, the mapping of fast-drying vegetation (blue areas in Figure B.1) corresponded well with ground-truthed areas of non-GDV *Acacia* midstorey. Outside of the major Creek system, remote sensing results were regarded as being unreliable due to the spurious reflectance attributes of sparsely vegetated portions of the landscapes, particularly where topographical features such as incised river valleys cause significant light-shade contrasts. From ground truthing, these areas are known to be sparsely vegetated and do not support the presence of GDV.

4 Groundwater Management at Iron Valley

4.1 Numerical Modelling of Groundwater and Surface Water

According to the conceptual understanding of the groundwater system for the Iron Valley site (AQ2 2016), the Iron Valley orebody lies within a transmissive, mineralised orebody aquifer system with an overlying layer of alluvium. This aquifer system is connected to the Weeli Wolli Creek via a fault that will form a strong conduit for flow from the creek to the mine site. Substantial dewatering will be required to keep open mine pits dry during mining, which will have an effect on regional groundwater levels.

Mine water demand is predicted to be much less than that required for dewatering such that there will be a water surplus that will need to be disposed. Review of all possible disposal options has identified the disposal to the adjacent Weeli Wolli Creek as the most suitable option (AQ2 2016). At present, disposal is being considered at three locations adjacent to the mine along Weeli Wolli Creek: DL1, DL4 and DL5. Predicted abstraction and disposal volumes from 2016 to 2015 (end of mining) are listed in Table 3. Of note for this report, location DL1 is only used for four years and for the majority of the mine life the discharge is split 50/50 between locations DL4 and DL5.

Table 3: Water balance summary, with annual average rates in kL/d, reproduced from Table 4.8 in AQ2 (2016).

Year	Total dewatering	Maximum water demand	Surplus	Disposal to DL1	Disposal to DL4	Disposal to DL5
2016	62,707	15,700	47,007	15,010	15,999	15,999
2017	63,175	15,700	47,475	15,010	16,233	16,233
2018	60,166	15,700	44,466	15,010	14,728	14,728
2019	57,129	15,700	42,429	22,094	10,167	10,167
2020	22,263	15,700	6,563	0	3,282	3,282
2021	31,695	15,700	15,995	0	7,998	7,998
2022	30,305	15,700	14,605	0	7,303	7,303
2023	30,369	15,700	14,669	0	7,335	7,335
2024	42,756	15,700	27,056	0	13,528	13,528
2025	38,340	15,700	22,640	0	11,320	11,320

Dewatering and disposal of surplus water from the Iron Valley mine will have a cumulative effect on the prevailing groundwater and surface water conditions in the region, given the historical and ongoing disposal of excess water by Rio Tinto and BHPBIO to southern areas of the Marillana-Weeli Wolli Creek system.

Numerical modelling was recently undertaken to assess the impact of mining operations on groundwater and surface water conditions in the area surrounding the mine (AQ2 2016). The model included:

- the aquifers associated with orebodies and the Weeli Wolli Creek
- recharge to the aquifer system from surface water flows in the Weeli Wolli Creek
- dewatering of the orebody aquifer
- groundwater inflow from the upper Weeli Wolli Creek catchment
- groundwater outflow to downstream.

A number of different scenarios were modelled over the expected life of the Iron Valley Mine (10 years), two of which were used in this report to assess the risk to GDV. These two scenarios, referred to as the Base Case and the Rio Tinto Case, are listed in Table 4.

Table 4: Summary of model predictions used to assess the risk to groundwater dependent vegetation from Iron Valley mining operations, modified from Table 4.7 in AQ2 (2016). TSF = Tailings Storage Facility.

Scenario	Description	Model inclusions	Model predictions used in this report
Base Case	Iron Valley impacts from dewatering and surplus disposal	• Dewatering from Iron Valley • Surplus disposal from Iron Valley • Operation of the TSF • Climatic variability (recharge from the Weeli Wolli Creek)	• Groundwater drawdown contours (end of mining, 2025) • Iron Valley surface water wetting front (end of mining, 2025)
Rio Tinto Case	Iron Valley impacts plus surplus disposal from Rio Tinto's proposed mine expansion	• Dewatering from Iron Valley • Surplus disposal from Iron Valley • Operation of the TSF • Climatic variability (recharge from the Weeli Wolli Creek) • Recharge from the Weeli Wolli Creek from Rio Tinto's Pocket and Billiard Operations	• Groundwater drawdown contours (end of mining, 2025) • Cumulative surface water wetting front (end of mining, 2025)

The full results of groundwater modelling are documented in AQ2 (2016) and only a short description is presented here to provide context for this report. Briefly, results for the Base Case suggest that during the mine life, groundwater levels around the mine and in parts of Weeli Wolli Creek would be lowered; however there are other areas where groundwater mounding would occur and water levels would rise to the surface in the creek, resulting in surface flow. For the Rio Tinto Case, groundwater levels would be lowered around the mine similar to the Base Case, but water levels would rise across most of the Weeli Wolli Creek system resulting in surface water flow that would likely extend for many kilometres along the creek (Appendix C). In effect, it was concluded that should Rio Tinto proceed with their expansion, their excess water disposal will override the predicted drawdown in the area of Weeli Wolli Creek from Iron Valley dewatering (AQ2 2016). According to modelling, groundwater levels are projected to recover to an equilibrium level relatively quickly (within 10 years) once abstraction has ceased.

With regard to surface water flow in the creek, AQ2 developed an analytical water balance model to predict the distance that dewatering discharge would travel downstream as surface flow from the discharge point (AQ2 2016). Briefly, the model split the alluvium creek aquifer into a number of consecutive downstream 'storage buckets', and used a cumulative monthly time series of estimated total creek discharges to fill each bucket and track how far downstream the discharges would fill. Input parameters for the model included an alluvium thickness of 15 m and alluvium width of 400 m.

For the Base Case, the surface water model predicted that the seepage front (wetting front) from the dewatering discharge would extend by approximately 6 km downstream of a single discharge point. Based on a 50/50 split of discharge between DL4 and DL5, it was assumed that a wetting front would extend 3 km downstream from each location, with the total wetting front for the Iron Valley disposal extending 6 km downstream of DL4. Although not modelled by AQ2, the Base Case must also necessarily include surface water flows as a result of current discharge by Rio Tinto operations. For this report, the wetting front from Rio Tinto's surplus discharge was conservatively assumed to extend 9 km downstream of the Marillana-Weeli Wolli Creek confluence as estimated by Dogramaci et al. (2014). For the Rio Tinto Case, the modelled wetting front was predicted to extend well beyond that predicted for the Base Case, as far as 23 km downstream from the Marillana-Weeli Wolli Creek confluence.

4.2 Conceptual Model of Surface Water Impacts

In the absence of a specific mechanistic model describing actual water flows, surface pooling and other surface water dynamics for Weeli Wolli Creek system, a simple conceptual model was developed for this report to describe the potentially harmful effects of surface water on GDV along the length of the wetting front. This model, which builds on the numerical surface water flow modelling undertaken by AQ2, is presented in Figure 1 and accompanying Table 5.

The conceptual model attempts to describe the reasonable assumption that surface flows, subsurface flows in the hyporheic zone, and the degree of saturation (waterlogging) of underlying alluvium will be greatest at the point of discharge and then diminish with increasing distance downstream. The model is framed on AQ2's model parameters that specify an alluvium width of 400 m and depth of 15 m. Conceptually, this can be applied to the creek bed such that the 400 m width spans 200 m either side of the creek bed centre line, working on the assumption that discharge occurs into the centre of the creek bed. Soil moisture in the alluvium to 15 m depth is assumed to be fully recharged to the point that surface water can be expressed. The 'waterlogging zone' closest to the discharge point (that is the super saturated zone in which subsurface flows might occur and plant roots would be exposed to hypoxic conditions) is assumed to extend to only the first few metres depth but deep enough to compromise the health of inundated large trees, with this zone expected to shrink laterally and vertically with increasing distance downstream of the discharge point.

When applied to the Marillana-Weeli Wolli Creek system, division of the linear length of projected wetting fronts into the defined surface water impact zones was based on on-ground observations of the wetting front from the ongoing Rio Tinto discharge, which putatively extends from the Rio Tinto discharge point along Marillana Creek (RTIO DL) to 9 km downstream of the Marillana-Weeli Wolli Creek confluence (Dogramaci et al. 2014). On-ground, it was observed that large permanent pools and flowing water were concentrated in the first 1 km to 2 km downstream of the discharge point; however it was conservatively estimated that the length should be divided equally to assign zones 1, 2 and 3 to account for seasonal effects and inter-annual variability in rainfall.

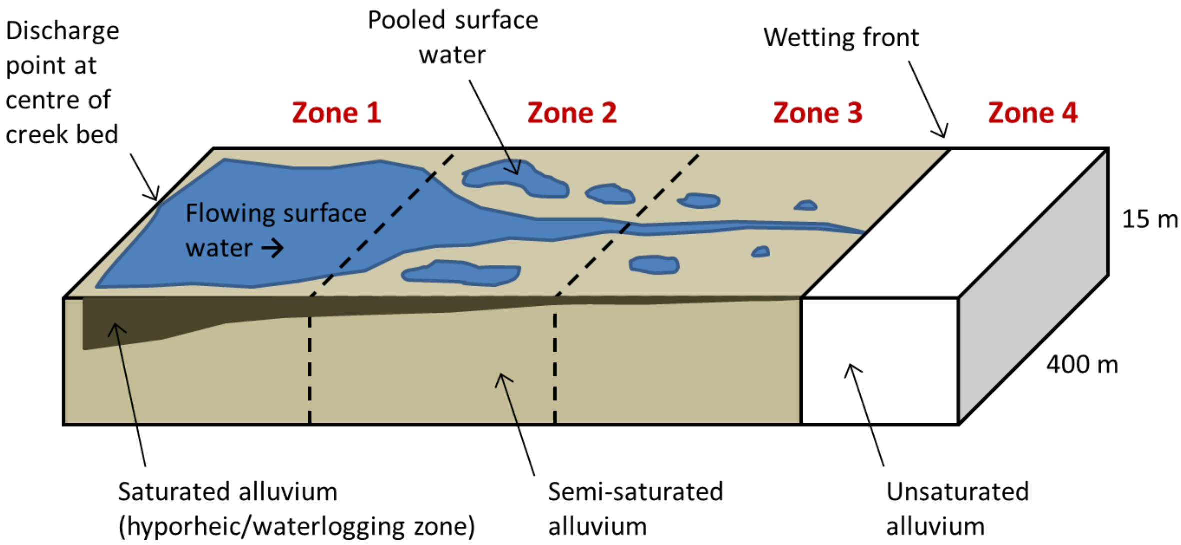

Figure 1: Conceptual model of the presence of surface water with increasing distance downstream of a discharge point, divided in to four impact zones. Impact zones and the potential impact of surface water on groundwater dependent vegetation within each zone are described in Table 5. Not drawn to scale.

Table 5: Description of surface water impact zones as shown in the conceptual model presented in Figure 1.

Surface water impact zone	Description	Effects on GDV		
		Inundation	Waterlogging	Likelihood of negative impact on health
1	Permanent surface and subsurface (hyporheic zone) flows across wide expanses of the creek.	Permanent inundation	Permanent waterlogging of large portion of surface root system	High
2	Permanent surface flows across narrow channels in the main creek bed. Large number of isolated large permanent and semi-permanent pools across wide expanses of the creek.	Regular inundation for months at a time	Moderate waterlogging affecting large portion of surface root system	Moderate
3	Semi-permanent surface flows across narrow channels, mainly restricted to the main creek bed, tapering to zero flow near the wetting front. Small number of isolated small permanent and semi-permanent pools, mostly restricted to the main creek bed.	Occasional inundation for several days to weeks at a time	Occasional mild waterlogging affecting small portion of surface root system, predominantly only very shallow roots	Low
4	No discharge-related surface water. Surface water only accumulates and flows during and shortly after significant rainfall events and then recedes.	None	None	Negligible

5 Risk Assessment

A risk assessment was conducted to identify areas of GDV in the vicinity of the Project that may be at high risk of impact from groundwater dewatering and discharge of surplus water into Weeli Wolli Creek. The specific risk under consideration is a biologically significant decline in GDV tree health. The aim of the assessment was to provide information that can be used to inform the selection of GDV management zones and monitoring sites inside the expected impact zone.

To frame the assessment, GDV risk was conceptualised as being determined by:

- exposure to unfavourable surface water conditions arising from the direct discharge of water into the creek bed.
- exposure to change in the groundwater level (compared to the pre-development level) arising from the combined effect of dewatering and discharge.

A simple risk model was developed to assess GDV risk, applied to the area of GDV identified and described in Section 3 and Appendix A, referred to as the GDV risk area. A scoring system for surface water impacts (SWI) and groundwater impacts (GWI) was developed for input into a risk model, as described in the sections below. The risk model was then applied to assess both the Base Case and the Rio Tinto Case scenarios.

5.1 Risk Model

5.1.1 Surface water impact score

Surface water impact scores represented the likelihood of a negative impact on GDV occurring as a result of direct discharge into the Creek. The assignment of scores was dependent on the proximity of GDV to the point of discharge, as described by the conceptual model of surface water accumulation for the Weeli Wolli Creek system presented in Section 4.2 (Figure 1 and Table 5). This model defines the specific area within the creek system that is at risk of SWI, along with four different levels (zones) of impact based on the distance downstream from the point of discharge. The model describes how surface water impacts are expected to diminish with increasing distance downstream.

Prior to assigning surface water impact scores, the GDV risk area was subdivided to define the area that was subject to both groundwater and surface water impacts (GWI+SWI risk area) and the area that was subject only to groundwater impacts (GWI risk area). Specifically, the GWI+SWI risk area was defined as the area within the GDV risk area that was 200 m either side of the main creek bed of the Marillana-Weeli Wolli Creek system, based on the assumption that water is discharged directly into the main creek bed.

Division of the GWI+SWI risk area into the surface water impact zones and subsequent assignment of surface water impact scores was based on linear division of the creek bed centre line. As a general rule, the length between the discharge point and the wetting front was divided equally to assign zones 1, 2 and 3, while the length downstream of the wetting front was assigned to zone 4.

For the Base Case, the length of the wetting front associated with current Rio Tinto discharge was assumed to extend 9 km downstream from the Marillana-Weeli Wolli Creek confluence (AQ2 2016; Dogramaci et al. 2014), while the length of the wetting front for the Iron valley discharge points considered (DL4 and DL5) was assumed to be 3 km downstream from each point (AQ2 2016).

For the Rio Tinto Case, zone 1 was conservatively assumed to extend all the way from the southern extents of the GWI+SWI risk area to the projected Iron Valley (Base Case) wetting front. This took into account the cumulative impacts of discharge from DL4 and DL5 on top of discharge from the Rio Tinto expansion upstream. The length of creek between the Iron Valley wetting front and the cumulative wetting front was then equally divided to assign zones 2 and 3.

For both cases, areas upstream of the Marillana-Weeli Wolli Creek confluence along Weeli Wolli Creek areas upstream of the current Rio Tinto discharge point along Marillana Creek were assigned to surface water impact zones based on on-ground observations.

The surface water impact scoring system is outlined in Table 6, along with a brief summary of the likely reasons for negative impacts (inundation and waterlogging) as suggested by the conceptual model (Figure 1, Table 5). Surface water impact scores were applied only to the GWI+SWI risk area.

Table 6: Description of surface water impact scores used in the risk model. These scores were applied only to the area within the groundwater dependent vegetation (GDV) risk area that was considered to be at risk from surface water impacts. MC = Marillana Creek, WWC = Weeli Wolli Creek. Surface water impact zones relate to the conceptual model presented in Figure 1 and Table 5.

<table>
<tr><th rowspan="2">Surface water impact zone</th><th rowspan="2">Surface water impact score</th><th colspan="2">Distance downstream from the MC-WWC confluence (km)</th><th rowspan="2">Likely period of inundation</th><th rowspan="2">Likely degree of waterlogging</th><th rowspan="2">Likelihood of a negative impact[1]</th></tr>
<tr><th>Base Case</th><th>Rio Tinto Case</th></tr>
<tr><td rowspan="4">1</td><td rowspan="4">3</td><td colspan="2">All areas upstream of the confluence along WWC</td><td rowspan="4">Permanent</td><td rowspan="4">Severe</td><td rowspan="4">High</td></tr>
<tr><td>0 to 3</td><td rowspan="3">0 to 15[4]</td></tr>
<tr><td>9[2] to 10</td></tr>
<tr><td>12[3] to 13</td></tr>
<tr><td rowspan="4">2</td><td rowspan="4">2</td><td colspan="2">0 km to 1 km upstream from the Rio Tinto discharge point along MC</td><td rowspan="4">Regular</td><td rowspan="4">Moderate</td><td rowspan="4">Moderate</td></tr>
<tr><td>3 to 6</td><td rowspan="3">15[4] to 19</td></tr>
<tr><td>10 to 11</td></tr>
<tr><td>13 to 14</td></tr>
<tr><td rowspan="4">3</td><td rowspan="4">1</td><td colspan="2">All areas > 1 km upstream from the Rio Tinto discharge point along MC</td><td rowspan="4">Occasional</td><td rowspan="4">Mild</td><td rowspan="4">Low</td></tr>
<tr><td>6 to 9[2]</td><td rowspan="3">19 to 23[5]</td></tr>
<tr><td>11 to 12[3]</td></tr>
<tr><td>14 to 15[4]</td></tr>
<tr><td>4</td><td>0</td><td>> 15[4]</td><td>> 23[5]</td><td>None</td><td>None</td><td>Negligible</td></tr>
</table>

1. Negative impact as a result of GDV roots becoming waterlogged and/or intolerance to inundation.
2. Iron Valley discharge location DL4.
3. Iron Valley discharge location DL5.
4. Base Case wetting front (AQ2 2016).
5. Rio Tinto Case wetting front (AQ2 2016).

5.1.2 Groundwater impact score

Groundwater impact scores represented the likelihood of a negative impact on GDV occurring as a result of a change in the groundwater level. Scores were assigned depending on whether the change in groundwater level was a projected decrease (drawdown) or increase (mounding), as described in Table 7. Surface water impact scores were applied only to both the GWI risk area and the GWI+SWI risk area.

In the case of drawdown, impact scores were assigned according the projected magnitude of drawdown (m). This was justified as follows: where GDV is initially present, it can be reasonably inferred (by definition) that groundwater is initially in contact with plant roots to some degree. From this, the potential impact of groundwater drawdown on GDV can be considered solely on the basis of the magnitude of drawdown without the need for exact knowledge of water table depth or maximum plant rooting depths, which cannot be determined with certainty. It is simply assumed that for any degree of initial root contact with groundwater, a larger decrease in the groundwater level is likely to have a greater impact on GDV than a smaller decrease.

In the case of mounding, impact scores were assigned according to the projected depth of the water table below ground (mbgl), rather than the magnitude of mounding. The justification for this is that although maximum rooting depths are uncertain, it is reasonable to assume that the root distribution of GDV species decreases exponentially with depth such that the closer the groundwater level is to the surface, the greater proportion of roots are potentially affected in a negative way by waterlogging associated with mounding.

Groundwater impact scores were spatially assigned by overlaying groundwater contour maps of projected drawdown and projected depth to water table on the mapped GDV risk area. These contour maps were the result of modelling that took into account the combined effects of both groundwater abstraction and discharge. Contour maps were supplied by AQ2 (2016) for both the Base Case and the Rio Tinto Case. Groundwater drawdown maps used positive numbers to represent a water level decrease and negative numbers to represent a water level increase such that drawdown areas could be distinguished from mounding areas. This enabled assignment scores to drawdown areas based on the magnitude of drawdown, and the assignment of scores to mounding areas based on depth to the water table, as per Table 7.

Table 7: Description of groundwater impact scores used in the risk model.

Groundwater impact score	Groundwater level decrease			Groundwater (gw) level increase		
	Projected drawdown (m)	Likely access to groundwater[1]	Likelihood of a negative impact	Projected gw level (mbgl)	Likely degree of waterlogging	Likelihood of a negative impact
6	> 10	No access	High	< 2	Severe	High
4	5 to 10	Limited access	Moderate	2 to 5	Moderate	Moderate
2	1 to 5	Some access	Low	5 to 10	Mild	Low
0	< 1	Full access	Negligible	> 10	None	Negligible

1. Relative to original level of access prior to development.

5.1.3 Risk score

As stated previously, the specific risk under consideration is a biologically significant decline in GDV tree health. For this assessment, risk was quantified in terms of an estimated probability (%) that a decline will occur.

Conceptually, risk models are designed based on the standard convention of defining *Risk* as the product of *Likelihood* and *Consequence* (Burgman 2005). In this assessment, likelihood represents the probability that a decline in GDV health will occur, represented by the groundwater and surface water impact scores as outlined above. Consequence represents the magnitude of decline, scored simply as either a one for vegetation at risk (that is, vegetation within the defined GWI and GWI+SWI risk areas) or zero for vegetation not at risk (all other surrounding vegetation within the assessment area). Logically, GDV species (including obligate phreatophytes such as *M. argentea* and facultative phreatophytes such as *E. victrix* and *E. camaldulensis*) face a greater consequence in response to groundwater drawdown of any given magnitude than species with minimal or no dependence on groundwater (for example, midstorey *Acacia* species'). Similarly, GDV species that occur in the path of direct discharge into the creek bed face a greater consequence than species that occur away from the creek bed. Thus, risk was determined simply as that defined by likelihood.

Final risk score for the GWI risk area was defined as the groundwater impact score, whereas the final risk score for the GWI+SWI risk area was defined as the sum of the groundwater impact score and the surface water impact score. Spatial layers for each of the impact scores were overlaid to calculate the final risk scores. Risk ratings were then assigned as outlined in Table 8, and the Low, Moderate and High risk ratings were mapped.

Of note, surface water impact scores were numerically less than groundwater impact scores, but no meaning should be attributed to this. The scoring system was formulated to produce a ranking of different scenarios for the GWI+SWI risk area that was both logical and intuitively reflected the relative contribution of each component. The scoring system was not designed to directly compare the magnitude of impact of each component. It is not implied, for example, that in areas with a groundwater impact score of 6 are subjected to double the impact of areas with a surface water impact score of 3. Risk scores for some example scenarios are provided in Table 9.

Surface water discharge plays a potentially positive role for GDV in areas where there is groundwater drawdown and it is recognised that this is not fully accounted for in the risk scoring system. The degree to which surface water can recharge underlying alluvium and the effect this has on mitigating loss of contact with groundwater for GDV species remains uncertain and difficult to estimate based on current information. After some consideration, this aspect was deemed too uncertain to include in the risk model; a conservative approach was taken to leave it out.

Table 8: Final risk scores used in the risk model.

Risk rating	Risk score	Estimated probability of decline
High	6 to 9	50% to 100%
Moderate	3 to 5	10% to 50%
Low	1 to 2	< 10%
Negligible	0	0

Table 9: Risk scores for example scenarios of where groundwater dependent vegetation is exposed to groundwater drawdown or mounding and surface water.

Projected groundwater drawdown (m)	Projected groundwater mounding (mbgl)	Groundwater impact score	Surface water impact zone	Surface water impact score	Risk score	Risk rating
> 10	-	6	1	3	9	High
> 10	-	6	4	0	6	High
5 to 10	-	4	2	2	6	High
5 to 10	-	4	3	1	5	Moderate
5 to 10	-	4	4	0	4	Moderate
1 to 5	-	2	2	2	4	Moderate
1 to 5	-	2	4	0	2	Low
< 1	-	0	1	3	3	Moderate
< 1	-	0	2	2	2	Low
< 1	-	0	4	0	0	Negligible
-	< 2	6	1	3	9	High
-	< 2	6	4	0	6	High
-	2 to 5	4	2	2	6	High
-	2 to 5	4	3	1	5	Moderate
-	2 to 5	2	4	0	2	Low
-	5 to 10	2	1	3	5	Moderate
-	5 to 10	2	2	2	4	Moderate
-	> 10	0	1	3	3	Moderate
-	> 10	0	2	2	2	Low
-	> 10	0	4	0	0	Negligible

5.1.4 Assumptions and limitations

It is important to state that the risk assessment is a hypothesis that provides only a general indication of risk. Although based on the best available knowledge of the GDV species involved, and the best available projections of groundwater levels and surface water from modelling (AQ2 2016), it is qualitative and involves some broad assumptions. Use of a simplified risk model was the only feasible approach taking into account the following:

- the coarse spatial resolution of GDV mapping, in which GDV status was assigned based simply on the presence of any of the following indicator species, irrespective of tree density or size: *E. victrix*, *E. camaldulensis* and *M. argentea*
- the coarse spatial and temporal resolution of projected groundwater drawdown contours
- response to drawdown reaches a limit, that is, increments of drawdown well beyond the maximum depth of the root zone will not cause any further response in GDV
- an incomplete understanding of the impact of inundation and waterlogging on established vegetation communities within the GDV risk area (for example, waterlogging tolerances of individual species).

Appropriately, in recognition of these limitations and assumptions, the risk model was conservative.

The conceptual model for surface water (Section 4.2, Figure 1 and Table 5) was developed in an attempt to provide guidance and limit bias in attributing surface water impacts to GDV given that there is currently no quantitative understanding of the relationship between inundation and waterlogging on GDV health for the Weeli Wolli Creek system. This approach has obvious limitations, but it provides a necessary starting point to frame these interactions, and it should be viewed as just one component of a generally broad assessment.

5.2 Results and Discussion

5.2.1 Risk assessment

GDV areas assessed to be at risk of decline from the combined effects of groundwater drawdown and discharge are shown in Figure 1 for the Base Case and Figure 2 for the Rio Tinto Case. The areas of vegetation in each risk category listed in Table 10. The area of vegetation assessed within the tenement was 26 ha.

For the Base Case (Figure 1), approximately one quarter of the GDV risk area (591 ha) was assessed to be at high risk (Table 10), spread across the area of the main creek bed from the Rio Tinto discharge point (RTIO DL) to approximately 6 km downstream of the Marillana-Weeli Wolli Creek confluence. The high risk area was also expanded out across the entire width of the GDV risk area along a 4 km portion downstream from the Marillana-Weeli Wolli Creek confluence. High risk was associated with groundwater drawdown from the Iron Valley mine coupled with surface water impacts from the existing Rio Tinto discharge. Surface water impacts from the Iron Valley discharge were assessed to pose a moderate risk immediately downstream of the discharge points (DL4 and DL5), with no risk to GDV beyond the projected Iron Valley wetting front where although groundwater levels are projected to rise, the water table remains relatively deep.

Similar to the Base Case, approximately one quarter of the GDV risk area (583 ha) was assessed to be at high risk (Table 10) for the Rio Tinto Case (Figure 2). High risk for the Rio Tinto Case was predominantly associated with surface water impacts along the main creek bed, from the Rio Tinto discharge point (RTIO DL) to around 14 km from the Marillana-Weeli Wolli Creek confluence, a couple of kilometres beyond the furthest Iron valley discharge point. In this case, high risk was associated with cumulative surface water impacts coupled with groundwater mounding in areas where groundwater levels were projected to rise very near the surface, which in some instances was also assessed to impose a high risk to GDV beyond the main creek bed.

Table 10: Areas of groundwater dependent vegetation (GDV) at risk for the Base Case (Figure 2) and the Rio Tinto Case (Figure 3). Areas do not include vegetation within the Iron Valley tenement boundary. The total area of vegetation assessed within the GDV risk area was 2,542 ha, out of a total assessed area of 31,416 ha (area within a 10 km radius of the Iron Valley mine).

Risk to GDV	Estimated probability of decline	Area of vegetation in ha (% of GDV risk area)	
		Base Case	Rio Tinto Case
High	50% to 100%	591 (23%)	583 (23%)
Moderate	10% to 50%	665 (26%)	676 (27%)
Low	< 10%	418 (16%)	739 (29%)
Negligible	0	867 (34%)	544 (21%)

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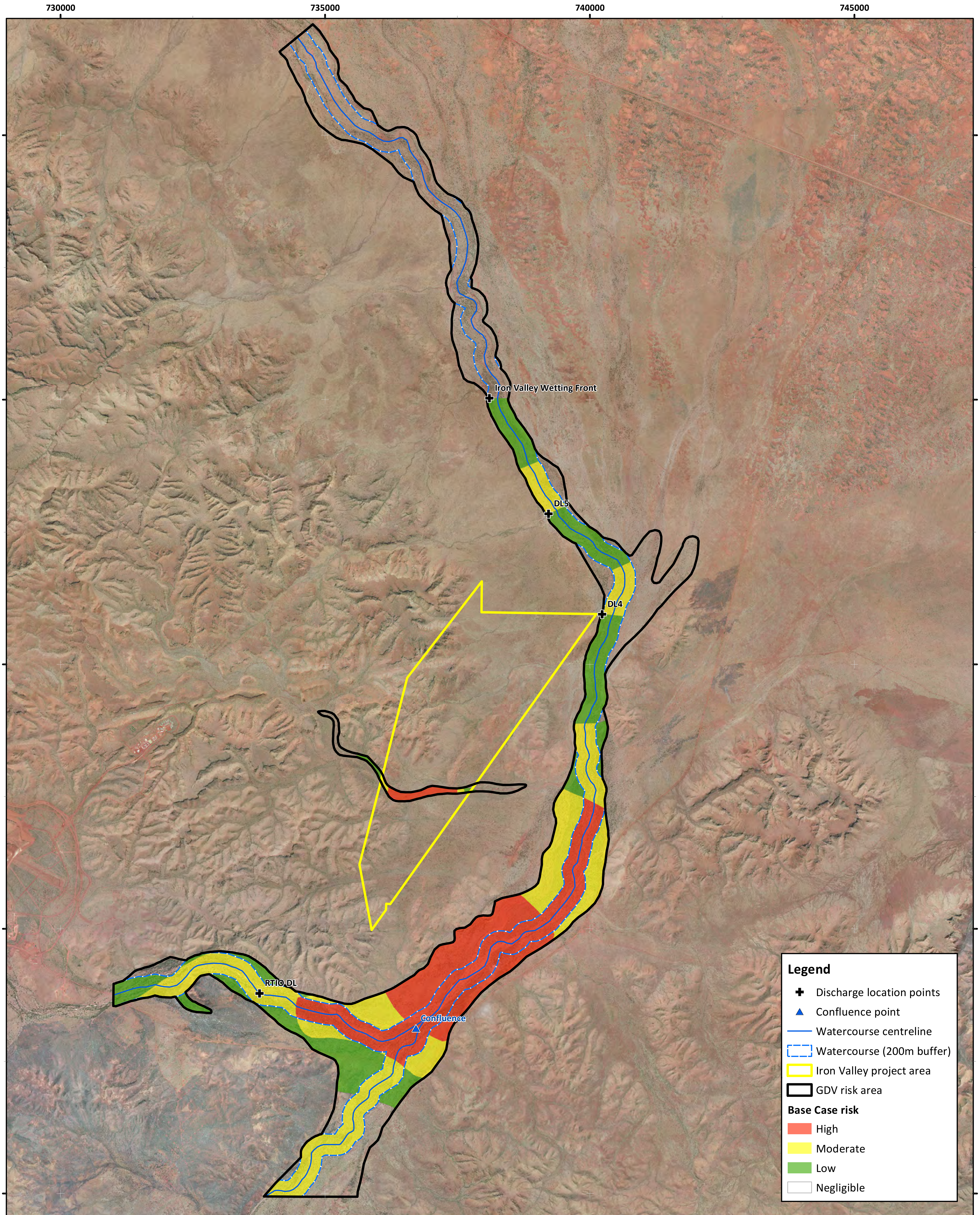

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Iron Valley Groundwater Dependant Ecosystem Investigation

Figure 2: Base Case - Groundwater abstraction and discharge risk model

astron

Author: T. Bleby	Date: 05-02-2016
Drawn: C. Dyde	Figure Ref: 13016A-15-MODR-1RevB_160205_Fig2_Base

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 Kilometres

N

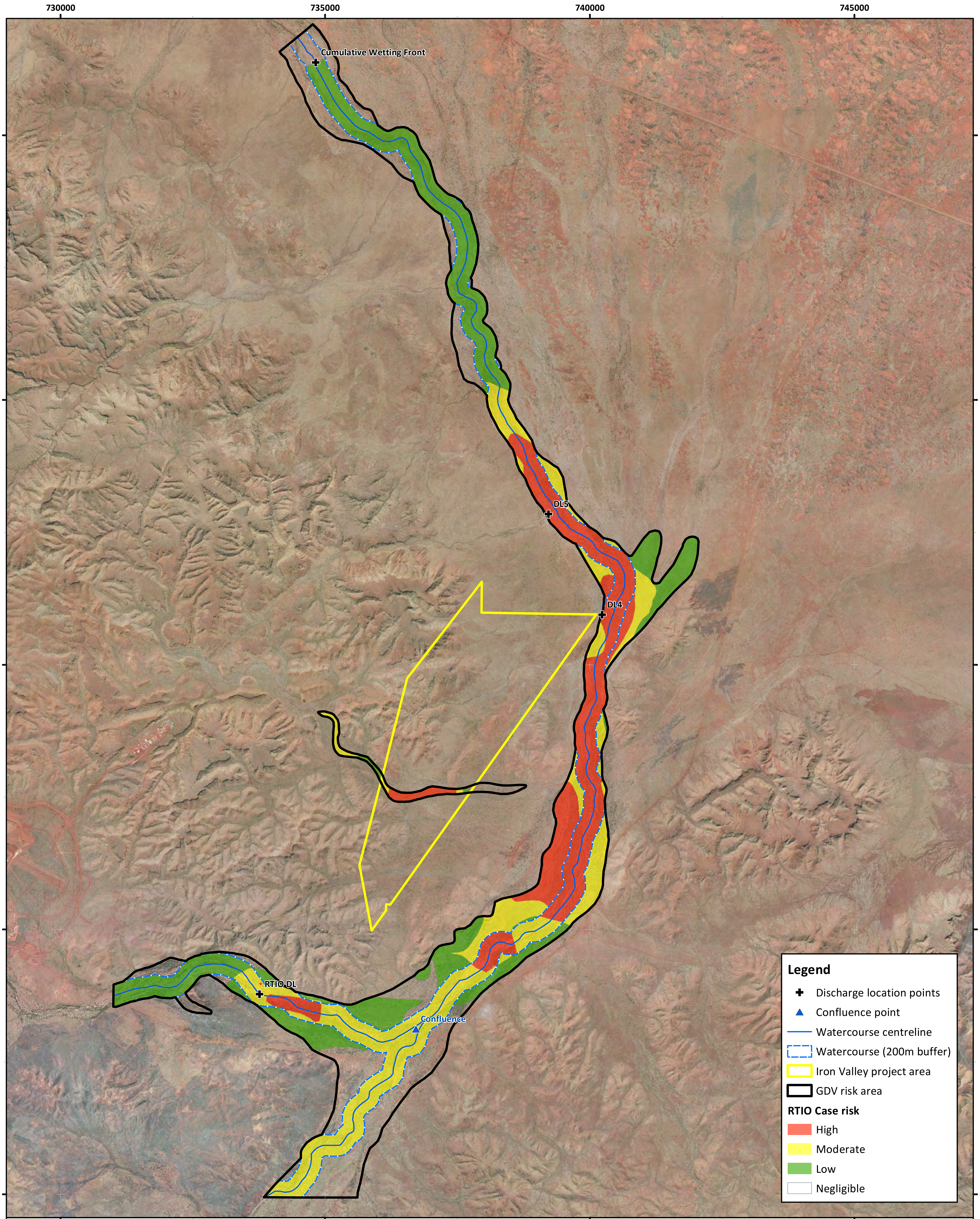

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Figure 3: Rio Tinto Case - Groundwater abstraction and discharge risk model

Author: T. Bleby	Date: 05-02-2016
Drawn: C. Dyde	Figure Ref: 13016A-15-MODR-1RevB_160205_Fig3_RTIO

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 Kilometres

N

5.2.2 Cumulative impacts of discharge

The risk assessment presented in this report considers the combined impacts of groundwater drawdown, mounding and surface water as a result of dewatering and discharge for the Iron Valley mine, along with the additional impact of discharge from neighbouring Rio Tinto mines. With regard to the cumulative impacts of discharge, the Rio Tinto Case assessed at the end of the Iron Valley mine life can be considered the 'worst case scenario'.

It is difficult to provide an accurate assessment of the cumulative impacts of discharge. Weeli Wolli Creek is an already impacted system that has already been subject to cumulative impacts from multiple sources. Such cumulative impacts are inherently complex and difficult to predict. On the one hand, there are sections of the creek where new GDV communities have become established only as a result of discharge, and where discharge most likely partially contributes to maintaining the health of pre-existing large trees via the recharge of soil moisture in the underlying alluvium, which is likely to benefit the facultative phreatophytes *E. victrix* and *E. camaldulensis*. These communities may continue to flourish and expand with additional discharge.

On the other hand, pre-existing large trees of these species are not well adapted to permanent water logging, rather, they are adapted to temporary periods of inundation that accompany high creek flows and flooding following cyclonic rainfall events. Permanent inundation and waterlogging arising from large volumes of discharge is likely to result in the decline of some vegetation including potentially the loss of large trees including *E. victrix* and *E. camaldulensis*. The extent to which large trees might be affected largely depends on the spatial distribution of trees in relation to areas of permanent water and the proportion of individual root systems that is subject to permanently waterlogging. If waterlogging impacts turn out to be highly localised, then it may be that the number of trees within the high risk area that are actually at high risk may be relatively small.

Contours of predicted groundwater level changes from Rio Tinto's disposal activities indicate that substantial mounding of groundwater levels will occur along the whole of the Weeli Wolli Creek system around the Iron Valley mine (see Appendix C). As noted in the AQ2 (2016) report, the magnitude of mounding in the southern (upstream) portion of the creek is approximately the same as the magnitude of drawdown predicted to occur from the Iron Valley Project, suggesting that discharge from upstream operations may have the beneficial effect of mitigating any negative impacts of dewatering. However, in the mid to northern (downstream) portions of the creek, it is likely that additional discharge from the Iron Valley mine would have a cumulative effect on mounding and surface water impacts that increases the risk to GDV.

5.2.3 Recovery after mining

It is difficult to predict with any certainty the long term consequences and recovery potential of GDV once groundwater and surface water regimes have stabilised and are back under natural influences after mining at Iron Valley has ended. According to AQ2's modelling, groundwater levels and creek water levels are projected to recover to an equilibrium level relatively quickly (within 10 years) once abstraction and discharge have ceased.

With regard to groundwater, there is a possibility that some GDV may potentially become adapted to groundwater mounding by increasing the allocation of roots to surface soil layers and dispensing with deeper roots. These individuals may then struggle to grow deeper roots fast enough to 'catch up' with falling groundwater levels. With regard to surface water it is likely that GDV communities would become adapted to the new surface water regime given sufficient time. However, this also means that adapted communities would not then be equipped to deal with the sudden decrease or removal of water supplied by discharge. It is reasonable to suggest that a phased withdrawal of discharge would be less risky to GDV than simply ‘turning off the tap’.

From a broader perspective, the Marillana-Weeli Wolli Creek is a fairly large ecosystem that may have some potential to buffer the temporary impacts of mining. The lifespan of established large trees is in the order of hundreds of years and if not subject to catastrophic change, would be expected to endure. This system also supports many healthy populations of the GDV species of interest both upstream and downstream of mining activities, providing a pool for recruitment should there be a loss of GDV in some areas. Overall, recovery of the ecosystem is expected, particularly if management measures such as staged discharge reduction are implemented.

6 Future Monitoring of Groundwater Dependent Vegetation

6.1 Requirement for Monitoring

Given the presence of significant GDV in the vicinity of the Project area, it is anticipated that there will be a monitoring requirement associated with any future approval for groundwater abstraction associated with BWT mining.

A carefully devised monitoring approach would be required to detect changes to tree health both upstream (already impacted by discharge and threatened by drawdown) and downstream (threatened by groundwater mounding cumulative discharge) of the creek system to demonstrate whether or not the Project has any negative (or possibly positive) effect on GDV as it is now and as it may potentially change in response to additional discharge by Rio Tinto.

Below is an outline of a potential monitoring program of the type that may be required to meet regulatory requirements. Note that this is an example only, and it does not represent a proposed final program suitable to meet the needs of regulators. This example is based on the assumption that the current monitoring program for AWT mining will be proposed as a model with some slight modifications to meet the needs of BWT mining.

6.2 Brief Outline of Potential Monitoring Program

6.2.1 Objective

The objective of monitoring would be to detect any changes to the health and condition of GDV attributable to groundwater drawdown associated with BWT mining operations at the Iron Valley Mine, in order to maintain compliance with legislative requirements for the Project. It is anticipated that specific GDV management zones with accompanying management objectives, targets and appropriate monitoring triggers would be formulated once legislative requirements are known. The objective would also be to incorporate an adaptive management approach that allows for regular revision of the monitoring program.

6.2.2 Design

The design of the monitoring program would be based on the Before-After, Control-Impact approach. Monitoring would be initiated as soon as possible to acquire a suitable amount of data over a baseline period before the commencement of dewatering. Monitoring would continue during and post dewatering for as long as mandated, possibly up to the end of life of mine. Monitoring would be conducted at a number of potential impact sites where GDV is a medium to high risk of decline in response to dewatering, and at appropriate control sites outside the expected area of groundwater drawdown.

6.2.3 Monitoring Sites

Potential monitoring sites are summarised in Table 11, drawn from the pool of inspection sites visited during the on-ground reconnaissance (Appendix A). These sites take into account the identified risk areas for both the Base Case and Rio Tinto Case scenarios and an appropriate level of spatial coverage from north to south along the Creek system. These sites are suggestions only and provide a starting point for a more in-depth consideration of monitoring requirements once legislative requirements are known. One approach may be to divide the Creek system into different management zones each with their own set of management objectives, targets and triggers to account for the potentially different impacts of groundwater drawdown, mounding and surface water discharge.

Table 11: Summary of proposed monitoring sites for a potential expanded groundwater dependent vegetation (GDV) monitoring program for the Iron Valley Project. Ec = *Eucalyptus camaldulensis*. N/A = Not Applicable. Assessed risk is based on the Rio Tinto Case.

Inspection site	Site type	Risk type	Assessed risk to GDV	Comment
18	Potential impact	Mounding and discharge	High	Downstream of Iron Valley discharge location DL5
5	Potential impact	Mounding and discharge	High	Downstream of Iron Valley discharge location DL4
7	Potential impact	Mounding and discharge	High	Downstream of current Rio Tinto discharge point
9	Potential impact	Mounding and discharge	High	Downstream of current Rio Tinto discharge point
11	Potential impact	Mounding and discharge	Moderate	Downstream of current Rio Tinto discharge point
14	Potential impact	Mounding and discharge	Moderate	Downstream of current Rio Tinto discharge point
12	Potential impact	Mounding	Low	Ec forest
Upstream of 3	Potential impact	Discharge	Low	Downstream of Iron Valley wetting front
Downstream of 3	Reference	N/A	Negligible	Downstream of cumulative wetting front
1	Reference	N/A	Moderate	Upstream of cumulative impact zone

6.2.4 Monitoring Parameters and Methods

Monitoring parameters that would enable tracking of performance against specified management targets and monitoring triggers are outlined in Table 12. Tree based measurements would be conducted on a minimum of 10 permanently marked representative trees per site, spread across the site, with most trees located near to the main Creek channel. Site based measurements would be made from one permanent sampling point established at each site.

Whole of ecosystem monitoring using remote sensing is also highly recommended. GDV monitoring using high resolution satellite imagery is now becoming standard practice. With such imagery, GDV canopy can be identified and distinguished from non-GDV canopy; areas of GDV canopy that undergo significant change can then be detected across the entire Project area. This approach is supported by field based monitoring of sites and targeted ground truthing. When a remote sensing monitoring component is included, on-ground monitoring effort can generally be less intensive than if remote sensing is not included.

6.2.5 Data analysis, Interpretation and Reporting

Data would be analysed, interpreted and assessed against monitoring triggers with the aid of control charts (Gove et al. 2013). Reporting would be via an annual report that presents all relevant data in a standard scientific format, and includes a discussion on evaluating performance against management targets, evaluates the effectiveness of the monitoring program, and provides recommendations on further investigations, management actions and revisions to the monitoring program if required. Ideally, a summary report card would also be prepared that simply indicates whether or not monitoring triggers have been exceeded, and includes a tally of the area of impact to GDV in relation to any approved areas of impact set out by legislation.

6.2.6 Roles and Responsibilities

Roles and responsibilities in relation to the monitoring program are listed in Table 13.

Table 12: Summary of proposed monitoring parameters for a potential expanded groundwater dependent vegetation (GDV) monitoring program for the Iron Valley Project. Also included is the scale at which parameters apply, the frequency of measurement and organisation responsible for data collection. Consult. = specialist GDV consultant.

Theme	Parameter	Method	Scale	Frequency	Who
GDV tree health	Visual health assessment	Souter et al. (2009; 2010)	Tree	Annual	Consult.
	Visual record	Digital photographs	Tree	Annual	Consult.
		Time lapse camera	Site	Daily	Consult.
	Tree height	Clinometer	Tree	Annual	Consult.
	Diameter at breast height	Tape measure	Tree	Start of monitoring	Consult.
	NDVI or derivative	Remote Sensing analysis of high resolution multispectral imagery (for example, WorldView)	Landscape	Annual	Consult.
Community composition and site condition	Vegetation condition classification	Keighery (1994)	Site	Annual	Consult.
	Site condition parameters: • GDV recruitment • weeds • understorey dieback • tree death • grazing impacts • surface water • evidence of recent fire • site photographs	Rapid visual assessments, simple abundance scale	Site	Annual	Consult.
Groundwater level	Depth to groundwater	Monitoring bores	Site	6 months	BC Iron
Climate	Rainfall, temperature and humidity	Weather station data from site or Bureau of Meteorology	Landscape	Daily	BC Iron

Table 13: Roles and responsibilities for a potential expanded groundwater dependent vegetation (GDV) monitoring program for the Iron Valley Project.

Role	Responsibility
BC Iron Environmental Manager	Co-ordinate implementation of the monitoring program, including liaison with relevant regulators as required
BC Iron Environmental Advisors	Implement the monitoring program
	Review monitoring reports and evaluate recommendations
	Initiate investigations as required
	Initiate management actions as required
	Oversee review and update of the monitoring program
	Oversee collection of groundwater and climate data
BC Iron Site Environmental Advisors	Supervise on-ground operations of mine operator (MRL)
	Supervise on-ground operations of GDV specialist consultant
	Supervise on-ground management actions
	Supervise collection of groundwater and climate data
GDV specialist consultant	Conduct on-ground monitoring
	Prepare monitoring reports

7 References

AQ2 Pty Ltd (AQ2) 2016, 'Groundwater Management Iron Valley – Below Water Table Mine', unpublished report to BC Iron Limited.

Astron Environmental Services (Astron) 2012, 'Iron Valley Project – Flora and Vegetation Survey', unpublished report to URS Australia Pty Ltd.

Astron 2014, 'Iron Valley Groundwater Dependent Ecosystem Monitoring Program, May 2014', unpublished report to Mineral Resources Limited.

Barron, OV, Emelyanova, I, Van Niel, TG, Pollock, D & Hodgson, G 2014, 'Mapping groundwater-dependent ecosystems using remote sensing measures of vegetation and moisture dynamics', *Hydrological Processes*, vol. 28, no. 2, pp. 372-85.

Benyon, RG, Theiveyanathan, S & Doody, TM 2006, 'Impacts of tree plantations on groundwater in south-eastern Australia', *Australian Journal of Botany*, vol. 54, no. 2, pp. 181-92.

Braimbridge, M 2010, *Yule River: ecological values and issues*, Department of Water, Perth.

Burgman, M 2005, *Risks and Decisions for Conservation and Environmental Management*, Cambridge University Press, Cambridge.

Canham, C 2011, 'The response of *Banksia* roots to change in water table level in a Mediterranean-type environment', PhD Thesis, Edith Cowan University.

Colloff, M 2014, *Flooded forest and desert creek: Ecology and history of the river red gum*, CSIRO Publishing.

Department of Parks and Wildlife 2015, 'Western Australian Herbarium database', Parks and Wildlife, Kensington.

Department of Water 2009, *Environmental considerations for groundwater management in the Northern Perth Basin*, Environmental Water Report Series Report No. 8.

Dogramaci, S, Firmani, G, Hedley, P, Skrzypek, G & Grierson, P 2014, 'Evaluating recharge to an ephemeral dryland stream using a hydraulic model and water, chloride and isotope mass balance', *Journal of Hydrology*, vol. 521, pp. 520-532.

Eamus, D, Froend, R, Loomes, R, Hose, G & Murray, B 2006, 'A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependant vegetation', *Australian Journal of Botany*, vol. 54, pp. 97-114.

Eamus, D, Hatton, T, Cook, P & Colvin, C 2006, *Ecohydrology: vegetation function, water and resource management*, CSIRO Publishing, Collingwood.

Florentine, S & Fox, J 2002a, 'Morphological and physiological adaptations to waterlogging by *Eucalyptus* seedlings from the semi-arid Pilbara, Western Australia', *Journal of the Royal Society of Western Australia*, vol. 85, pp. 61-70.

Florentine, S & Fox, J 2002b, 'Seed longevity of *Eucalyptus victrix* in grassland in the floodplain of the Fortescue River, Pilbara, Western Australia', *Biologia Plantarum*, vol. 45, no. 3, pp. 477-9.

Florentine, SK 1999, 'Ecology of *Eucalyptus victrix* in grassland in the floodplain of the Fortescue River', PhD Thesis, Curtin University of Technology.

Froend, R, Loomes, R, Horwitz, P, Bertuch, M, Storey, A & Bamford, M 2004, *Study of ecological water requirements on the Gnangara and Jandakot mounds under section 46 of the Environmental Protection Act, Task 2: Determination of ecological water requirements*, report to The Waters and Rivers Commission.

Gibson, AC, Bachelard, EP & Hubick, KT 1994, 'Growth strategies of *Eucalyptus camaldulensis* Dehnh. at three sites in northern Australia', *Australian Journal of Plant Physiology*, vol. 21, pp. 653-62.

Gove, A, Sadler, R, Matsuki, M, Archibald, R, Pearse, S & Garkaklis, M 2013, 'Control charts for improved decisions in environmental management: a case study of catchment water supply in south-west Western Australia', *Ecological Management & Restoration*, vol. 14, no. 2, pp. 127-34.

Graham, J 2001, 'The root hydraulic architecture of *Melaleuca argentea*', PhD Thesis, The University of Western Australia.

Heute, A 2012, 'Vegetation Indices, Remote Sensing and Forest Monitoring', *Geography Compass*, vol. 6, pp. 513-32.

Horton, J & Clark, J 2001, 'Water table decline alters growth and survival of *Salix gooddingii* and *Tamarix chinensis* seedlings', *Forest Ecology and Management*, vol. 140, pp. 239-47.

Jackson, RB, Canadell, J, Ehleringer, JR, Mooney, HA, Sala, OE & Schulze, ED 1996, 'A global analysis of root distributions for terrestrial biomes.', *Oecologia*, vol. 108, pp. 389-411.

Jensen, J, Lin, H, Yang, X, Ramsey, E, Davis, B & Thoemke, C 1991, 'The measurement of mangrove characteristics in southwest Florida using spot multispectral data', *Geocarto International*, vol. 6, pp. 13-21.

Keighery, BJ 1994, Bushland Plant Survey. A Guide to Plant Community Survey for the Community. Wildflower Society of WA (Inc.), Western Australia.

Kramer, PJ & Boyer, JS 1995, *Water Relations of Plants and Soils*, Academic Press, San Diego.

Kranjcec, J, Mahoney, JM & Rood, SB 1998, 'The responses of three riparian cottonwood species to water table decline', *Forest Ecology and Management*, vol. 110, pp. 77-87.

Loomes, R 2010, *Determining water level ranges of Pilbara riparian species*, *Environmental report no. 17*, Department of Water, Government of Western Australia, Perth.

Marcam Environmental 1998, *Water use by creekline eucalypts (Eucalyptus camaldulensis and E. victrix) near Newman, East Pilbara. BHP Orebody 23 tree monitoring programme Report No 98/5*, unpublished report to BHP Billiton Iron Ore Pty Ltd.

Marshall, JK, Morgan, AL, Akilan, K, Farrell, RCC & Bell, DT 1997, 'Water uptake by two river red gum (*Eucalyptus camaldulensis*) clones in a discharge site plantation in the Western Australian wheatbelt', *Journal of Hydrology*, vol. 200, pp. 136-48.

Mensforth, LJ, Thorburn, PJ, Tyerman, SD & Walker, G 1994, 'Sources of water used by riparian *Eucalyptus camaldulensis* overlying highly saline groundwater', *Oecologia*, vol. 100, pp. 21-8.

Morris, JD & Collopy, JJ 1999, 'Water use and salt accumulation by *Eucalyptus camaldulensis* and *Casuarina cunninghamiana* on a site with shallow saline groundwater', *Agricultural Water Management*, vol. 39, pp. 205-27.

Naumburg, E, Mata-gonzalez, R, Hunter, RG, McLendon, T & Martin, DW 2005, 'Phreatophytic vegetation and groundwater fluctuations: A review of current research and application of ecosystem response modeling with an emphasis on Great Basin vegetation', *Environmental Management*, vol. 35, no. 6, pp. 726-40.

O'Grady, A, Eamus, D, Cook, P & Lamontagne, S 2006, 'Groundwater use by riparian vegetation in the wet-dry tropics of northern Australia', *Australian Journal of Botany*, vol. 54, pp. 145-54.

O'Grady, A, Carter, J & Holland, K 2010, *Review of Australian groundwater discharge studies of terrestrial systems*, CSIRO: Water for a Healthy Country National Research Flagship.

O'Grady, AP, Cook, PG, Eamus, D, Duguid, A, Wischusen, JDH, Fass, T & Worldege, D 2009, 'Convergence of tree water use within an arid-zone woodland', *Oecologia*, vol. 160, pp. 643-55.

Orellana, F, Verma, P, Loheide II, S & Daly, E 2012, 'Monitoring and modelling water-vegetation interactions in groundwater-dependent ecosystems', *Reviews of Geophysics*, vol. 50, pp. RG3003, doi:10.1029/2011RG000383.

Pfautsch, S, Dodson, W, Madden, S & Adams, MA 2014, 'Assessing the impact of large-scale water table modifications on riparian trees: a case study from Australia', *Ecohydrology*, vol. 8, no. 4, pp. 642-51.

Pfautsch, S, Keitel, C, Turnbull, TL, Braimbridge, MJ, Wright, TE, Simpson, RR, O'Brien, JA & Adams, MA 2011, 'Diurnal patterns in water use of *Eucalyptus victrix* indicate pronounced desiccation-rehydration cycles despite unlimited water supply', *Tree Physiology*, vol. 31, pp. 1041-51.

Scott, ML, Shafroth, PB & Auble, GT 1999, 'Responses of riparian cottonwoods to alluvial water table declines', *Environmental Management*, vol. 23, pp. 347-58.

Soilwater Consultants 2015, 'Increase in Groundwater Abstraction at Iron Valley – Impact Assessment', unpublished report to Mineral Resources Limited.

Thorburn, P & Walker, G 1994, 'Variations in stream water uptake by Eucalyptus camaldulensis with differeing access to stream water', *Oecologia*, vol. 100, pp. 293-301.

Tucker, C 1979, 'Red and photographic infrared linear combinations for monitoring vegetation', *Remote Sensing of Environment*, vol. 8, pp. 127-50.

Western Australian Herbarium 1998-2015, 'FloraBase – the Western Australian Flora', Department of Parks and Wildlife. http://florabase.dpaw.wa.gov.au.

Zencich, SJ, Froend, RH, Turner, JV & Gailitis, V 2002, 'Influence of groundwater depth on the seasonal sources of water accessed by *Banksia* tree species on a shallow sandy coastal aquifer', *Oecologia*, vol. 131, pp. 8-19.

Zolfaghar, S, Villalobos-Vega, R, Cleverly, J, Zeppel, M, Rumman, R & Eamus, D 2014, 'The influence of depth-to-groundwater on structure and productivity of *Eucalyptus* woodlands', *Australian Journal of Botany*, vol. 62, pp. 428-37.

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