EUCALYPTUS VICTRIX, KARIJINI NATIONAL PARK REPORT TO EPA

By Frank Batini

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Table of contents

List of figures

(contained at end of report)

List of tables

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1. Context

The Marandoo Mine Phase 2 proposal is being assessed under the *Environmental Protection Act 1986* at the Public Environmental Review (PER) level of assessment. The PER document was released for public review in late 2008 and the Environmental Protection Authority (EPA) undertook a site visit in July 2009 to view key aspects of the proposal. Subsequent to the site visit, the EPA has requested additional information in order to progress the assessment of the proposal. This report specifically addresses the additional information request relating to the Coolibah (*Eucalyptus victrix*) woodland.

The purpose of this report is to synthesise the current state of knowledge in relation to the dependence or otherwise of *E. victrix* on groundwater and/or soil water, in the absence of undertaking any additional field work/investigations. This report will be peer reviewed prior to being presented to the EPA.

2. Summary

1. The Coolibah (*E. victrix*) woodland that grows in the Mt Bruce flats within the Karijini National Park is considered to be in good condition. The woodland is listed by the Department of Environment and Conservation (DEC) as a Priority Ecological Community (PEC) and is also listed as a wetland of National importance. It is a seasonal wetland, with the Coolibah located in the lower contour levels and is inundated once or twice each decade after significant rainfall events.

2. The EPA has some residual concern that the dewatering proposed by Rio Tinto Iron Ore (RTIO) for its Marandoo Mine Phase 2 (below water table) proposal could affect the health of the Coolibah woodland in the Mt Bruce flats.

3. Data have been collated on Coolibahs from several sites in the Pilbara, including: climate variability and natural changes to groundwater tables; root structure; potential sources of water for transpiration; modelling the effects of dewatering on shallow and deeper aquifers below the Mt Bruce flats; and monitoring data of Coolibah health at Hope Downs 1 in areas affected by groundwater drawdown (dewatering).

4. Having considered the available data and knowledge, the weight of evidence indicates that:

    - *E. victrix* woodland in the Mt Bruce flats relies primarily on the available stored soil-water and can grow where no access to groundwater is available. At times, *E. victrix* may draw at least some of its water needs from the capillary zone above the shallow groundwater table, especially when this rises rapidly after rain.

  - *E. victrix* is quite a resilient tree, able to survive some flooding, rapid rises and falls of up to 10 m in the groundwater table and also extended periods of drought.

  - Reductions in the groundwater table over 2.5 years by up to 19 m as a result of dewatering at Hope Downs 1 have not lead to a substantial decline in *E. victrix* and *E. camaldulensis* foliage cover. An annual change in foliage cover of up to 15% is not unusual under natural conditions at reference sites.

  - Should *E. victrix* require access to groundwater, the fall in the shallow groundwater table predicted by modelling should not affect the health of the Coolibah woodland in the Mt Bruce flats since:

    - the predicted fall is small in magnitude (3 – 4 m) compared to natural events (10 m)
    - the predicted rate of fall is slow (21 years), compared with Hope Downs 1 (2.5 years)
    - the required rate of root growth to keep up with this change even if they were dependent on this water source is 0.5 mm per day, which appears possible
    - at the worst case scenario there would still be some saturated soil profile remaining below the Coolibah woodland
    - the impact of human intervention predicted is well within the amplitude of natural variations observed at the landscape scale
    - at least four major rainfall/recharge events are expected to occur within the projected mine life of 21 years.

- Monitoring systems that include soil moisture, bore water levels and various tree health measurements will be in place to provide an “early warning” to allow for adaptive management by RTIO.

- Should the modelling predictions, which are conservative, be incorrect (in magnitude or rate) there is still the opportunity to implement remedial measures by periodically flooding the Coolibah.

3. Current state of knowledge

3.1 The Coolibah (*E. victrix*) woodland in the Mt Bruce flats

The continuing health of this community of Coolibah is of importance to the EPA since:

1. This community covers about 174 ha and is located within the Karijini National Park on the Mt Bruce flats, which is vested in the Conservation Commission of Western Australia (CCWA) and is managed by the DEC. The Karijini National Park Management Plan (1999 – 2009) specifically identifies the area where the *E. victrix* woodland is located as a Natural Environment Management Zone, which implies that the area will be "managed to preserve the abundance and diversity of native plants and animal species".

   (Note: The area of Coolibah is quoted by both English (1999) and Environment Australia (2001) as 82 ha. However, data provided recently by Ms J Neiman (RTIO Environmental approvals specialist) calculates the area as 174 ha. The latter figure appears to be more accurate).

2. This community has been listed by DEC as a PEC as the community is uncommon in the Pilbara and is considered to require special protection. Potential threats identified by DEC include changes to surface hydrology, to subsurface aquifers by mine dewatering, to fire damage, weed invasion, grazing and trampling by feral animals, and climate change (DEC 1999). Dr S Van Leeuwen (Principal Research Scientist at DEC, pers. comm.) describes the species assemblages found in this woodland as "unique", both in structure and composition.

3. The woodland is seasonally inundated, about twice each decade, and is listed as a wetland of National importance (English 1999, Environment Australia 2001).

A recent survey of the Coolibah woodland near Marandoo, carried out for RTIO in April 2008 (Batini 2008a), showed that the woodland was in good condition, with a 3:1 ratio of healthy to poorer crowns. The survey also provided some baseline data on co-dominant height (15 m), crown cover (20%), density (basal area and stems per hectare at nine square metres/ha and 90 stems/ha respectively) and diameter class distribution. There was no field evidence that the extent of Coolibah woodland distribution has changed markedly in recent years. There appears to be an adequate number of trees in the smaller size classes to ensure the regeneration of the woodland.

The Coolibah trees are "patchily" distributed with some open areas and others where the trees are clumped closely together (Batini 2008a). The DEC has established a Pilbara Biological Survey site within this woodland and has survey lists of flora and fauna species. The Coolibah woodland in the Mt Bruce flats at Karijini National Park, as surveyed in April 2008, is a healthy, open woodland of Coolibah, with a dense understorey dominated by native grasses with the occasional lignum (*Muehlenbeckia florentula*) (Figure 1).

Previous surveys of crown condition were carried out in 1991, 1993 and 1995 by Mattiske and Associates on various transects within the Coolibah woodland. These data show a severe level of stress in 1991 and 1993, due variously to insect attack, termite damage and past fire damage. Between 1993 and 1995 there was an overall improvement in canopy condition, with a marked improvement shown on two transects and a slight deterioration within another. The data show that Coolibah will increase or decrease its canopy cover in response to seasonal conditions. It may be desirable to have Mattiske and Associates repeat this work in 2010, to similar standards and compare the results.

RTIO have established two permanent sampling sites within the Coolibah, each with ten trees. At each tree, two spots are marked with steel pegs and at each peg vertical photographs are taken annually of the tree crowns. These photographic images are then converted to foliage cover. Data provided by Ms S Madden (RTIO Special advisor ecology) for the 2007 and 2008 monitoring show a significant reduction in foliage cover in 2008, at both sites, of 6 and 8% respectively, even though the crowns were still rated as being generally in good condition (Batini 2008a). This difference was probably due to rainfall, with 700 mm recorded at Marandoo in 2007 and only 350 mm in 2008. Annual changes in foliage cover of this magnitude, primarily in response to rainfall, are not considered as unusual (Professor M Adams UNSW pers. comm.).

There was no field evidence that the extent of Coolibah distribution had changed markedly in recent years. If Coolibah were actively expanding its range, there would be many younger cohorts established on the edges, whereas if Coolibah were retreating, there would be the evidence of dead trees and stumps on the edges of the current woodland. These field observations are supported by a study by Gaia Resources (2008) for RTIO. Using various sets of remotely sensed data acquired between 1972 and 2008, their study concludes:

> "*In respect of the Coolibah woodland, we find little evidence of substantial change in distribution over the period of this study*" (Gaia Resources 2008).

The Coolibah woodland is located in a topographic low within a large drainage basin that can hold a total volume of 100,000,000 cubic metres of floodwater with a calculated ARI of 10 years (Beckett 2009; Figure 2). Periodically, the area of the Coolibah woodland can be inundated for several weeks, occasionally to a height of as much as 1.5 metres under storm conditions (Figure 3). The Coolibah woodland may then hold about 2,000,000 cubic metres of floodwater, though 0.5 m and 1,000,000 cubic metres would be a normal (regular) flood event (Dr. K Beckett RTIO Specialist hydrologist pers. comm.).

This allows the recharge of the shallow aquifer to occur and a rapid rise in water table. A rise of 9.5 metres (from 20 m to 10.5 m below ground level) was recorded at Bore OW 12s (located within the woodland and constructed in the shallow aquifer) during late March/early April 2006. Over the next nine months the water level in this bore fell 6 m (to 16.5 m below ground level) as this groundwater mound gradually drained outwards (Batini 2008b).

3.2 Climate of the area

The Mt Bruce flats site has an arid, tropical climate with a wet summer season (October to April) and a dry winter (May to September). Average annual rainfall at Marandoo over nine years is 415 mm, which is greatly exceeded by an annual potential evaporation of about 1900 mm. This rainfall is characterised by frequent, but low intensity events as well as annual, high intensity events that may be associated with tropical cyclones (Beckett 2008). Rainfall probabilities (24 – 72 hours) of >110 mm have a 1 in 2 year recurrence interval with a 92% probability of occurring in the next 5 years. Cyclone impact may be expected on average every 5 years, thus during the anticipated mine life of 21 years, at least four significant recharge events are likely to occur.

These high intensity events can result in 100 – 200 mm of rain falling within a 24-hour period. This often leads to large scale flooding and erosion. It is these major events that flood the topographic lower areas (sumps) within the Coolibah woodland. Flooding may reach up to 0.5 m in depth and last for several weeks. Generally, a rainfall event in excess of 80 mm is required to generate significant runoff into the Mt Bruce flats (Beckett 2008).

At the other extreme, the area can be subjected to drought conditions over several consecutive years. Records at Marandoo over nine years give a range of 187 to 697 mm of rain per annum. Longer-term trends of groundwater levels (1968 – 2004) from Wittenoom, located some 80 km to the north of Marandoo, indicate trends that are not obvious from short-term records. Data show periods of steady rainfall (1968 – 1982), and drying (1982 – 1994 and 2001 – 2004) and wetting trends (1995 – 2000) (Figure 4).

Climate change analyses to 2060 carried out for Rio Tinto in 2007 by an independent consulting group, Environmental Modelling and Prediction P/L Australia, predict a more variable climate for the area in the future, with a 30% reduction in annual rainfall, longer droughts, but also an increase in extreme rainfall events and more flooding.

3.3 Root structures, soil moisture and potential sources of water for the Coolibahs in the Mt Bruce flats

3.3.1 The Vadose Zone (the unsaturated soils above the water table)

Surface soils

The root system of trees provides the major plant needs for survival and growth-stability, water and nutrients. A very extensive system of feeder roots is usually present in the top one metre of soil (Carbon *et al* 1980, Jacobs 1955, Dell *et al* 1983) where most of the organic matter, nutrients and moisture are available for growth and where the soil is well aerated.

In the Coolibah woodland, at a density of about 90 stems/ha, each tree would have an approximate growing space of 110 square metres (about a 6 m radius from the trunk) and be able to access about 110 – 160 cubic metres of soil, depending on soil depth. In jarrah (*E. marginata*) forest, these roots may extend horizontally for up to 20 m (Dell *et al* 1983). However, individual roots of woodland trees may explore much further, up to 35 m (Jacobs 1955).

The moisture content of the surface one metre of soil is replenished by rainfall, by surface flows and by temporary inundation. This moisture is then reduced by drainage (to Field Capacity, about 0.3 Atmospheres), by evaporation from the soil surface and by transpiration by grasses and trees (to Wilting Point, about 15 Atmospheres). The difference between these two values is the soil moisture that is available to plants. In clayey soils such as those below the Coolibah woodland, this value could be about 15 – 20% by weight.

Thus, the water that could be stored in the surface 1.5 m of soil below each tree, after a major rain event, could range between 25,000 and 49,000 litres (area, 110 m^2 x soil depth, 1 or 1.5 m x specific gravity of soil, 1.5 x soil moisture content by weight, 0.15 or 0.20). RTIO proposes to undertake investigations (in consultation with DEC) to map soil profiles at the Coolibah site to confirm these predictions.

The deeper soil layers above the shallow water table

The root-ball and major roots anchor the tree to the soil and provide access to deeper layers in the profile and possibly to a water table. These sources of water are required for survival, especially in arid regions where rainfall is erratic.

Coolibah is considered primarily a vadophyte, that is a species that primarily utilises the water held in the vadose zone and, though it may occasionally use available groundwater, it is not a species that is dependent on the watertable for survival. It is a species that is tolerant to long periods without flooding or rainfall (Muir Environmental 1995).

On some sites in the Pilbara, Coolibah are found growing with red gum (*E. camaldulensis*) adjacent to river banks where the water table may only be 2 – 3 m below the ground surface and readily accessible to tree roots. This situation is very different to that observed on the Mt Bruce flats.

Some trees, such as jarrah growing on laterite-clay soil derived from granite, have a well-developed system of "sinker roots" which travel vertically for 30 – 40 m down "preferred pathways" such as fissure and old root channels (Kimber 1974; Dell *et al* 1983). However, jarrah adapts its root structure depending on the soil in which the tree is growing (Figure 5a). On more fertile soils derived from dolerite, occupation of the deep clay by large and fine roots is more diffuse (Dell *et al* 1983). Kimber (1974) also observed a zone of proliferation of fine roots above the water table in the "capillary zone". This may not necessarily be a general feature (Dell *et al* 1983).

Although only a small proportion of sinker roots are successful in locating channels, each jarrah tree has potential access to 100 – 200 preferred pathways and each channel contained two to three roots (Dell *et al* 1983). These channels ranged from 5 to 30 cm in diameter and are generally well aerated being made up of coarser materials. There was limited exploration between channels. Thus, the deeper roots explore only a small fraction of the deeper soil below each tree.

Other trees rely on a well-developed “tap-root” system rather than “sinker-roots” to penetrate into the deeper soil profile. Coolibah seedlings are able to produce a long tap-root during early development, as a survival mechanism (Florentine 1999). Coolibah has a strongly dimorphic root system, with extensive, superficial feeder roots that spread beyond the width of the canopy, as well as one or several long tap-roots (Florentine 1999, Adams *et al* 2005, Dr P Grierson UWA pers. comm.).

A diagrammatic representation of the soil profile and probable root system of Coolibahs in the Mt Bruce flats is shown in Figure 5b.

Trees are adaptable and the specific root structure depends on the site where the tree is growing. For example, excavation of *E. victrix* growing above a very shallow groundwater table adjacent to a river bank showed that roots did not extend much below 2 m in depth. However, Coolibah has also demonstrated a lesser degree of adaptation to soil conditions (root plasticity) (Dr P Grierson UWA pers. comm.) than the roots of either *E. camaldulensis* (red gum) or *Melaleuca argentea* (paperbark).

Any excavations to expose these root systems to confirm root structure would need to be carried out over several trees, preferably located within the Coolibah woodland in the Mt Bruce flat or in similar sites where the groundwater table is at some depth. Approval for such extensive excavations within the National Park would require submissions to be made to the CCWA.

The capillary zone

Above the saturated water table there is zone where water is held by capillary rise. The height of this zone is dependent on the soil type; it may be 40 – 50 cm in sandy soils and between 1.5 – 2 m in heavy clay soils. The capillary zone rises and falls reflecting the rise and fall of the water table. This soil water in the capillary zone is readily available to plant roots. As water is removed by transpiration it is continually replenished from the watertable through capillary rise.

In August 2009, RTIO staff used a down-hole video camera at Bores OW 6s, 12s and 15s constructed in the shallow aquifer to observe if any root development could be seen inside the slotted casing. Of these bores, OW 12s is located within the Coolibah woodland and OW 6s and 15s are located near-by. The bores surveyed were constructed in 1992 and other pertinent details have been tabulated in Table 1. However, no roots were observed over the slotted and screened intervals at depths from 12 – 31m (J Neiman, RTIO Environmental approvals specialist, pers. comm.).

Data from bores in the jarrah forest show that the high moisture content within the slotted casing above a water table is usually a very suitable environment for root proliferation, with root masses often blocking down-hole access. The observations on the Mt Bruce flats at OW 12s suggest that Coolibah root development on this site is not prolific at or near the shallow water table.

Table 1 Construction details for bores surveyed

Bore	Easting	Northing	Collar mRL	Drilled depth (m)	Cased depth (m)	Diameter (mm)	Screened interval (from – to m)	Screened formation
OW 6s	625926	7496251	705	36	31.8	50	19 – 31	Calcrete and clay
OW 12s	623093	7496212	703	31	30	50	18 – 30	Calcrete and clay
OW 15s	625758	7496632	705	26	24	50	12 – 24	Calcrete and clay

3.3.2 The shallow (unconfined) aquifer

The shallow aquifer below the Coolibah woodland has a total depth of between 24 and 36 m below the natural surface and water levels have been measured at depths of between 10 and 20 m below ground level. The available data indicate that a saturated zone has always been present during the period of measurement.

Jarrah roots have been observed to a depth of 40 m (Kimber 1974) so it is likely that Coolibah roots can explore to at least 20 m if required. At this depth below the Coolibah woodland, the soil is constantly saturated, with high levels of available water, but also with very low oxygen levels. Thus, the saturated zone is an inhospitable habitat for good root growth.

3.3.3 The deep (confined) aquifer

The deep aquifer, is between 75 and 200 m below ground level, is separated from the shallow aquifer by a thick layer of dense clays and is considered to be far too deep to be accessible to tree roots.

3.4 Potential effects of mine dewatering

3.4.1 On surface soils

The moisture content of the surface one metre of soil is replenished by rainfall, by surface flows and by temporary inundation. This moisture is then reduced by drainage, evaporation and transpiration by grasses, understorey and trees. Moisture content of surface soils will not be affected by mine dewatering of the deep aquifer or by the pit-wall intersection of the shallow aquifer.

3.4.2 On the deeper soil layers above the shallow aquifer

The moisture content of the vadose zone (the unsaturated zone above the water table, up to 20 m in depth) is replenished primarily by vertical drainage from the soil surface, usually along "preferred pathways" along fissures and root channels. This moisture is then reduced by drainage and transpiration, primarily by trees. The moisture content of the vadose zone will not be affected by mine dewatering of the deep aquifer or by the pit-wall intersection of the shallow aquifer.

3.4.3 On the capillary zone

The moisture content of the capillary zone is dependent on access to a permanent water table. To date, this water table has been measured as between 10 and 20 m from the soil surface. As long as mine pit-wall or dewatering do not dry up the shallow aquifer fully (as predicted by the modelling), the capillary zone will not be affected.

3.4.4 On the shallow (unconfined) aquifer

This is an extensive calcrete horizon located at a depth of about 10 – 36 metres below the soil surface, although some calcrete is occasionally seen near the soil surface. This aquifer is replenished primarily during large rainfall events when the topographic lows coincident with the Coolibah woodland become inundated for several weeks and water moves vertically. The resulting groundwater mound then dissipates radially outwards.

The shallow aquifer is isolated from the deep aquifer by a sequence of tight reactive clays that are at least 30 m deep. The results of a dewatering trial carried out in 2005 over a period of 80 days within the deep aquifer have been reported by Evans and Youngs (2007). No measurable change to the water table levels were recorded from the bores constructed into the shallow (unconfined) aquifer within the National Park (OW 22s at a distance of 1.5 km from the dewatered area and OW 12s at the edge of the Coolibah woodland, some 5 km from the dewatered area). Of the four bores into the shallow aquifer located closer to the dewatering trial, only one, OW 21s, located within 0.5 km, showed a drawdown of 0.27 m due to the dewatering. Bore OW 21s is near the proposed mine pit where the clay layer begins to thin.

These data confirm that the shallow (unconfined) and deep (confined) aquifer systems are not hydraulically connected directly beneath the Coolibah stand; but are some-what connected on the edge of the flats where the dewatering is to occur.

However, if mining proceeds below the water table, the mine pit-wall will intersect the shallow aquifer and impervious clay layers and the implications of this action also required to be modelled. At the mine pit, the shallow aquifer is thinner, has low permeability and is therefore expected to de-saturate quickly.

Extensive modelling of both systems has now been conducted. The evidence of field - testing and numerical modelling indicates that the proposed dewatering combined with the intersection by the mine pit-wall would have a drawdown effect of between

2.5 and 4 m on the shallow aquifer below the Coolibah woodland, some 2 km away from the pit (Figure 6). This maximum drawdown would be gradual, taking approximately 21 years to occur. The gradual change should allow the root growth of the Coolibahs to keep pace with the rate of dewatering should they require access to this water source. This would require an average root growth of only 0.5 mm per day to keep up with the predicted change. Also, it is quite likely that up to four, large, natural recharge events would occur during this period (Beckett 2008).

Results from existing bores in the shallow aquifer show rapid, natural variations below the Coolibah woodland of up to 9.5 m, when substantial rainfall follows a run of dry years (Figures 7 and 8). These trees should therefore be able to cope with the predicted fluctuations in the water table caused by mining operations, especially if they are gradual and relatively small in comparison to natural events.

At the end of the dry period, when the water levels in the unconfined aquifer were about 20 m below ground level, there was still a saturated zone 7 to 12 m deep above the clay layer.

3.4.5 On the deep (confined) aquifer

The principal deep (confined) aquifer units, collectively referred to as the ‘deep aquifer’, are the karstic Wittenoom Formation and the mineralised Marra Mamba Iron Formation (Liquid Earth 2005). The deeper, confined aquifers are found some 75 to 200 m below the surface, show smaller rises (about 0.7 m) and also react more slowly to rainfall events, most probably because the main recharge areas are located some distance away from the bores.

The proposed dewatering bores for the mine are expected to be at least 100 to 150 m deep and the anticipated time period for dewatering will be at least 21 years. The cone of depression within the deep aquifer will be substantial, up to 110 m (see PER Figure 25).

However, these aquifers are far too deep to be accessible to tree roots and are separated from the shallow aquifer by at least 30 metres of tight clays. Although no “aquiclude” provides a perfect seal, the reality is that the shallow aquifer now persists despite a 30 – 40 m of pressure head between the aquifers. Were this head to be increased by pumping, the situation would not change, the rate of “leakage” between the two aquifers would remain unchanged and no sudden “holes” linking the aquifers are expected to appear.

3.5 Reliability of groundwater model predictions

The groundwater model was developed by the best expertise available to RTIO. The model has been tested by extensive dewatering trials and improved as required. The model has also been “peer reviewed” by appropriately qualified hydrogeologists, including staff from the Department of Water, prior to and during the PER review process.

In addition to this, at the request of EPA, RTIO has engaged Dr P Commander to undertake a further technical peer review of the model. The results of his review are not yet available and will be reported on separately to EPA.

Critics of modelling will emphasise that the results could underestimate the magnitude or rate of change, but the opposite (an overestimation) is also possible, especially if a conservative approach is taken. It should be noted that the groundwater model is conservative in its estimation of potential impacts (Dr W Dodson, RTIO, Principal Hydrogeologist pers. comm.), as the permeability of the lacustrine clays separating the deep and shallow aquifers has been assigned a value of 1×10^{-4} m/d which is the higher end of the range for such clays. The lower end of the range would tend towards a value of the order of 1×10^{-7} m/d (Domeinico and Schwartz 1990).

If the predicted drawdown due to dewatering is between 3 and 4 m, the indications are that the Coolibah woodland would be able to cope with this change, should they rely on this source of water. If the drawdown is less than that forecast, the Coolibah woodland would also not be affected.

Even if the drawdown is 8 m (twice the maximum forecast), there should still be a water table some metres deep below the Coolibah woodland that could be used by the trees. Given the expertise used in the modelling and the peer reviews undertaken, this outcome is considered as unlikely.

3.6 Transpiration by *E. victrix*

At times when water availability is low, *E. victrix*, in common with many other arid species, can reduce its demand for water by shedding surplus leaves, stomatal control, aligning leaves to reduce insolation and with its thick cuticles and bark. An annual leaf loss/gain of leaf area of about 15% from a baseline is common in the Pilbara region, depending on the season (S Madden, RTIO Special advisor ecology, pers. comm.).

However, some water is still required for survival and techniques to estimate where this water may be sourced from include isotope analysis, measurement of sap flow and mass water balance studies.

3.6.1 Isotope analysis

Isotope analysis was carried out for RTIO by the University of Western Australia (UWA) in the summer of 2007 – 2008. A comparison was made of samples from tree twigs (xylem) of *E. victrix* and from the shallow aquifer. The water was cryogenically extracted before isotopic analysis and all samples were measured in duplicate or triplicate.

The depleted signatures of the xylem samples taken at that point in time matched those from the shallow aquifer very closely. However, as the shallow aquifer, the capillary zone above this aquifer and the deeper soil layers are in proximity, it is expected that their soil water isotopic signatures would be very similar. This may not be so if the groundwater were flowing in from elsewhere; however, the groundwater below the Coolibah woodland is replenished by rainfall and then drains radially outwards.

Hence, the observed water use (by isotope analysis) could be coming from any (or all) of these layers and this technique is not able to distinguish between these zones with the required level of accuracy.

Isotopic analyses of soil samples obtained by drilling cores taken from several depths within the profile could help resolve this question. However, even with further studies, a definitive result is not assured (Dr C Macfarlane CSIRO; Dr P Grierson UWA pers. comm.)

3.6.2 Sap flow measurements

This technique relies on the Heat Ratio Method where a short pulse of heat is used as a tracer and the magnitude and direction of water flux in the xylem is measured with temperature sensors (Mcfarlane and Silberstein 2009). Other measurements made usually include forest structure; sapwood area, density and water content; crown cover and leaf area.

From these data, the sap velocities between seasons, between trees of different size and between species can be compared and estimates of total water use by a tree or a stand of trees can be made.

Data on sap flow were collected for RTIO for several trees at the Coolibah woodland in a collaborative program that includes UWA, UNSW and Melbourne University. These data are currently being analysed.

Similarly to the isotope analyses, measurements of sap flow would have difficulty distinguishing whether the water being used by a tree came only from the deeper soil layers, or from the capillary zone and/or the shallow aquifer. All these zones are in proximity and the writer is not aware of any technique that can currently distinguish, with the required degree of accuracy, between these closely related sources of soil water.

Even with further studies, a definitive answer to this question is not assured (Dr C Macfarlane CSIRO; Dr P Grierson UWA pers. comm.).

3.6.3 Mass water balance studies

These studies basically rely on estimating inputs (such as rainfall, surface flows), soil moisture characteristics, storage coefficients (such as in shallow soils, deeper soils, water tables) and losses (such as evaporation from soils, transpiration by plants and vertical and/or horizontal drainage). However, there are many factors that need to be measured or estimated, some of which may be difficult to determine accurately and the procedure also requires a great deal of scaling-up (e.g. from a few individual measurements of sap-flux on a tree, to estimating the transpiration of that tree, to estimating the transpiration by a whole stand of trees of different size).

While these studies would be useful (Dr P Grierson UWA pers. comm.), they may not yield absolutely conclusive results, especially if the critical differences in water use essential for survival are small (Dr C Macfarlane CSIRO pers. comm.).

4. Mitigation activities, triggers and delivery systems

The current state of knowledge strongly suggests that the Coolibah in the Mt Bruce flats is a vadophyte that relies primarily on stored soil water and can grow where there is no access to groundwater. However, in a “belt-and-braces” approach, RTIO has also developed an adaptive management plan to address any unanticipated impacts of drawdown on the Coolibah woodland. This plan will aim to periodically flood parts of the topographically low areas within the Coolibah woodland so as to simulate natural flood events, should any unanticipated impacts due to dewatering operations eventuate. The flooding will then naturally recharge and raise the shallow water table which will then gradually drain outwards, as occurs now. Because the flooding will be intermittent and will “mimic’ natural events, it is not expected that the Coolibah root structures will need to change or adapt.

As an example, experience with artificial supplementation at Hope Downs 1 monitoring location BH 16 have been provided by Ms S Madden (RTIO Special advisor ecology). Over a period of 20 months irrigation has maintained the water level in the shallow aquifer to within 4 m of the surface and there have been no losses in tree foliage cover (Figure 10).

The adaptive management plan will require three elements:

1. A large source of good quality water.
   This would be available from the dewatering required for the minesite where the peak design rate for dewatering was set at 75 ML/day. The water is of good quality and fresh (neutral pH and 450 – 650 TDS).

2. A suitable delivery system to take this water to the Coolibah woodland.
   There appear to be two possible delivery systems; surface discharge along natural drainage lines and piping to the Coolibah woodland. The former would require more water to be discharged as some would seep into the drainage lines prior to reaching the low point within the Coolibah woodland. However, there would be no works required within the National Park. Piping would require high-density polyethylene (HDPE) pipes to be laid, most likely above ground, within the National Park. There would probably be several discharge points with appropriate spreaders to minimise erosion.

   This would require access for pipe laying and maintenance and there would be some disturbance within the National Park. Preferably, access and design should be approved in advance by DEC and the required materials pre-purchased and stored at the minesite.

3. Appropriate trigger mechanisms to know when to implement the plan.
   There is a need to decide on appropriate triggers to initiate remedial action. If the trigger is set too low, action (and disturbance) may follow when it is not required. If the trigger is set too high, action may be taken, but possibly too late to be of value. Appropriate trigger indicators would appear to be a combination of: (a) an estimate of soil moisture content; (b) the water levels in the shallow aquifer; and (c) some measure of reduction in foliage cover.

(a) Soil moisture content

The moisture content in the surface soils (which contain most of the soil-stored water as well as most of a tree's roots), say to a depth of 1.5 m, could be monitored by (1) installing soil moisture probes within small diameter holes/bores to continuously log soil moisture in the surrounding soil; or (2) by burying sensors (in contact with the soil) at various depths, say 25, 75 and 125 cm. Option one (installed soil moisture probes) would require the drilling of new holes within the Coolibah woodland as the soil characteristics need to mapped in order to calibrate the probes. The second option (buried sensors) require contact with the surrounding soil; however, one of the problems with "cracking clay" soils, such as those within the Coolibah woodland, is not being able to retain a good contact between the soil and the buried sensors. Therefore, the installed soil moisture probes are considered more preferential to the buried sensors.

Soil moisture content deeper in the soil profile (e.g. beyond 1.5 m) could also be monitored using soil moisture probes permanently installed in small diameter bores (same as those described above).

Baseline soil moisture data can be collected using the above methods as well as surface magnetic resonance imaging (SMRI) or electrical resistivity imaging (ERI) techniques. SMRI and ERI techniques are low-impact and can provide a "snapshot" in time of the soil moisture profile (surface and deeper soil layers to the water table).

Field data need to be collected before some appropriate "triggers" for soil moisture content can be selected. Therefore, RTIO has submitted a request to DEC for access to the Coolibah woodland to undertake these soil moisture investigations and to install soil moisture probes.

(b) Water level in the shallow aquifer

Reduction in the shallow aquifer to between 21 and 23 m below ground level (to RL's 683, 682 and 681 m) in shallow bores OW 25, 27, 28, 30, 12 and 15 could be selected as suitable triggers for more frequent monitoring, concern and action respectively. These RL's are 1, 2 and 3 m below the lowest levels recorded in these bores to date. At these RL's, there would still be between some metres of water in the shallow aquifer and a saturated zone that the Coolibahs could draw on, should the Coolibahs require access to this water source.

It would be advisable to fit these bores with recoding devices such as "swimmers or divers" to provide a daily record of water level, particularly as the Coolibah woodland becomes inaccessible after rain.

As bores OW 12 and 28 lie between the 2.5 and 3 m estimated drawdown contour they could act as "control" bores. Bores OW 15 and 25 are closest to the 4 m contour, and would be able to provide an "early warning" of the rate as well as the amount of drawdown (Figure 6).

(c) Reduction in foliage cover

Reduction in foliage cover of 20, 30 and 40% from an accepted baseline reading (for example the foliage cover observed in the 20 sample trees in 2008 when the trees were considered as being healthy) could be suitable triggers for more frequent monitoring, concern and action respectively, as long as there is no other obvious cause for the decline (e.g. insect attack or wildfire).

However, this measure should be used in conjunction with observed changes to water levels in the shallow aquifer, or some other measures, such as soil moisture content. It is possible that foliage cover losses of this magnitude could occur without any observed reduction in the shallow water table. If this situation occurs, a management response by flooding the Coolibah area would not seem appropriate.

It is also possible that water tables may fall, but without any substantial reduction in foliage cover. This situation has been observed at Hope Downs 1 (S Madden, RTIO Special advisor ecology, pers. comm.). Data provided for bores BH 15 and BH 31 at Hope Downs 1 show rapid and substantial decline in groundwater levels of 8 m (from 8 to 16 m) and 19 m (from 11 to 30 m) respectively over a period of 2.5 years as a result of dewatering commencing in early 2007. Yet, measurements of tree foliage cover of *E. victrix* and *E. camaldulensis* at sites HD 3 (near BH 15) and HD 2 (near BH 32) over the same time period show very little variation in foliage cover, aside from losses associated with a bushfire (Figure 11). Rainfall records suggest that summer rainfall may be providing the required moisture to sustain the trees, by replenishing the soil water storage.

If this situation occurs in the Coolibah in the Mt Bruce flats (i.e. the water tables falls, but without any substantial reduction in foliage cover), the management response is unclear and would need to be determined in advance, in consultation with DEC. Additional measurements, for example soil moisture content, deaths of branchlets (flagging) caused by cavitation within the xylem or tree growth data (e.g. using electronic recording dendrometer bands that can be fitted to smooth-barked trees to accurately monitor growth, swelling and shrinkage associated with soil-water content and growing conditions) may assist with a decision.

Artificial flooding of the Coolibah would be required if both the foliage cover and the shallow water table were to fall to within the respective action levels.

5. Conclusions

Having considered the available data and knowledge, the weight of evidence indicates that:

- *E. victrix* woodland on the Mt Bruce flats relies primarily on the available stored soil-water and can grow where no access to groundwater is available. At times, *E. victrix* may draw at least some of its water needs from the capillary zone above the shallow groundwater table, especially when this rises rapidly after rain.

- *E. victrix* is quite a resilient tree, able to survive some flooding, rapid rises and falls of up to 10 m in the groundwater table and also extended periods of drought.

- Reductions in the groundwater table over 2.5 years by up to 19 metres as a result of dewatering at Hope Downs 1 have not lead to a substantial decline in foliage cover of *E. victrix* and *E. camaldulensis*. An annual change in foliage cover of up to 15% is not unusual under natural conditions at reference sites.

- Should *E. victrix* require access to groundwater, the fall in the shallow groundwater table predicted by modelling should not affect the health of the Coolibah woodland in the Mt Bruce flats since:

    - the predicted fall is small in magnitude (3 – 4 m) compared to natural events (10 m)
    - the predicted rate of fall is slow (21 years), compared with Hope Downs 1 (2.5 years)
    - the required rate of root growth to keep up with this change even if they were dependent on this water source is 0.5 mm per day, which appears possible
    - at the worst case scenario there would still be some saturated soil profile remaining below the Coolibah woodland
    - the impact of human intervention predicted is well within the amplitude of natural variations observed at the landscape scale
    - at least four major rainfall/recharge events are expected to occur within the projected mine life of 21 years.

- Monitoring systems that include soil moisture, bore levels and various tree health measurements will be in place to provide an "early warning" to allow for adaptive management by RTIO.

- Should the modelling predictions, which are conservative, be incorrect (in magnitude or rate) there is still the opportunity to implement remedial measures by periodically flooding the Coolibah.

6. Disclaimer

This report has been collated by Frank Batini exclusively for RTIO and is based on data provided to me by staff employed by RTIO (such as the PER, tree health and bore hole data) and by RTIO's consultants (such a Liquid Earth and UWA). No attempt has been made to verify these data. In addition, I have carried out a brief survey of the Coolibah woodland for RTIO, and have consulted appropriate references and individuals in the preparation of this document.

7. Acknowledgements

I am grateful for assistance and comments provided to me by RTIO staff and other specialists; particularly Ms J Neiman, Ms S Madden, Mr T Eckersley, Mr J Matta, Dr W Dodson, Mr P Cesare, Dr P Grierson (UWA), Dr C Macfarlane (CSIRO).

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Figures

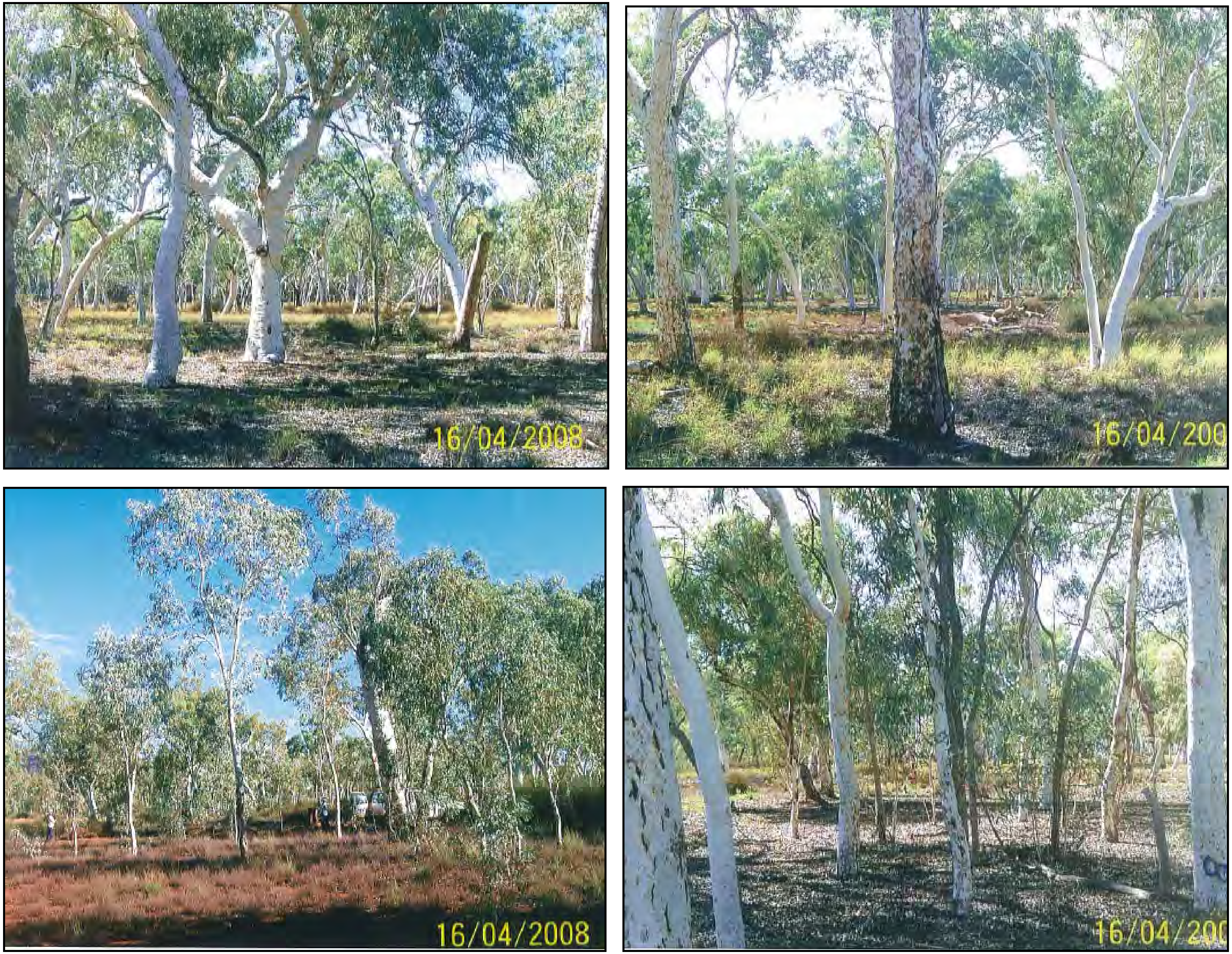
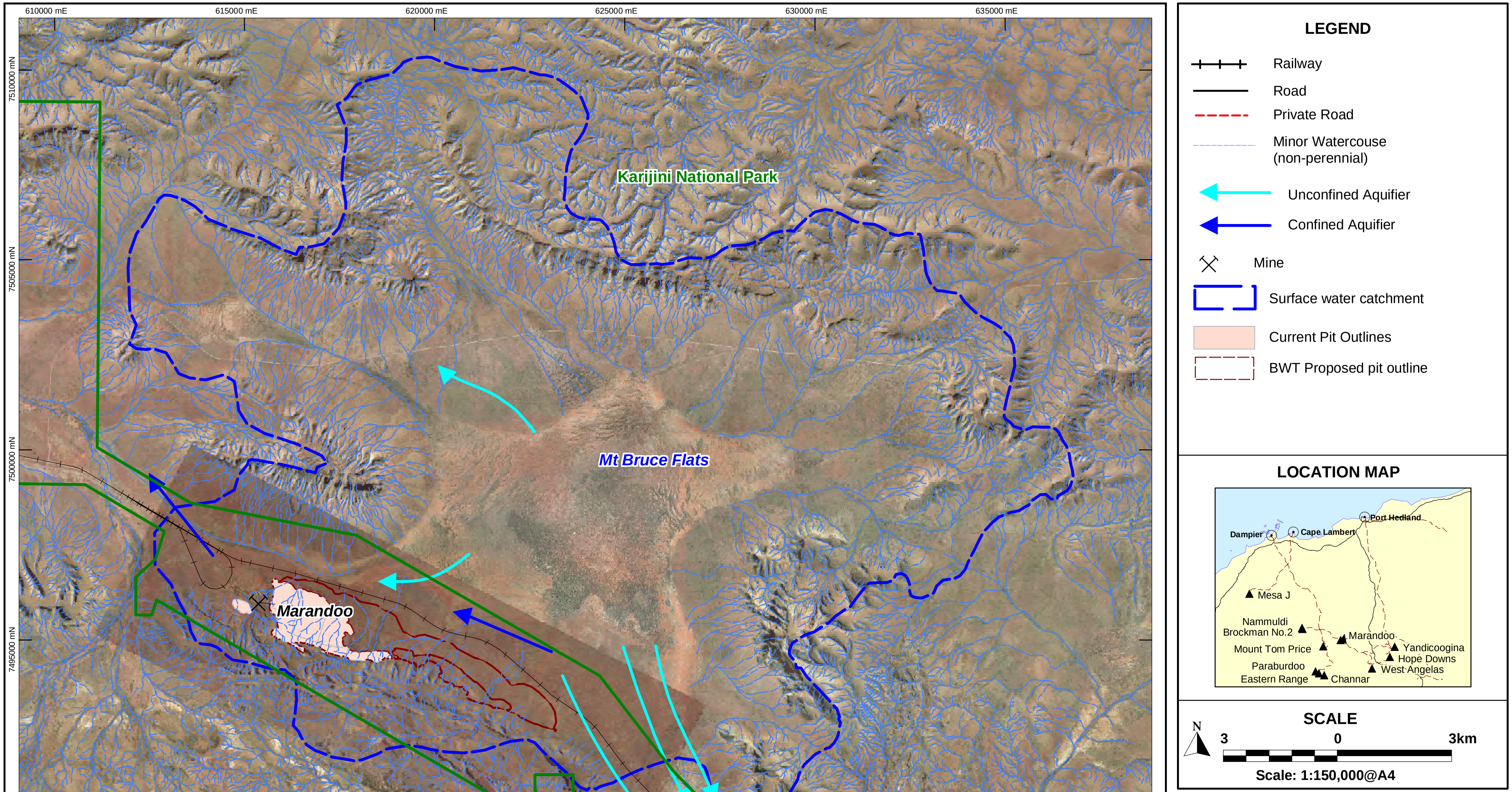


Figure 1



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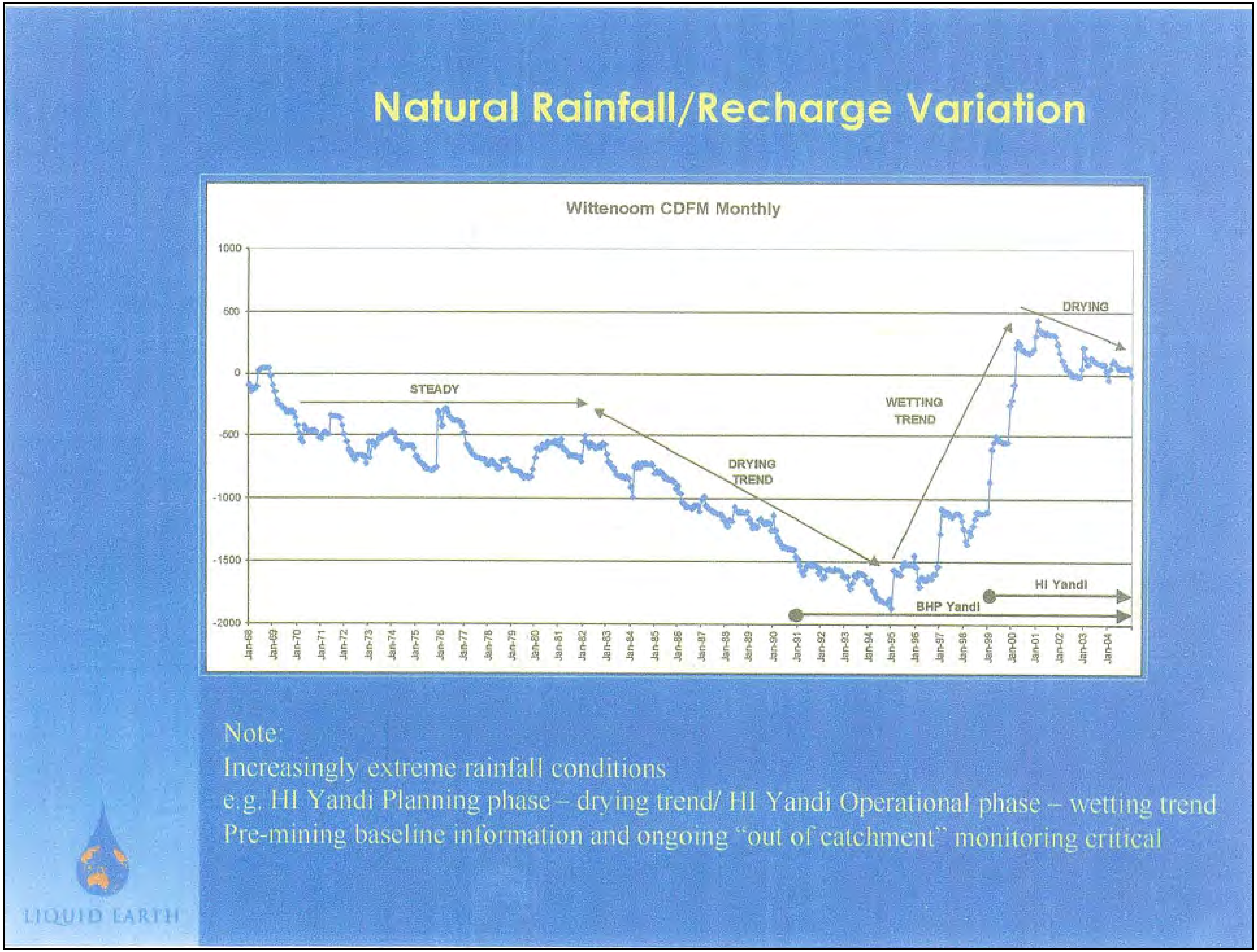
Strategic Assets - Perth

Figure 2:
Marandoo Hydrogeology

Drawn: TC
Date: Feb 2008

Plan No. PDE0052053v1
Proj: MGA94-50

Figure 3



Natural Rainfall/Recharge Variation

Note:

Increasingly extreme rainfall conditions

e.g. HI Yandi Planning phase – drying trend/ HI Yandi Operational phase – wetting trend

Pre-mining baseline information and ongoing "out of catchment" monitoring critical

LIQUID EARTH

Figure 4

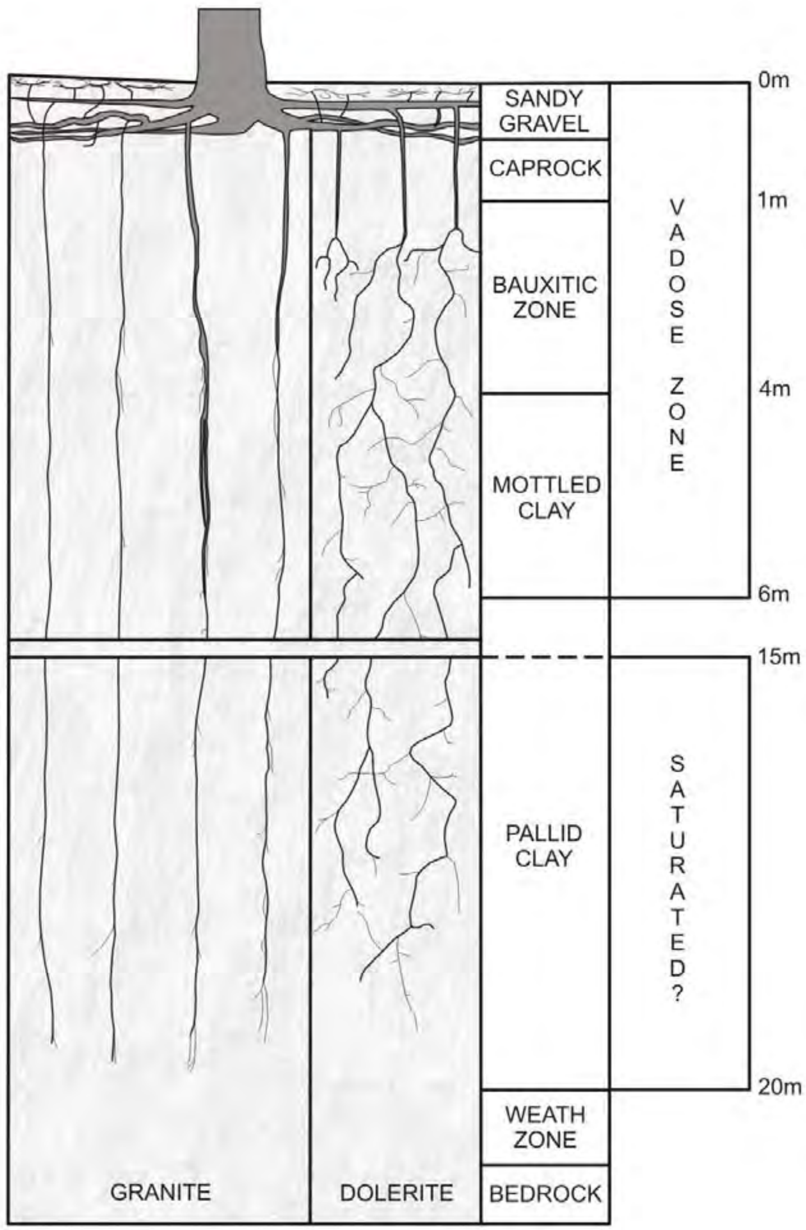


Figure 5a Root system of jarrah (*E. marginata*) (Dell *et al* 1983)

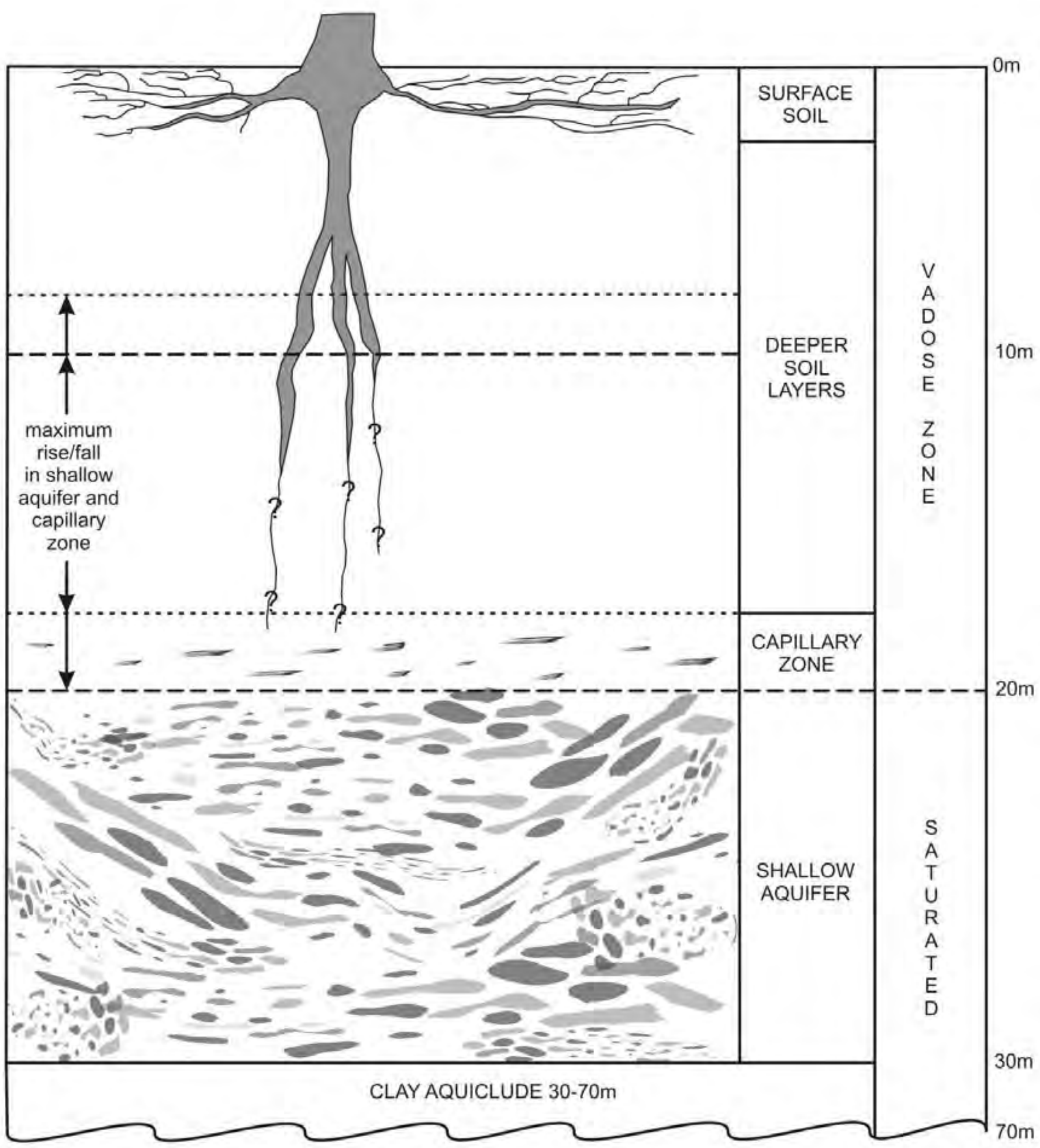
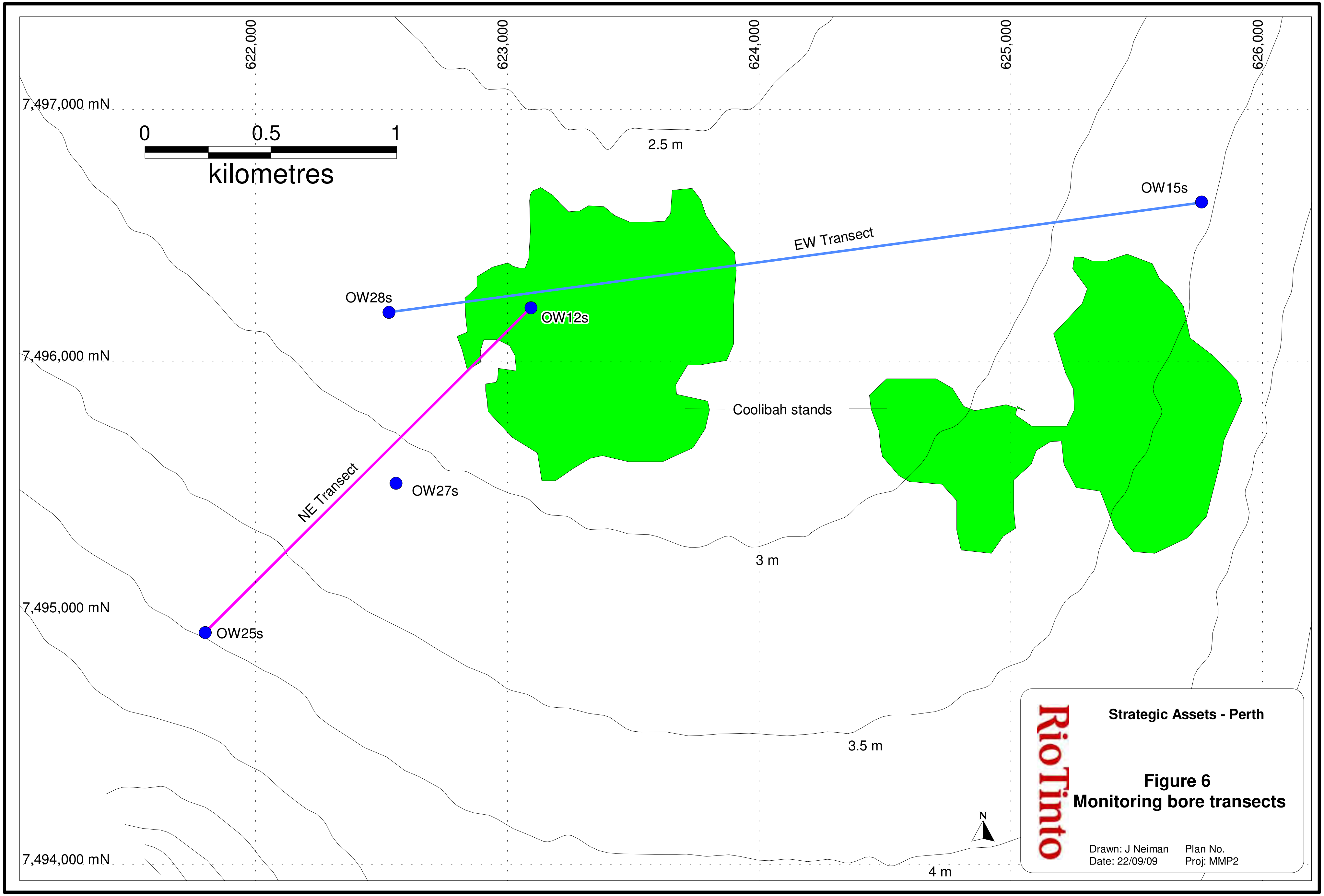


Figure 5b Probable root system of Coolibah (*E. victrix*), Mt Bruce flats, and soil profile below Coolibah (Batini 2009)



RioTinto

Strategic Assets - Perth

Figure 6
Monitoring bore transects

Drawn: J Neiman
Date: 22/09/09

Plan No.
Proj: MMP2

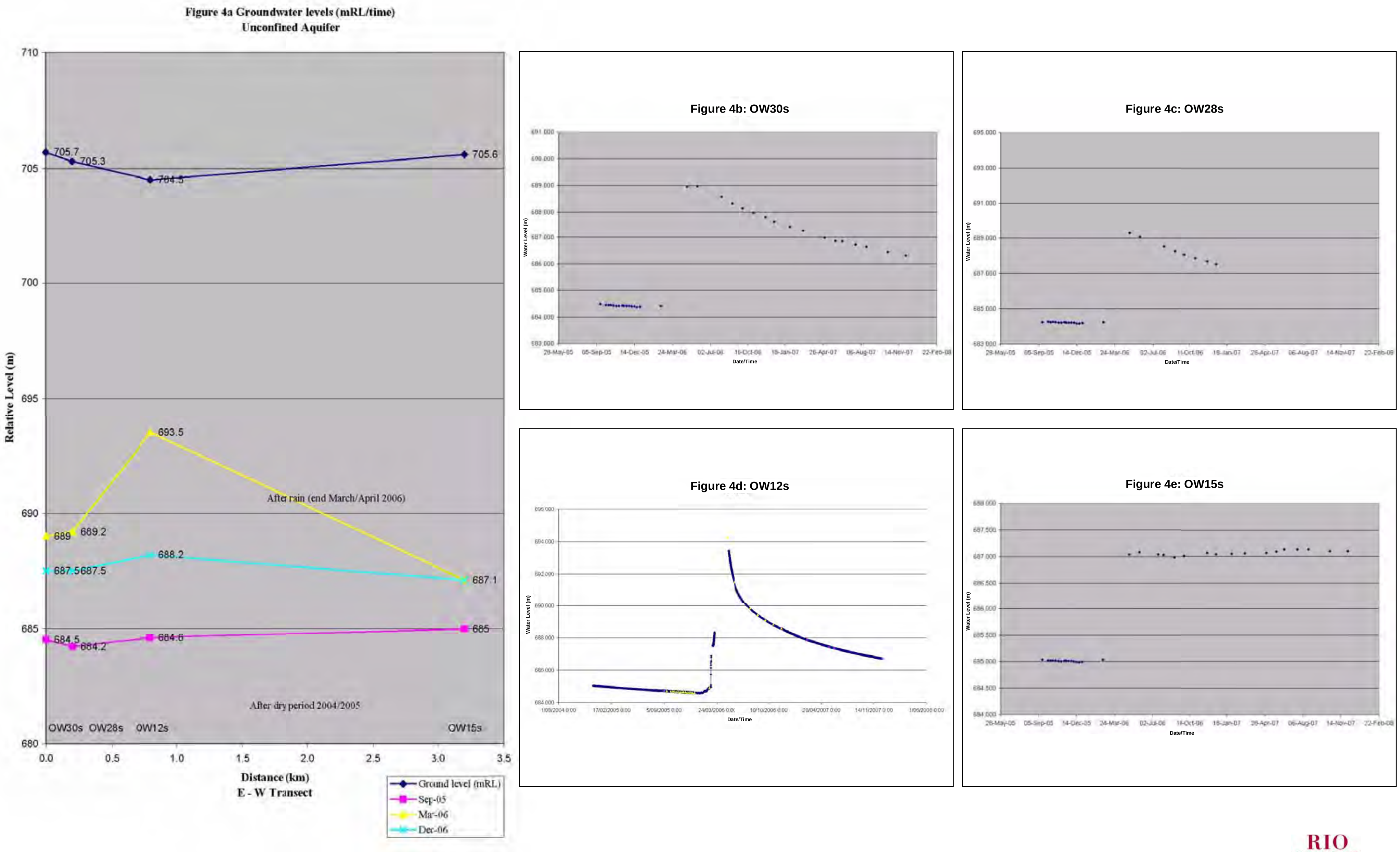


Figure 4a Groundwater levels (mRL/time)
Unconfined Aquifer

Figure 4b: OW30s

Figure 4c: OW28s

Figure 4d: OW12s

Figure 4e: OW15s

Figure 7: Unconfined Aquifer- Water level changes in Boreholes OW12s, OW15s, OW28s and OW30s

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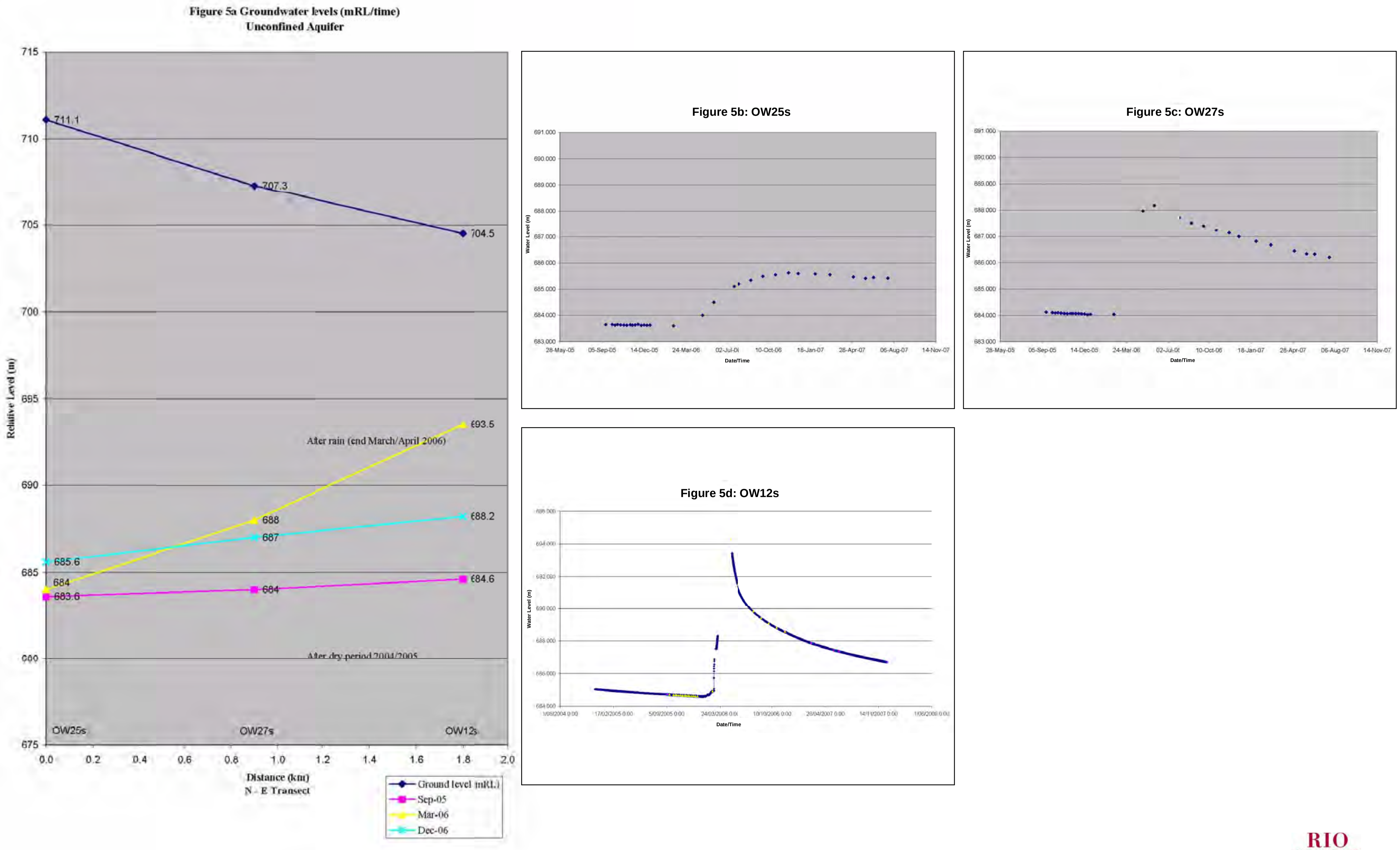

Figure 8: Unconfined Aquifer- Water level changes in Boreholes OW25s, OW27s and OW12s

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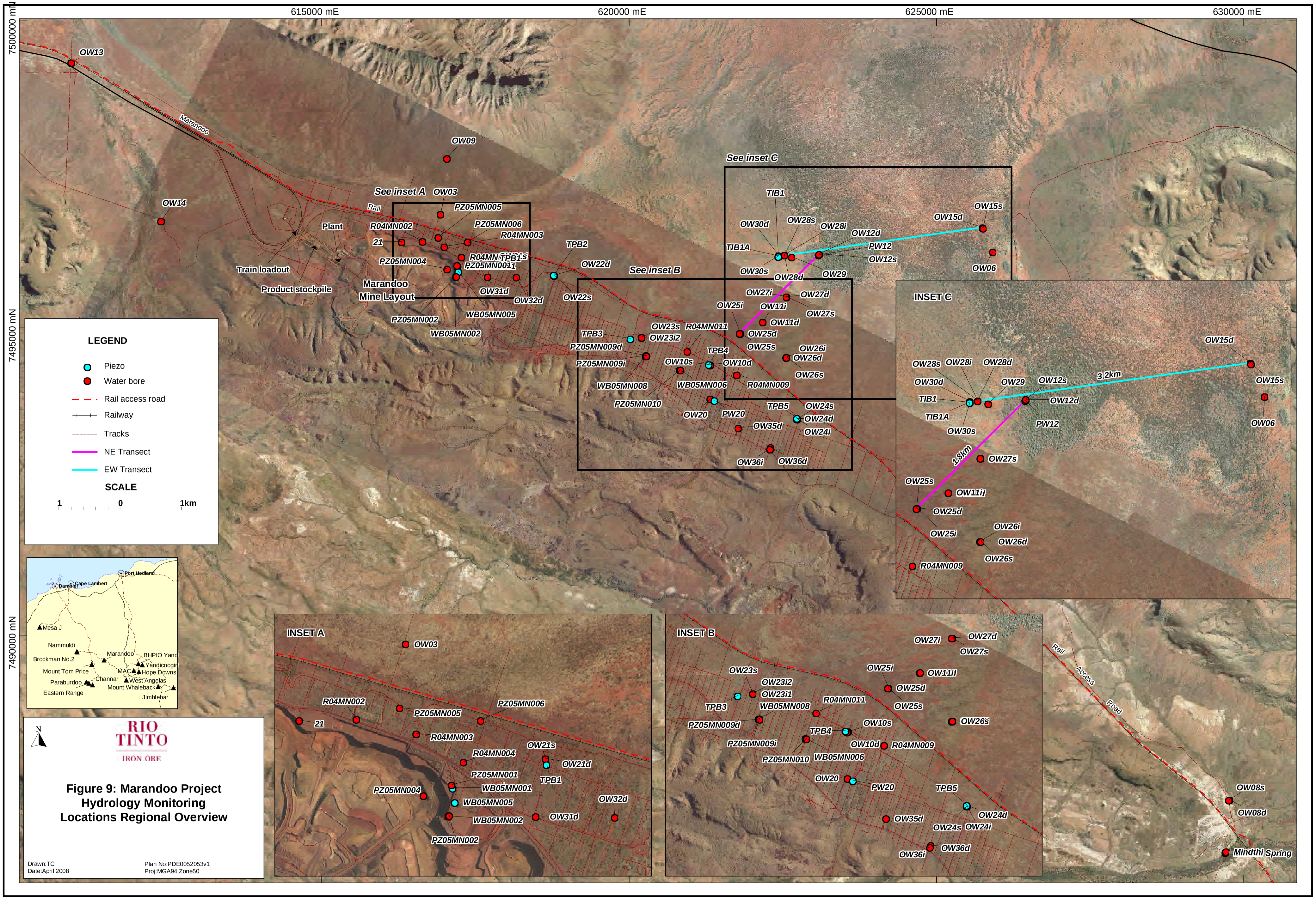
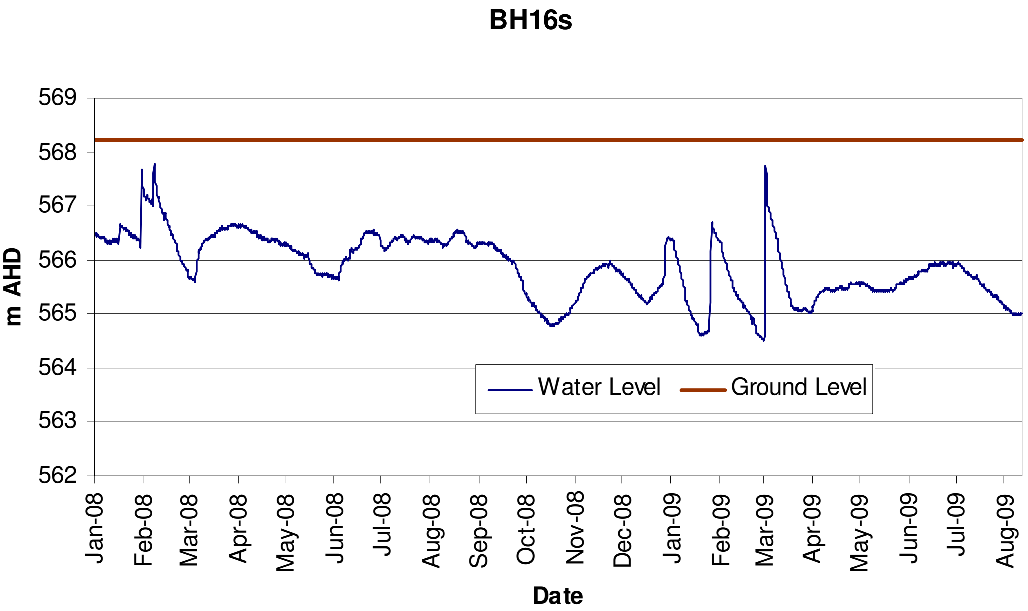


Figure 9: Marandoo Project Hydrology Monitoring Locations Regional Overview

Drawn:TC
Date:April 2008

Plan No:PDE0052053v1
Proj:MGA94 Zone50

Artificial supplementation (irrigation) at Hope Downs 1



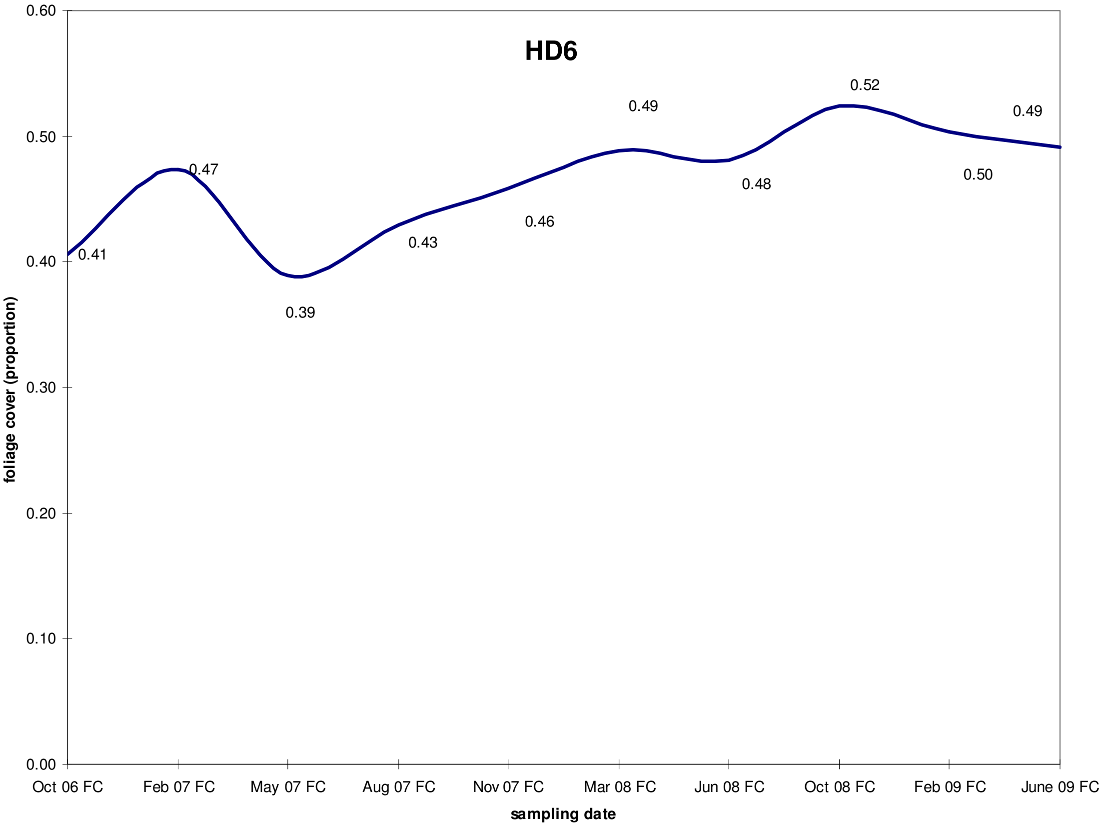
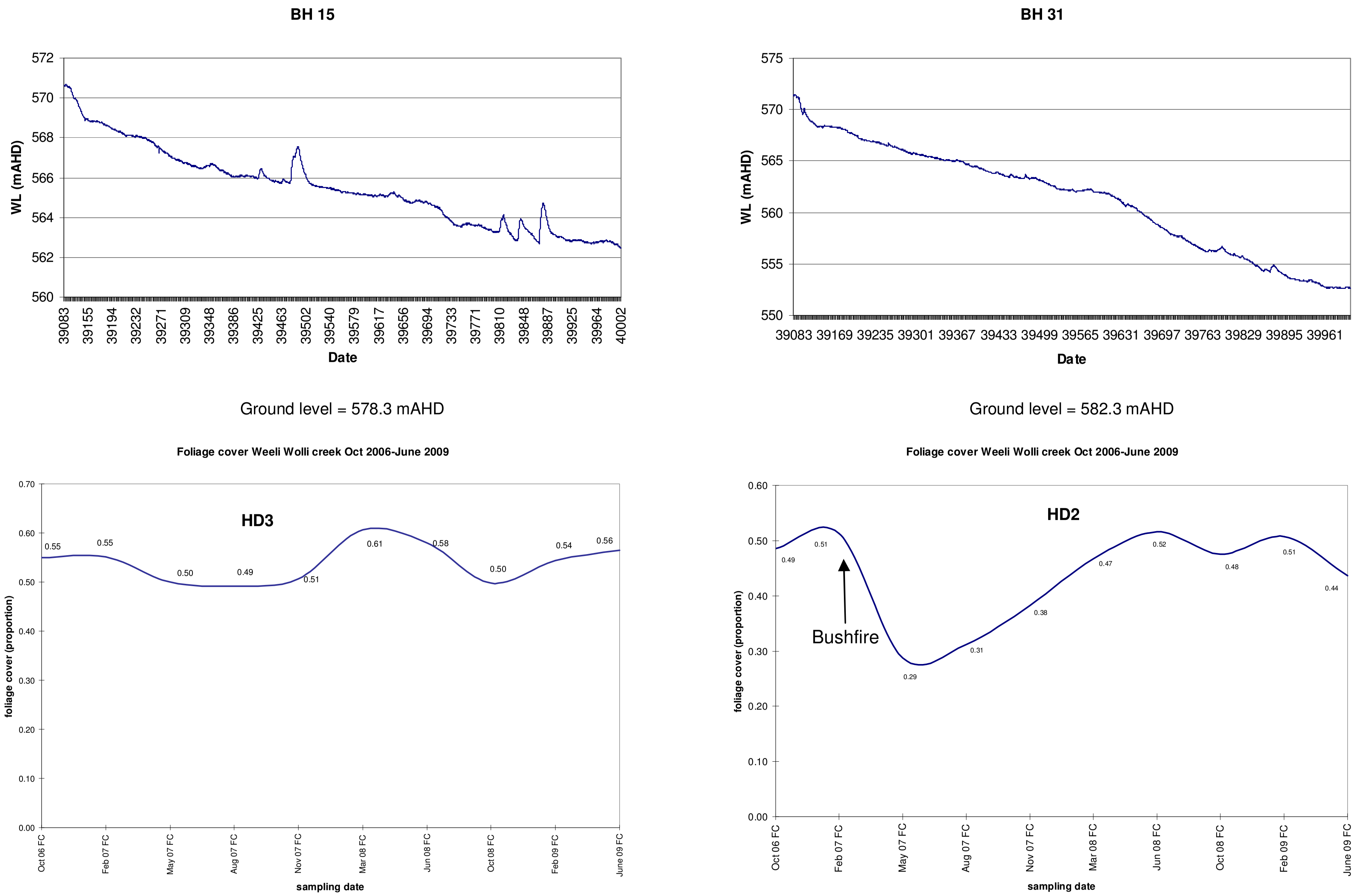


Figure 10

Water level & tree health response (*E. victrix* and *E. camaldulensis*) to dewatering at Hope Downs 1



BH 15

BH 31

Ground level = 578.3 mAHD

Ground level = 582.3 mAHD

Foliage cover Weeli Wolli creek Oct 2006-June 2009

Foliage cover Weeli Wolli creek Oct 2006-June 2009

Figure 11