Barwon Downs Groundwater Dependent Terrestrial Vegetation Investigations

BARWON WATER

Understanding Tree Water Use

| FINAL REPORT

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Contents

Executive Summary

Background

Barwon Water uses the Barwon Downs Borefield to augment Geelong's potable supplies during dry times. The groundwater extraction licence for Barwon Downs is due for renewal in 2019 and to be prepared for this, Jacobs has undertaken a range of studies on behalf of Barwon Water. The focus of this study is to improve the understanding of groundwater use by deep rooted terrestrial vegetation in the catchment.

As part of the overall works program fourteen vegetation monitoring sites have been established in the Barwon Downs region in recent years. In addition to monitoring the condition and health of vegetation, groundwater levels are also monitored regularly. Many of the vegetation monitoring sites are located close to streams and drainage lines where the groundwater is typically shallow. Vegetation at many of these sites is expected to be drawing from groundwater, particularly during the drier months. At these sites vegetation health has the potential to be impacted when groundwater levels fluctuate in response to climate and other stresses.

Objectives of this study

The objectives of this investigation are:

- To determine whether terrestrial vegetation in the study area is using groundwater; and,
- To assess whether there is any evidence of impact from historical groundwater pumping on the condition of vegetation that is determined to be using groundwater.

This study focusses on groundwater use by deep rooted trees rather than shallow rooted shrubs, sedges or grasses. Deep rooted plants can utilise groundwater at great depth hence the potential groundwater dependence of this vegetation type covers a much larger portion of the study area.

Approach

The project involved a field program and analysis of remote sensing data. The field program provided a snapshot in time of vegetation water use. Remote sensing analysis enabled spatial comparison between sites across the study area, which provided an indication of changing vegetation activity over many years.

The **field study** focused on thirteen of the fourteen vegetation monitoring sites where groundwater monitoring shows the watertable to be sufficiently shallow for vegetation to use groundwater. One of the terrestrial vegetation sites (TB3) was excluded from this study on the basis that the depth to watertable is too deep for groundwater use by vegetation at the site.

Field sampling was undertaken during late summer 2015 (February/March) following a period of lower than average rainfall. Sampling included measurement of water potential and analysis of stable isotopes from vegetation, soils and groundwater. From the results conclusions were drawn as to the likely source of water for the vegetation at the time of sampling.

The **remote sensing assessment** measured vegetation condition and health by using the Normalised Difference Vegetation Index (NDVI). The NDVI provides a measure of active vegetation. By comparing the NDVI between sites and across periods of expected high and low water stress, the health of the vegetation can be assessed. Further analysis contrasting groundwater levels at different times can show the potential for changed groundwater level to have affected vegetation health. NDVI data was captured for four dates that represent a baseline, two time periods showing water stress due to drought and borefield pumping and a borefield recovery period. For each time period, the vegetation condition was assessed during the winter and summer to allow assessment of seasonal differences.

Key Findings

The NDVI analysis suggests that **vegetation uses groundwater during periods of low water availability**, as there is higher NDVI where the watertable is shallow, compared to where the watertable is deep. Conversely, this trend is not observed in periods of relative water availability.

At most of the sites, vegetation relies on a combination of soil water and groundwater to meet water requirements. At six sites groundwater use was inferred from the field data. At a further three sites, whilst groundwater use was not directly measured, it was considered very likely that trees close to the drainage line were using groundwater. At two sites, there was evidence of historical groundwater use, because tree roots were found at depth. Ten out of thirteen sites have evidence of present or past groundwater use or nearby vegetation utilised groundwater. The field program supports the hypothesis of groundwater use by trees and is also consistent with the conclusions from the NDVI analysis.

There is no evidence that groundwater extraction from the Barwon Downs borefield has had a negative impact on vegetation activity or condition, as measured by NDVI. This is based on assessment of areas of shallow groundwater, where groundwater use is more likely, and on vegetation across the area in general.

While groundwater pressures in the pumped aquifer (Lower Tertiary Aquifer or LTA) have declined in the aquifer outcrop area near the borefield, **this study has determined that trees using groundwater have not been adversely affected by declining groundwater levels.** This is likely due to a combination of factors, including:

- The presence of perched aquifers, which may be more widespread in the outcrop area than previously considered. Perched groundwater was observed one site. Perched groundwater, by definition, behaves independently to regional groundwater levels and is hence unaffected by bore field pumping.
- Hydraulic buffering between shallow and deeper units within the LTA. Changes in groundwater levels in the deeper part of the LTA are significantly reduced in the watertable aquifer.
- The ability of trees to adapt to changing lower levels such as by sinking deeper roots. There is evidence supporting this behaviour in the past at some of the field sites.

Recommendations

This study recommends ongoing monitoring of vegetation. In particular,

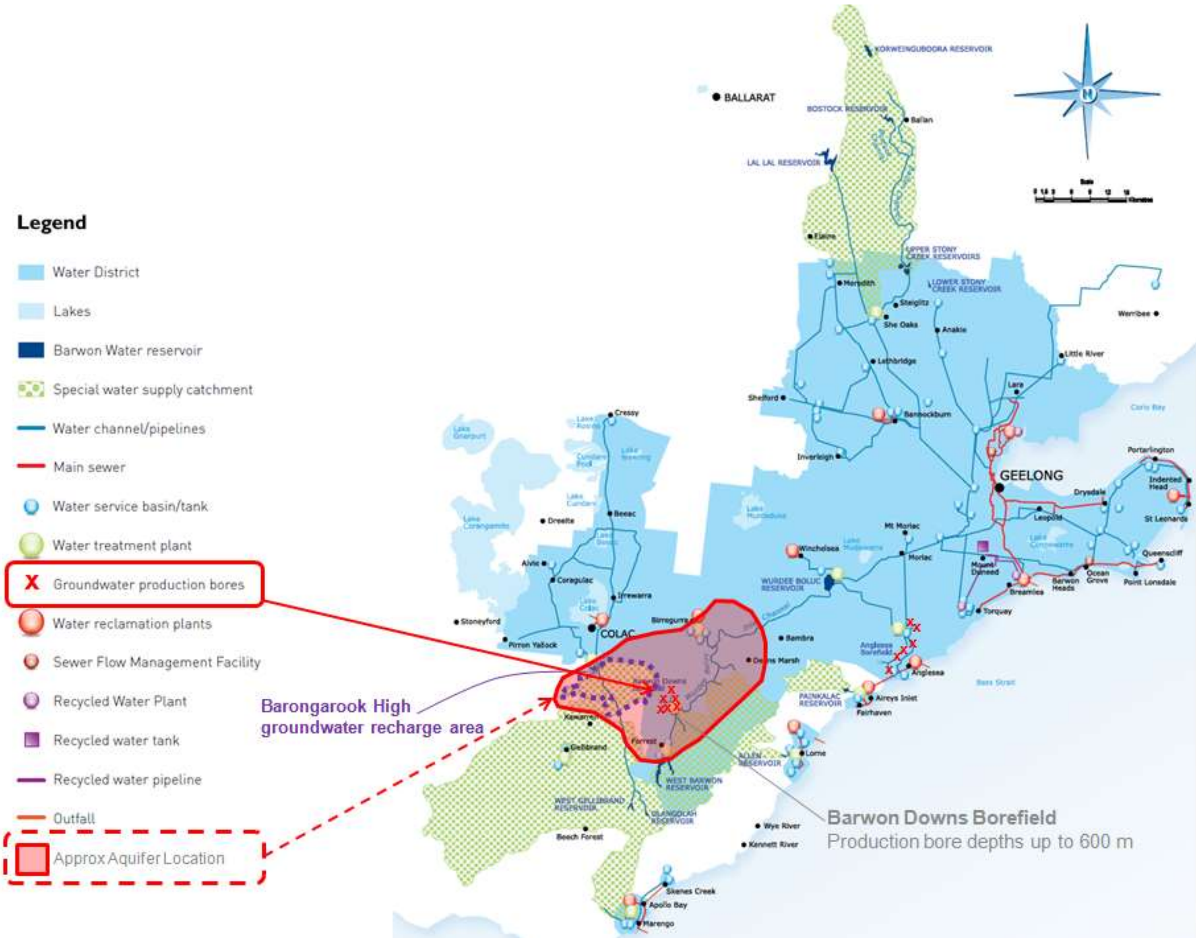
- Annual vegetation monitoring at the vegetation survey sites whilst the bore field is operating, as recommended by Jacobs (2016) vegetation survey report.
- Review of NDVI data after each period of borefield use to monitor potential changes in the regional vegetation condition that is not possible in the site by site assessment.

1. Introduction

1.1 Barwon Downs region

The Barwon Downs bore field is located approximately 70 km south west of Geelong and 30 km south east of Colac (refer to Figure 1-1). The surrounding land is a mixture of agriculture and state forest. A substantial proportion of the study area has been farmed for over a century which has resulted in some parts of the landscape being highly modified compared to the surrounding natural environment.

Figure 1-1 Map of the Barwon Downs region including the aquifer extent and the primary groundwater recharge area



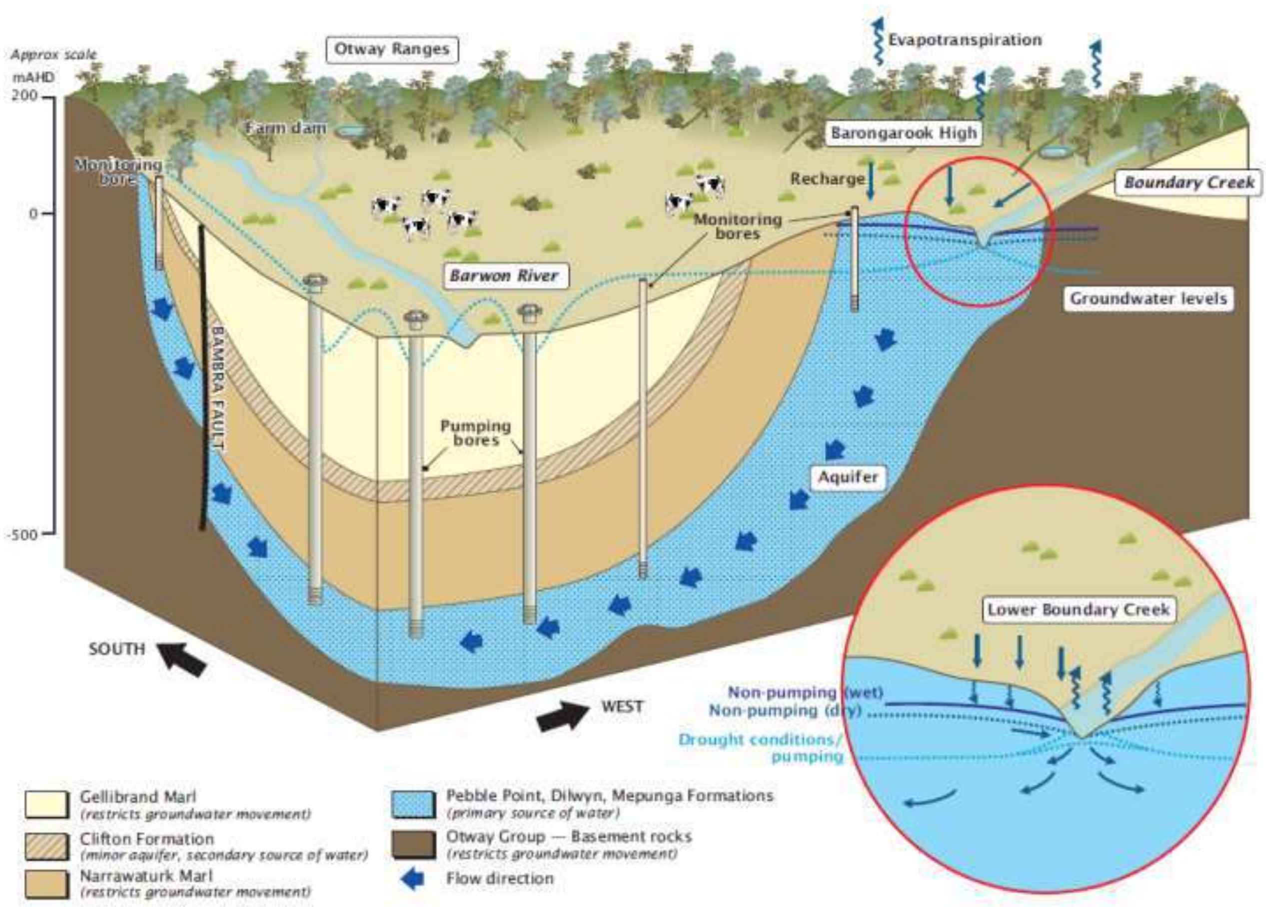
The regional groundwater system extends beneath two surface water catchments, the Barwon River catchment and the Otways Coast catchment.

The Barwon River and its tributaries rise in the Otway Ranges and flow north through Forrest and Birregurra. The Barwon River West Branch and East Branch drain the southern half of the catchment and come together just upstream of the confluence with Boundary Creek. Boundary Creek flows east across the Barongarook High and joins the Barwon River around Yeodene.

The Otways Coast catchment is a large catchment with many rivers that flow towards the coast. The Gellibrand River is in the Otways Coast catchment and rises near Upper Gellibrand and flows in a westerly direction towards Gellibrand. The Gellibrand River discharges to the ocean at Princetown.

The borefield taps into an underground source of water, known as the Lower Tertiary Aquifer, with depths of up to 600 metres at the borefield. The aquifer covers an area of approximately 500 km^2 below the surface and is connected to the surface in both the Barwon River catchment (Barongarook High) and the Otways Coast catchment near Gellibrand. Barongarook High is the main recharge area of the aquifer because of its unconfined nature.

Figure 1-2 Schematic of the Lower Tertiary Aquifer and where it outcrops at the surface



1.2 History of the Barwon Downs borefield

1.2.1 Borefield history

In response to the 1967-68 drought, when water supplies reached critical levels, the Geelong Waterworks and Sewerage Trust (now Barwon Water) began investigating groundwater resources as a means of supplementing surface water supplies used for the Geelong region. Investigations conducted in the Barwon Downs region revealed a significant groundwater resource with potential to meet this need.

In 1969 a trial production bore was built and tested close to the Wurdee Boluc inlet channel at Barwon Downs. With knowledge gained from these results another bore was built at nearby Gerangamete in 1977. A long term pump testing programme from 1987-1990 confirmed that the borefield should be centred on Gerangamete.

There are now six production bores in the borefield each between 500 and 600 metres deep. Pumps in each bore are capable of providing daily flows of up to 12 megalitres (ML) per day per bore. The pumped water is treated by an iron removal plant prior to transfer to Wurdee Buloc Reservoir. Total borefield production capacity is 55 ML per day.

1.2.2 Groundwater extraction

Barwon Water operates the borefield in times of extended dry periods. This has occurred only five times in the last 30 years. The borefield is a critical back up source for Barwon Water because it is buffered from climate variability due to the depth and large storage capacity of the aquifer, whereas surface water catchments are susceptible to seasonal fill patterns mostly driven by rainfall.

Although extraction occurs infrequently, large amounts of groundwater are drawn when needed to supplement surface water storages during drought. This is completed in compliance with the groundwater licence (refer to Section 1.3). This operational philosophy of intermittent pumping has been an effective way to provide customers with security of supply, especially in times of prolonged dry conditions.

To date, Barwon Water has extracted the following volumes from the aquifer:

- 3,652 ML from February to April in 1983 due to drought,
- 19,074 ML during a long term pump test in the late 1980s,
- 36,817 ML during the 1997 - 2001 drought,
- 52,684 ML during the 2006 – 2010 millennium drought, and
- 2,383 ML in 2016 to boost storages after a very dry summer.

Groundwater extraction has supplemented surface water supply by a total of 114,610 ML, equating to approximately 10 per cent of total water consumed over a 30 year period.

1.2.3 Licence history

The first licence was issued in 1975 but did not come into effect until 1982, as the bores were not brought into operation until the 1982-83 drought. This was the first time the borefield was used to supply water to Geelong. The licence issued by the State Rivers and Water Supply Commission (now Southern Rural Water) was to allow Barwon Water to operate four production bores based on the following conditions:

- Extraction for the purpose of urban water supply;
- Maximum daily extraction rate of 42.5 ML;
- Maximum annual extraction rate of 12,600 ML;
- Maximum ten-year extraction rate of 80,000 ML; and
- Periods of licence renewal of 15 years (1975 – 1990).

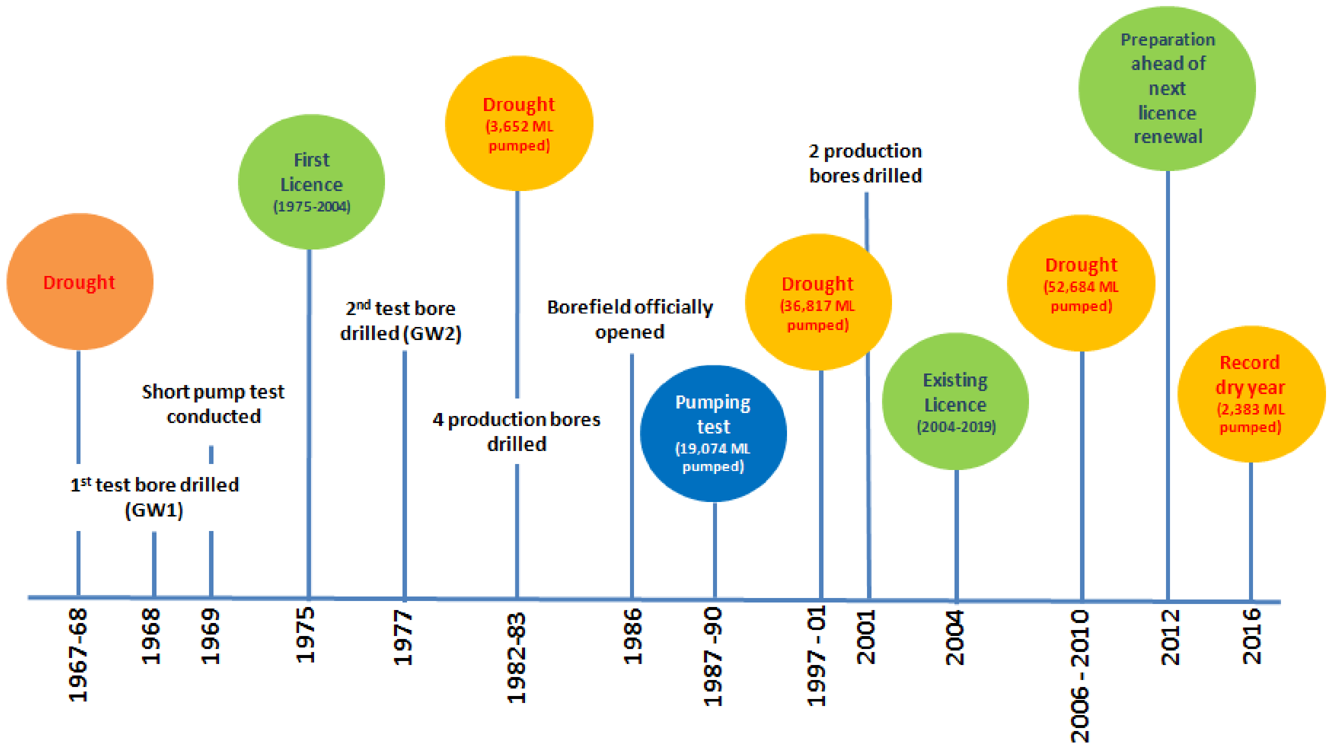
The licence was subsequently renewed for two periods of five years up to 2000. From 2000, the licence was temporarily extended three times for a total of four years to allow the licence renewal to take place through to 31 August 2004.

In 2002[1], Barwon Region Water Authority (now Barwon Water) applied to renew the Barwon Downs borefield licence for extraction of groundwater to meet urban water supply needs. The application proposed the following:

- Maximum daily extraction rate of 55 ML;
- Maximum annual extraction rate of 20,000 ML;
- Maximum ten-year extraction rate of 80,000 ML;
- Long term (100 year period) average extraction rate of 4,000 ML/year; and
- Licence renewal period of 15 years.

From 2004 to 2006, the licence was temporarily extended to allow for the licence renewal to take place. Licence conditions were drafted by the panel taking into consideration the findings of the technical groups and the submissions received. This licence is valid to 30 June 2019.

Figure 1-3 Timeline of events that surround the development and use of the Borefield



[1] *Note: Bulk Entitlement was considered in 2002 so that the Upper Barwon System could be managed conjunctively. This was put aside as the view at the time was that the rights to groundwater should continue to be contained in a licence and subject to regular review.*

1.3 Current groundwater licence

The Barwon Downs borefield is operated under licence from Southern Rural Water. This licence was granted in 2004 and is due for renewal by June, 2019.

This licence makes provision for extraction limits on a volumetric basis over a range of time scales. As part of the licence conditions, Barwon Water monitor groundwater levels and quality, subsidence, flow in Boundary Creek and Barwon River, as well as the protection of riparian vegetation, protection of stock and domestic use and the protection of flows in the Barwon River tributaries.

Reporting against these licence conditions is provided in an annual report to Southern Rural Water who administers and regulates groundwater licences on behalf of the Water Minister..

1.4 Strategic drivers for the Barwon Downs technical works monitoring program

Ahead of the upcoming 2019 licence renewal process, Barwon Water instigated a technical works monitoring program to improve the comprehensiveness of the current monitoring program to ensure the submission of a technically sound licence application.

Driving the need for this monitoring program is the reliance on the borefield to provide water security for Barwon Water customers, to address outstanding community issues particularly where the relationship between cause and effect is not yet fully understood, and to close out any known technical knowledge gaps.

1.4.1 Water security

The Barwon Downs borefield provides water for the regional communities of Geelong, the Surf Coast, the Bellarine Peninsula and part of the Golden Plains Shire.

A prolonged period of unprecedented drought (known as the Millennium drought) saw a sustained dry climate average from 1997 to 2011. In 1997, many of the region's water storages were close to capacity, however by January 1998, after high consumption and low catchment inflows, water restrictions were necessary to balance supply and demand in the Geelong area. This clearly highlighted that even by having large storages the region was susceptible to rapid changes.

In 2001, strong catchment inflows from healthy rainfall refilled storages, ending water restrictions in Geelong. Five years later, after a very dry year, strict water restrictions were again required with climate extremes exceeding the historical record. At the height of the Millennium drought, Geelong's water storages dropped to 14 per cent when catchment inflows were severely reduced. To meet demand during this time 52,684 ML was extracted from the borefield providing up to 70 per cent of Geelong's drinking water.

In 2010, improved rainfall restored storages and restrictions were again slowly lifted in the Geelong area. This allowed the Barwon Downs borefield to be switched off and to begin recharging. Without the use of the borefield during this time, residents and industry in Geelong, Bellarine Peninsula, Surf Coast and southern parts of the Golden Plains Shire would have run out of water.

The township of Colac will soon be connected to the Geelong system through construction of a pipeline between Colac and Geelong. This interconnection will also allow the borefield to supply Colac residents and will provide additional water security for the water supply system which is currently susceptible to seasonal fill patterns.

1.4.2 Community issues

Although Barwon Water is compliant with the monitoring program associated with the 2004 licence, it is accepted that this program is not comprehensive enough to address community interest about specific issues centered on potential environmental impacts in the local catchment.

Areas of community interest recently have included the:

- extent of stream flow reduction and any ecological impacts at various points along Boundary Creek,
- potential to increase existing acid sulphate soil risks in the Yeodene peat swamp,
- potential to increase the existing fire risk at the Yeodene peat swamp, and
- extraction limits and the current operational regime of the borefield, and whether they are sustainable under climate change projections.

A Community Reference Group was established in 2013 to provide community feedback and input into the technical works monitoring program.

1.4.3 Informing the licence renewal

To address community interest adequately and inform the licence renewal in 2019, Barwon Water commissioned a review of the existing monitoring program associated with the 2004 licence. This technical review recommended that a revised technical works monitoring program be developed with the following objectives:

- Better understand the environmental impacts of groundwater extraction;
- Estimate, and quantify where possible, the causes and relative contributions of groundwater variability (for example, groundwater extraction and drought) in contributing to environmental impacts; and
- Provide additional monitoring data and subsequent analysis required to support the licence renewal process.

1.5 Overview of the technical works monitoring program

1.5.1 Monitoring program development

The development of the technical works monitoring program is shown in Figure 1-4 and can be broken down into the following stages.

<u>Stage 1: Review of the existing monitoring program</u>

In 2012, Barwon Water initiated a review of the Barwon Downs monitoring program. The technical works monitoring program was developed in response to the:

- desire to address key community issues (see section 1.4.2), and
- 2008-09 flora study which recommended a long term vegetation and hydrogeological monitoring program be designed and implemented to better understand a range of factors such as groundwater extraction, drought and land use changes that were contributing to the drying of the catchment.

This review took into account both the social and technical issues that needed to be addressed to inform the licence renewal process in 2019 and was initiated early to allow sufficient time to establish a comprehensive monitoring program. A risk based approach was used to rank these issues, and control measures were developed to downgrade the residual risk ranking, which included activities such as additional monitoring and technical studies.

Stage 2: Technical works monitoring program scope refinement

In 2013, the scope of the technical works monitoring program was developed based on the recommendations of Stage 1. The Technical Works Monitoring Program was designed to improve the capacity to differentiate between groundwater extraction and climate effects on the groundwater system, predict water table and stream flow changes, and increase understanding of potential ecological impacts. Key improvement areas include:

- differentiating between groundwater extraction and climate effects on the regional groundwater system,
- understanding the potential risks of acid sulphate soils and whether that could change future extraction practices,
- assessing whether vegetation in areas dependent on groundwater will be at risk from water table decline, which could change future extraction practices,
- assessing flow requirements in Boundary Creek to determine if the current compensatory flow is effective,
- characterising groundwater dynamics in the aquitard to improve hydrogeological understanding of groundwater flow and quantity, and
- better understanding of groundwater and surface water interaction, particularly along Boundary Creek where groundwater contributes to base flow.

In the same year, the Barwon Downs Groundwater Community Reference Group was also formed by Barwon Water to ensure where possible, the monitoring program was adjusted and the scope refined, to take into consideration community issues and views. This was a critical contribution towards the broader licence renewal strategy as it raised confidence that the right monitoring data would be captured to specifically target key areas of community concern.

Stage 3: Construction of additional monitoring assets

During 2014-15, the following construction works were completed:

- 33 new groundwater monitoring bores drilled, including the replacement of one existing bore,
- 3 existing bores refurbished,
- 4 new potential acid sulphate soils monitoring bores were installed,
- 32 data loggers and two barometric loggers installed in new and existing bores,
- 1 new stream flow gauges installed, and
- 2 existing stream flow gauges replaced refurbished and reinstated.

Stage 4: Ongoing monitoring

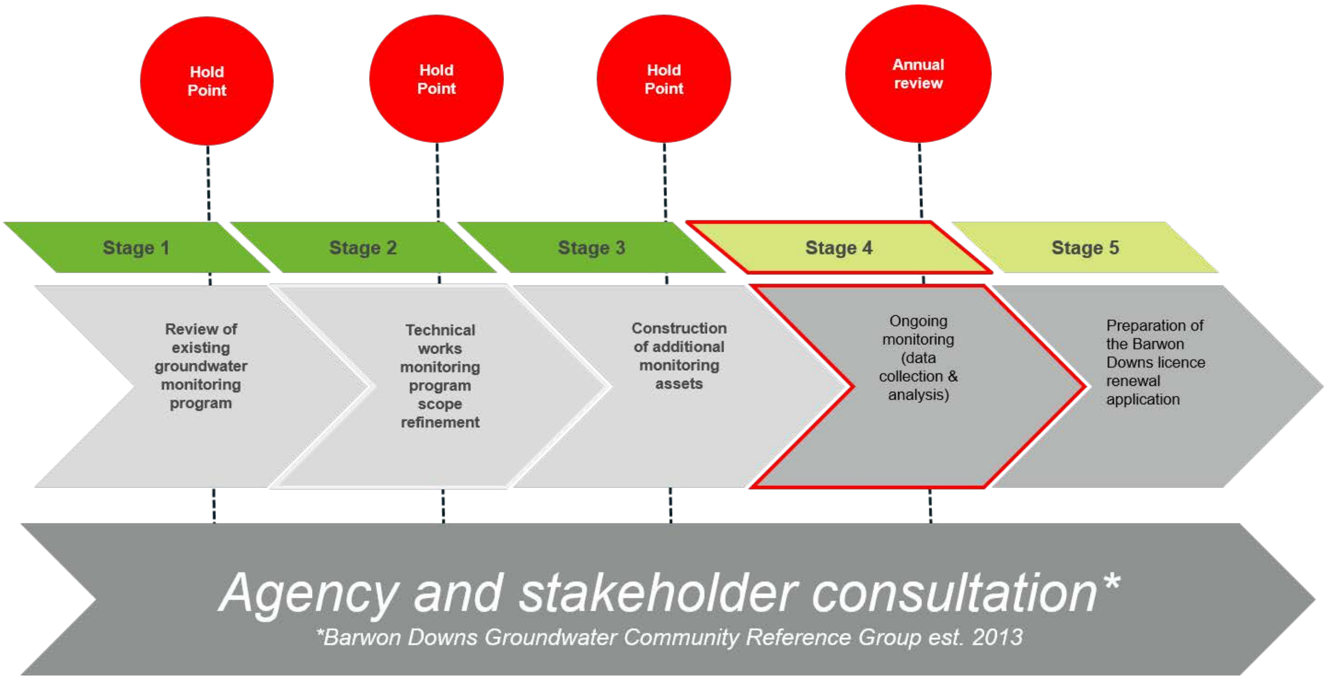
The technical works monitoring program is now in a phase of data collection and preliminary analysis. The intention of this stage is to update the conceptual understanding of the hydrogeology in the Barwon Downs region. This will be based on data collected from additional and existing monitoring assets and the outcomes of a range of investigative technical studies, all of which will be used to update and calibrate the groundwater model.

Preparation will also begin at this stage to form a comprehensive licence application.

Stage 5: Preparation for licence renewal submission

Prior to 2019, Barwon Water will need to formally submit a licence renewal application to Southern Rural Water. This will initiate a groundwater resource assessment process as set out under the Water Act.

Figure 1-4 Development of the technical works monitoring program



1.5.2 The inter-relationships of the technical works monitoring program

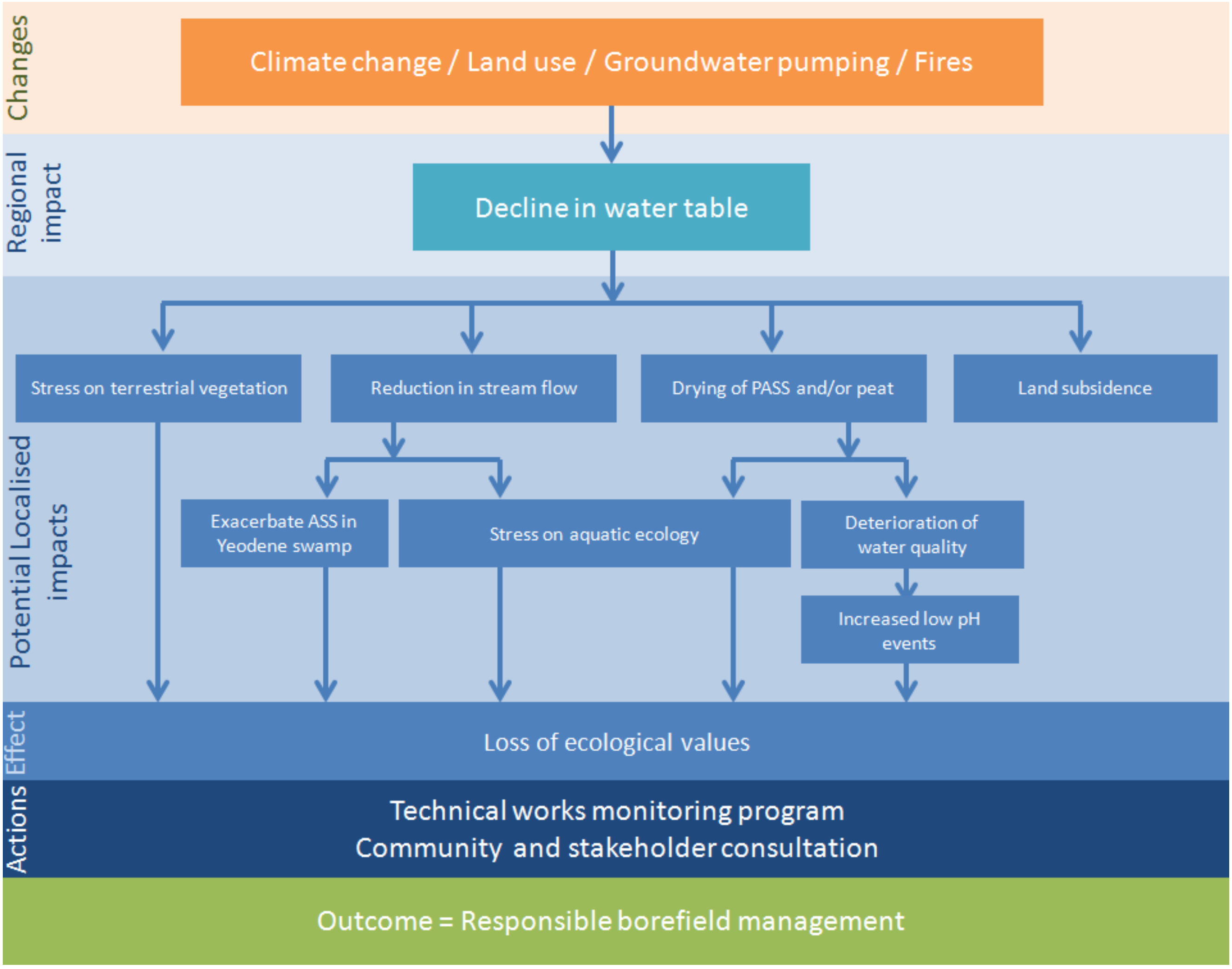
The technical works monitoring program is a complex, multi-disciplinary project due to the overlapping nature of the various components of the program as shown in Figure 1-5.

Changes in climate, land use practices and groundwater pumping will alter water availability throughout the catchment, including stream flow and groundwater levels. Many receptors are sensitive to changes in groundwater levels and stream flows, particularly those that are dependent on groundwater. Ultimately this can lead to the loss of ecological values (refer to Figure 1-5).

For example, a decline in groundwater level beneath a stream can cause a reduction in stream flow, which in turn can impact the habitat of aquatic ecology in the stream. Declining groundwater levels or reduced stream flow also has the potential to impact riparian vegetation and potential groundwater dependent activities.

The technical works monitoring program is designed to address knowledge gaps to better understand potential impacts from the borefield. The program is underpinned by scientific rigor using multiple lines of evidence-based techniques to establish the relationship between cause and effect for potential impacts caused by groundwater extraction.

Figure 1-5 Potential impacts in the catchment from changes in the catchment



1.6 This project

1.6.1 Project objective and scope

The dual objective of this investigation is to determine whether terrestrial vegetation in the study area is using groundwater and to assess whether there is any evidence of impact from historical groundwater pumping on the condition of that vegetation.

This study uses two approaches to determine if vegetation is using groundwater:

1. Field sampling program comprising a range of field based techniques to measure tree water use, soil moisture and groundwater levels and chemistry to determine if terrestrial vegetation uses groundwater.

2. Remote sensing data was used to determine the Normalized Difference Vegetation Index (NDVI) which facilitated spatial comparison of sites across the study area. It also provided an historical indication of changing vegetation activity across time, and assessment of vegetation activity before and after the commencement of groundwater pumping.

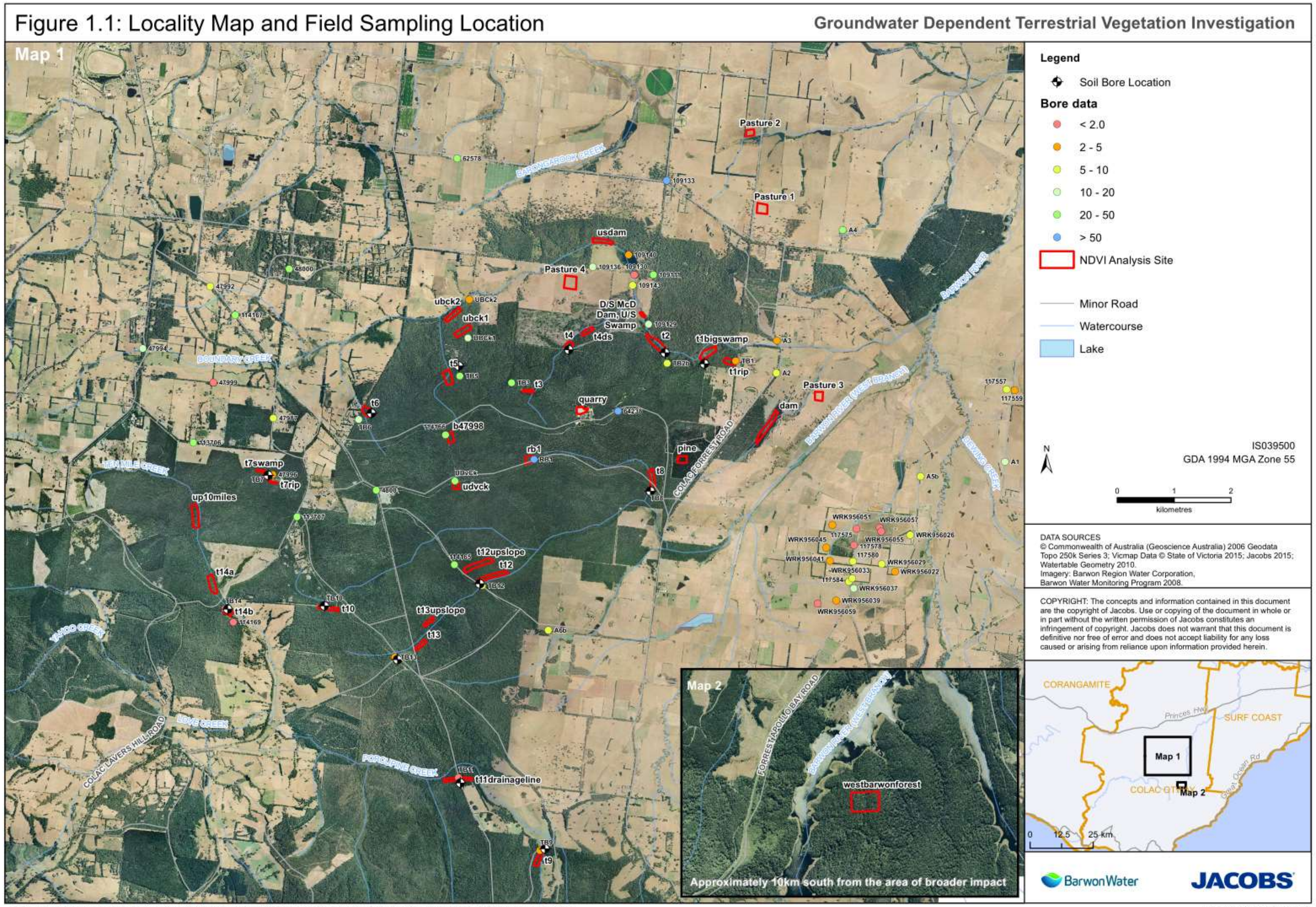
This study focusses on deep rooted species (i.e. trees) rather than shallow rooted species (i.e shrubs, sedges, grasses) for several reasons. Groundcover and mid-storey species have relatively shallow roots and are therefore very unlikely to be using groundwater beyond approximately 1-2m below ground level. Hence it is only in areas of very shallow groundwater where this vegetation is likely to have groundwater dependence, which represents a relatively very small proportion of the study area. Trees have the capacity for significantly deeper roots and can utilise groundwater to 10m deep (or greater) and hence the potential groundwater dependence of this vegetation type covers a much larger portion of the study area.

Small fluctuations generated by natural long term trends or seasonal variations in groundwater levels can be significant for shallow rooted species. In contrast this is much less likely for deep rooted species. While shallow rooted species are likely to be more sensitive to small changes, they are more resilient than deep rooted species as they can revegetate rapidly compared to trees. For deep rooted species, recovery from death (i.e. via recolonisation of an area) would take many decades. This study therefore focuses on the area of greatest consequence for potential vegetation impacts.

1.6.2 Study area

The study area is located in the hinterlands of the Otway ranges in State Forest approximately 10km south of the city of Colac in south western Victoria. The study area is shown in Figure 1-6. The vegetation of interest in this study is the remnant vegetation located west and north west of the borefield. In general, the remnant vegetation consists of dry sclerophyll forest with an overstory consisting mainly of Messmate Stringy Bark (*Eucalyptus obliqua),* and Peppermint Gum *(Eucalyptus radiata).* Rainfall is highest during the winter months with the annual average being around 1000 mm/year. The wettest month is August and the driest month is January. Average maximum temperatures range from around 25 °C in January down to around 12 °C July.

Figure 1-6 Locality plan



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Date Published: 29 May 2015

2. Approach

In order to determine the likelihood of terrestrial vegetation in the study area using groundwater, a multi-evidence approach was required. This study uses both field based measurements and remote sensing techniques to characterise the potential for groundwater use by deep-rooted trees across the catchment.

The target species are large deep-rooted trees, with water use patterns that are yet not fully understood. The rainfall within the study area is relatively high (750 - 1000 mm/yr), with seasonally low evaporative demand throughout the winter period. This indicates it is likely that the majority of the evapotranspiration (ET) demand of vegetation during winter would be met via direct rainfall recharge to soil water stores. This reduces the likelihood of vegetation requiring an additional water source, such as groundwater, except during dry periods where a reduction in rainfall fed recharge may lead to a depletion of soil water stores.

If groundwater levels decline in areas where vegetation is accessing groundwater, it is a reasonable assumption that a reduction in vegetation activity would occur. The reduction in groundwater levels may be caused by climatic conditions and/or pumping from the aquifer during dry periods. Declining groundwater levels also create a reduction in water availability in the unsaturated zone.

Figure 2-1 illustrates the difference between unsaturated zone and the saturated zone. Soil water or unsaturated zone water refers to any water located in the soil or rock matrix above the watertable. This report refers to both soil water and unsaturated zone water and these terms are used interchangeably throughout the report. Tree water use from below the watertable is referred to as groundwater use. Tree water from the capillary zone is also discussed at some sites, and this water is considered to be groundwater use.

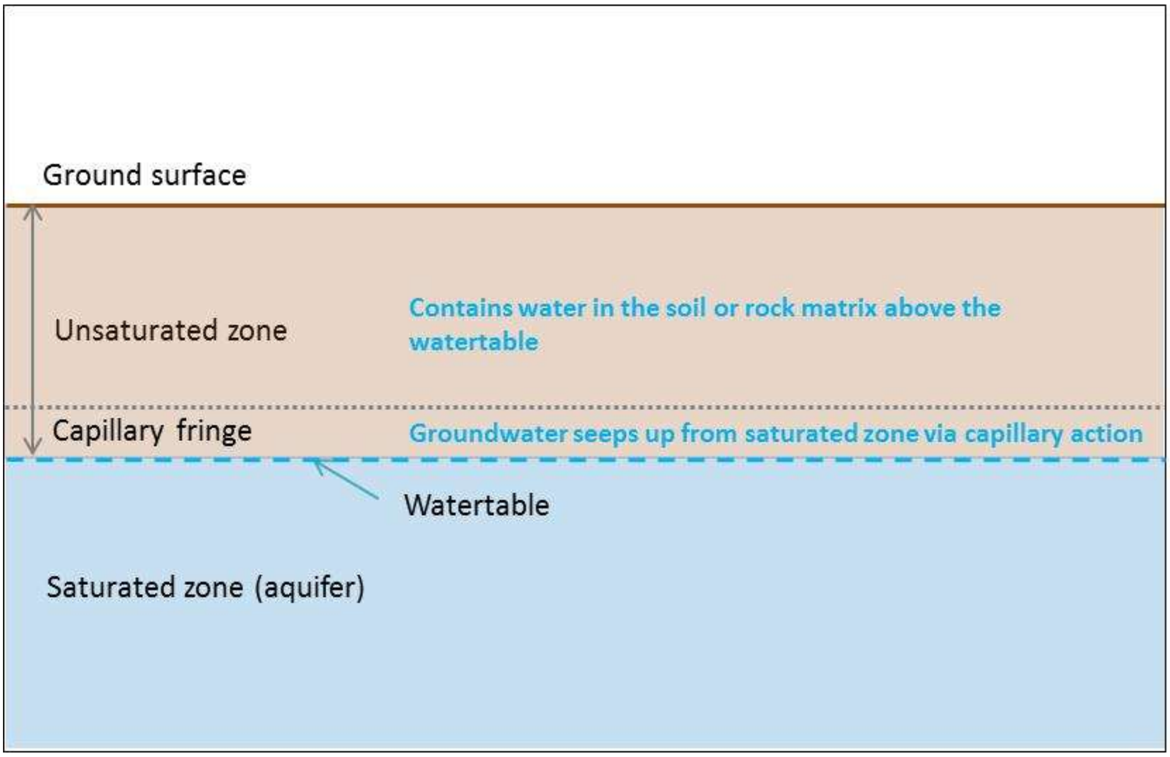


Figure 2-1 Schematic diagram illustrating the unsaturated, capillary and saturated zones

In order to achieve the project's objectives, the following two issues were investigated:

1) Does terrestrial vegetation within the study area use groundwater?

2) Is there any historical evidence that changes in groundwater levels have affected the condition and activity of vegetation?

To address the first issue, field based measurements of tree water use, combined with measurements of soil moisture and groundwater levels and chemistry were required. This data may provide an actual measure of groundwater use, potentially confirming the role groundwater plays in the water use patterns of the vegetation. It should be noted however, that the field data provides only a snap shot in time of tree water use, reflecting climate conditions prior to and at the time of sampling.

During the millennium drought (approximately 1997 – 2009), there were record low rainfall periods that impacted on the available soil water stores for vegetation. Groundwater was extracted from the Barwon Downs borefield, leading to decline in groundwater levels. It is reasonable to assume that if vegetation was using groundwater, a decline in activity is likely to have occurred as a result of increased stresses during this period.

In the absence of detailed time series field based measurements, the only effective means to observe historical water use patterns and any potential stress caused by a reduction in groundwater levels, is to utilise remote sensing data sets. The advantage of the remote sensing data is that it covers the entire study area and the imagery date can be selected to align with specific climate and water management events. This allows observation of the relationship between vegetation activity and the potential increase or decrease in water availability due to declining groundwater levels. A limitation of the approach is that it provides a relative assessment of vegetation activity and not a direct measurement. The results are based on an assumption that the trends observed are caused dominantly by changes in the water regime.

3. NDVI Assessment

3.1 Introduction

3.1.1 What is NDVI?

The Normalized Difference Vegetation Index (NDVI) is an index of plant “greenness”, which provides a measure of vegetation density and condition. Vegetation indices are based on the fact that different surfaces reflect different types of light differently. Photo-synthetically active vegetation, in particular, absorbs most of the red light that hits it, while reflecting much of the near infrared light. Vegetation that is dead or stressed reflects more red light and less near infrared light. Non-vegetated surfaces have a much more even reflectance across the light spectrum (USDA-ARS, 2015). NDVI is influenced by the fractional cover of the ground by vegetation, the vegetation density and the vegetation greenness. It indicates the photosynthetic capacity of the land surface cover.

NDVI is calculated using Landsat imagery which has 30 m optical resolution. Images are obtained twice monthly which gives rise to opportunities for examining seasonal patterns in vegetation surface cover. By taking the ratio of red and near infrared bands from a remotely-sensed image, an index of vegetation “greenness” can be defined. The NDVI is the most common of these ratio indices for vegetation. NDVI has found a wide application in vegetative studies and is often directly related to other ground parameters such as percent of ground cover, photosynthetic activity of the plant, surface water, leaf area index and the amount of biomass. NDVI is calculated as the normalised difference between the red and near infrared bands.

NDVI is a ratio of two bands, so NDVI helps compensate for differences both in illumination within an image due to slope and aspect, and differences between images due to things like time of day or season when the images were acquired. For example, the formula allows for the fact that two identical patches of vegetation could have different values if one were, for example in bright sunshine, and another under a cloudy sky. Thus, vegetation indices like NDVI make it possible to compare images over time to look for ecologically significant changes in vegetation activity.

NDVI values can range in value from -1 to 1 but values less than zero typically do not have any ecological meaning, so the range of the index is truncated to 0 to +1. In practice, highly negative values represent water, values around zero represent bare soil and values over approximately 0.55 to 0.6 represent dense green vegetation (Rodderick et al, 1996).

An inherent aspect of the NDVI approach is that only the upper layer of vegetation can be assessed. Where there are multiple vegetation stories, only the upper story will reflected in the NDVI result. For the overwhelming majority of the study area, the upper layer of native vegetation cover is trees. The mid-story or ground cover species are not included in this study as these vegetation species typically have shallow roots and will not be accessing groundwater beyond 1-2 m depth.

3.1.2 Objectives of the assessment

The objective of the NDVI analysis is to identify areas of vegetation within the theoretical influence of the Barwon Downs borefield that may potentially be using groundwater. Areas within theoretical influence of the borefield include the Barongarook High and areas of the aquitard with remnant vegetation.

The underlying assumption is that the change in NDVI provides an indication of the water availability across the season and years (all other things being equal). The Barwon Downs borefield is used during periods of low rainfall which results in low storage in reservoirs. During these times of below average rainfall, groundwater levels are subject to the dual effect of reduced groundwater recharge and the impact of groundwater pumping. It is also during these periods that vegetation is most likely to be reliant on groundwater, as there is less water available in the unsaturated zone. While other factors such as disease or fire could also impact on vegetation activity/health, this analysis assumes that these factors are not significant across the region during the assessment timeframe and where encountered, the assessment attempts to correct for them.

The assessment also aims to identify areas of water stress; such as locations without access to a reliable source of water during dry periods. In contrast, vegetation with high levels of activity during periods of water stress may indicate areas of potential groundwater use. While this analysis may not be not definitive in that vegetation using deep unsaturated zone water could give a similar response to vegetation using groundwater, it refines areas of potential groundwater use.

A further objective of the study is to assess how vegetation activity has changed in areas with significant change in groundwater levels due to groundwater extraction.

3.2 Method

The NDVI assessment uses remote sensing imagery (Landsat) to determine the NDVI. An important step in the approach is to broadly select relevant time periods to conduct the analysis including the exact dates and associated remote sensing images to use within that time period. This section documents the date selection process, data analysis method and NDVI data processing.

3.2.1 Date selection

The rationale for date selection was to select:

1. Contrasting periods of high and low water stress to assess periods representative of drought and periods of relative water abundance
2. Contrasting periods of groundwater levels to include timeframes with relatively high and relatively low groundwater levels within the area potentially impacted by the borefield.

Given that the Barwon Downs borefield is generally used during below average rainfall conditions, the above two criteria are generally complementary. To this end, groundwater hydrographs were used as one of the key selection tools in the broad identification of target dates for the analysis. Figure 3-1 shows an example of one of the hydrographs and the remainder are provided in Appendix A. The green shaded areas in Figure 3-1 highlight the target years for the analysis.

The objective was to target:

- one “background” period to identify conditions in a relatively un-impacted state
- two periods of water stress at the end of the drought (at low points in the groundwater hydrographs)
- one “recovery” period to identify conditions after several years of recovery of water levels following drought and groundwater extraction. This is to test the rate of recovery in vegetation condition associated with the drought and pumping.

Wet and dry season dates were selected within each of these time periods.

Figure 3-2 presents a cumulative departure from average (monthly) rainfall plot, also referred to as a rainfall residual mass curve. This chart shows periods of above average rainfall as rising trends and below average rainfall as declining trends. The selected NDVI analysis periods are marked on the graph, including the particular “wet” and “dry” season dates that were selected.

The rainfall residual mass curve shows that the background analysis date is situated at the end of prolonged above average rainfall from 1989 through to 1994. The hydrographs in Figure 3-1 and Appendix A indicate that the ‘background’ time period (1993/94) is not a fully un-impacted date in terms of groundwater change. However the hydrograph in Figure 3-1 indicates that the watertable aquifer (represented by bore 109111) is only impacted to a small degree at this date (less than 2m compared to 1980 levels), and hence is considered suitable for use as a reference / background date. The alternative was selecting a date in the late 1980s, however the Landsat imagery at that time had coarser data resolution, and would have made comparison with later dates more difficult.

The first ‘impact’ analysis date was selected to be 1999-2000 and occurs at the end of three years of significantly below average rainfall and almost at the lowest point in groundwater levels during this time.

The ‘recovery’ analysis date was selected to be 2005-06 and follows five to six years of slightly above average rainfall. While Figure 3-2 suggests that this period occurs six to 12 months into the next dry phase, Figure 3-1 shows that due to the lag in groundwater levels, groundwater levels were at an interim peak at the time of the analysis.

The second ‘impact’ analysis date is 2009-10 and lies at the end of five years of significantly below average rainfall and at the historically lowest point in groundwater levels during the groundwater hydrograph record.

Figure 3-1: Groundwater levels at nested bore site 109110 and 109111 (near McDonalds Dam). Green shaded years indicate target dates for the NDVI analysis.

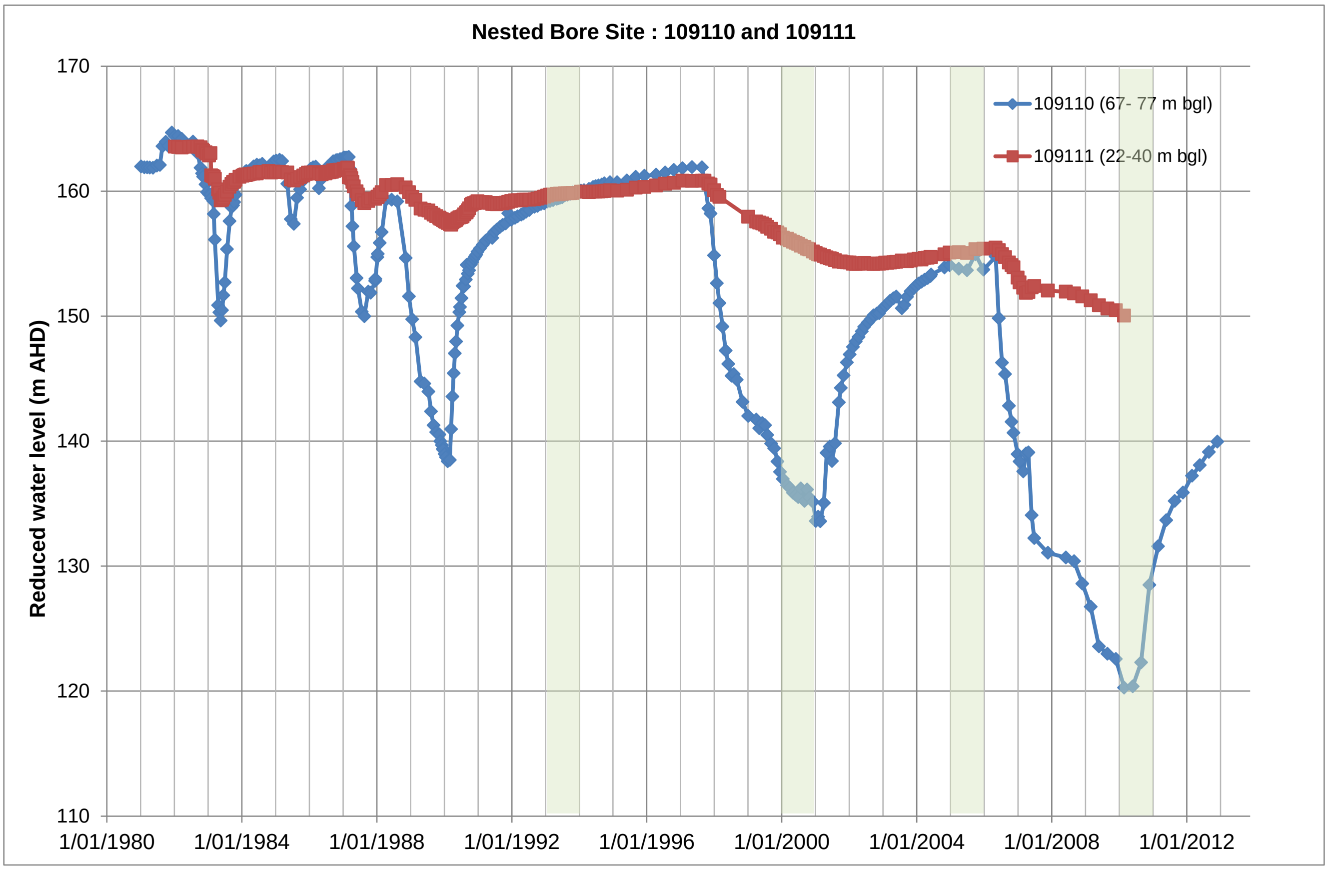
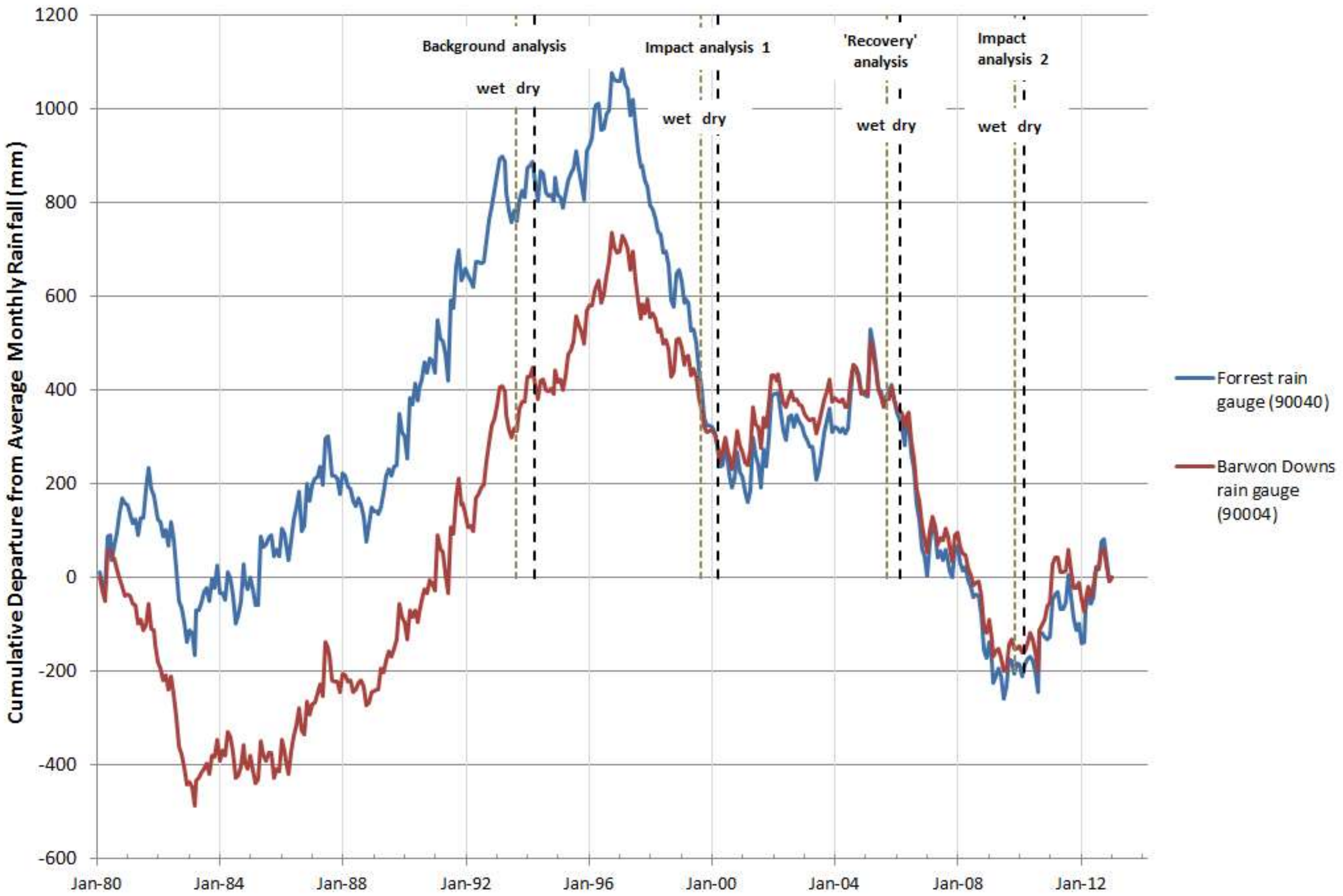


Figure 3-2: Rainfall residual mass curve - cumulative departure from mean monthly rainfall and NDVI analysis dates



Appendix B summarises the rationale for the date selection process, and the finally selected dates. The table includes a discussion of the rainfall preceding the selected NDVI date. Appendix B contains plots of the rainfall conditions in the months prior to each of the dry season analysis dates. Significant rainfall prior to the analysis date is not preferred as the underlying premise of the analysis is that there is limited water available in the near surface. The assumption then for the summer NDVI analysis is that the vegetation activity of plants is broadly correlated to their access to deep water, an assumption which can be compromised if plants preferentially use shallow rather than deep water. Appendix B only discuss rainfall conditions prior to the ‘summer’ (or ‘dry season’) date, as soil conditions during the ‘wet season’ date are assumed to contain moisture throughout the profile that is readily available to plants.

Appendix B plots rainfall minus daily pan evaporation assuming a 0.75 pan evaporation multiplier. Rainfall less evaporation is of more relevance to this assessment than rainfall only. This is because in the middle of summer, evaporation can account for a significant proportion of rainfall and, depending on the amount and intensity of rainfall, very little or no water may penetrate to any significant depth in the soil profile and hence be practically unavailable to plants (expect perhaps very shallow rooted plants, which are not the focus of this study). For each date a two day cumulative rainfall minus two day cumulative evaporation and a three day cumulative rainfall minus three day cumulative evaporation are also plotted, as rainfall will often be evaporated from the surface or very shallow soil depth within several days of the precipitation event.

3.2.2 NDVI data processing

Landsat is a medium resolution satellite sensor and is obtained twice monthly which gives rise to opportunities for examining seasonal patterns in vegetation surface cover. To achieve consistency in comparing results over time, the Landsat image series was employed for each time epoch in the analysis. Specifically, the sensors used in this project were Landsat TM 5 and Landsat ETM+ 7.

1993	Landsat TM 5
1994	Landsat TM 5
1999	Landsat TM 5
2000	Landsat ETM+ 7
2005	Landsat TM 5
2006	Landsat ETM+ 7
2009	Landsat TM5
2010	Landsat ETM+ 7

There is little difference in the sensors between Landsat TM 5 and Landsat ETM+ 7; however in 2003 a hardware failure in the Landsat 7 sensor resulted in linear data gaps in the imagery post-2003. This covers about 75% of the image scene (USGS, 2015). Where there are gaps in the data for the 2006 and 2010 images, the gaps were treated as null and were not infilled by other images (i.e. treated as null across all images, so they were not considered in the analysis at all). This is a legitimate approach, as the primary use of the data was for analysis rather than creating an image. The result just meant a smaller sample size in calculating the mean NDVI value.

Landsat tiles were acquired from USGS processed to Level 1T (precision and terrain corrected). These were then post-processed and calibrated for top-of-atmosphere reflectance. This converts the image data to a common radiometric scale so that images across different epochs can be compared.

From Chandler et al. (2009), the top of atmosphere correction is as follows:

$$\rho_{\lambda Pixel,Band} = \frac{L_{\lambda Pixel,Band} \cdot d_{ES}^2 \cdot \pi}{Esun_{\lambda Band} \cdot \cos(\theta_S)}$$

where :

$\rho_{\lambda Pixel,Band}$ = Top of atmosphere spectral reflectance

$L_{\lambda Pixel,Band}$ = Top of atmosphere averaged spectral radiance

d_{ES} = Earth-Sun distance during the image acquisition

$Esun_{\lambda Band}$ = band averaged solar spectral irradiance normal to the surface being illuminated

θ_S = solar zenith angle during image acquisition

Following radiometric correction, normalised difference vegetation index (NDVI) was carried out on each set of images across the time series. NDVI is an indicator of density and vigour of green areas on the surface and is estimated as:

$$NDVI = \frac{\rho_N - \rho_R}{\rho_N + \rho_R}$$

where:

ρ_N = reflectance in the near-infrared spectral band

ρ_R = reflectance in the red spectral band

3.2.3 Data analysis method

The NDVI results were analysed using three different approaches:

- Comparison of wet and dry seasons
- Comparison of depth to watertable
- Temporal assessment

Wet-dry seasonality assessment

In order to target the analyses of the dates previously determined, specific sites in the landscape were chosen as target sites. The sites were chosen manually as representative of the full range of water use that occurs in the landscape. 33 sites were selected (Table 3-1) that represent a range of land uses, depth to watertable and likely impact from the bore filed. The sites include some of the current vegetation monitoring sites, open water in dams, a sand quarry, pasture, irrigated pasture and plantations.

The different sites will have a vast range of NDVI and importantly a large range in the change in NDVI across seasons and years. This spread of data enables the results to be verified to ensure NDVI of pasture returns different results as tall woody riparian vegetation. Using a range of different sites allows for the natural variation in the NDVI to be observed, giving context for the natural variability in the selected sites.

These sites were plotted as paired data sets, being dry season NDVI versus the adjoining wet season NDVI for the same time period. A table of the sites and associated key information is presented in Table 3-1. A map of the sites is shown in Figure 3-3. To the extent practical, the sites were selected to be approximately that same size, however depending on the particular feature being assessed, this was not always possible.

The advantage of plotting the results as a wet versus dry statistic is that more information on seasonal changes is provided, which can be equally informative regarding potential (deep) water use as the dry season NDVI alone.

Depth to watertable based assessment and areas of potential impact

The evaluation involved looking for trends in NDVI and depth to watertable. The hypothesis behind this analysis is that areas with shallow depth to watertable are more likely to be using groundwater and therefore may have a higher summer NDVI than areas where the watertable is deeper. Depth to groundwater was divided into five broad categories of less than 2 m, 2 – 5 m, 5 – 10 m, 10 – 20 m and greater than 20m.

The depth to watertable data was produced using an algorithm that generates a watertable surface that is a subdued reflection of topography. The extent to which the watertable surface mimics topography can be varied in the analysis. The appropriate watertable surface is selected based on ‘calibration’ against groundwater level data. Data from across the period 2012-14 was used to develop the watertable map. This time period was used to allow use of data from bores installed in 2014, and also allow use of the latest records from databases which had not been updated since 2012. For the majority of bores, the difference between a 2012 and 2014 groundwater level will be relatively minor. Some manual correction of the maps was required in order to produce realistic watertable elevations in some areas. The maps included the watertable surface for the LTA outcrop, and also for the aquitard areas. The map is presented in Figure 3-4. The focus of the map was on achieving acceptable results in the areas of native vegetation cover.

The study area was also assessed in relation to proximity to areas of potential impact from the Barwon Downs borefield. Areas of potential impact area are greatest where the Lower Tertiary Aquifer outcrops and this was divided into areas of high (greater than 10 m drawdown), moderate (2 to 10 m drawdown) and minor or no impact (less than 2 m drawdown). These drawdowns were based on a 2012 drawdown map and a map of these three areas is presented in Figure 3-3.

Temporal assessment

The aim of this assessment is to look for any evidence of impact of the borefield on vegetation across time. The temporal assessment examined trends across time in the NDVI data using three different spatial groupings:

- within the three broad zones of potential impacts described above
- within different categories of depth to watertable and
- at some of the terrestrial vegetation monitoring sites.

Table 3-1 : Key information for sites used in NDVI analysis

Site no.	Site name	Description	Purpose	Depth to water-table[1] (m)	Surface cover / vegetation cover	Outcrop Geology	Site area, m^2 (no. of pixels)
1	Dam	Dam on tributary of lower Boundary Ck. To provide reference.	REFERENCE - Provide points of reference, as low NDVI surfaces	-	Water	MTD	40,500 (45)
2	Quarry	Sand quarry on Westwood Road. To provide reference.		50-100m	Sand	LTA	18,000 (20)
3	Pasture 1	Paddock off De La Rues Rd	REFERENCE - Provide points of reference as potentially high winter/low summer NDVI	>20m	Pasture	MTD	31,500 (35)
4	Pasture 2	Paddock off De La Rues Rd		10 - 20m	Pasture	MTD	14,400 (16)
5	Pasture 3	Paddock, south lower Boundary Creek		5 - 10m	Pasture	MTD	18,900 (21)
6	Pasture 4	Paddock west of McDonalds Dam		>20m	Pasture	LTA	45,000 (50)
7	Pine trees	Pine plantation, off Colac-Forrest Rd	REFERENCE - Provide points of reference, as potentially high NDVI surfaces	> 20m	Pines	MTD	18,000 (20)
8	West Barwon Forest	Vegetation (south of Forrest, near West Barwon Reservoir)		>20m	Native forest	Bedrock	48,600 (54)
9	RB1(Nat. veg, deep WT)	Vegetation (off Westwood Track), near former bore 64239 (current bore RB1)	REFERENCE - Provide points of reference in nat. vegetation where watertable is known to be deep	50-100m	Lowland forest	LTA	14,400 (16)
10	Bore 47998 (Nat. veg, deep WT)	Vegetation (off Westwood Road), near bore 47998		20-50m	Lowland forest	LTA	17,100 (19)
11	TB1(Big Swamp)	Big Swamp, on Boundary Creek	Assess change due to fire / ASS	< 2m	Lowland forest, Swampy riparian woodland	QA over MTD	31,500 (35)
12	TB1(Riparian)	Vegetation adjacent to Big Swamp, on Boundary Creek	IMPACT - monitoring sites within the LTA	~ 2m	Lowland forest	QA over shallow MTD	16,200 (18)
13	T2	Vegetation adjacent to Boundary Creek, upstream of Big Swamp		1 – 5m	Swampy riparian woodland	LTA	45,000 (50)

Site no.	Site name	Description	Purpose	Depth to water-table[1] (m)	Surface cover / vegetation cover	Outcrop Geology	Site area, m^2 (no. of pixels)
14	T3			> 10m	Heathy woodland	LTA	8,100 (9)
15	T4	Vegetation adjacent tributary of Boundary Creek		2 – 5m	Riparian scrub/swampy riparian woodland complex	LTA	13,500 (15)
16	T4 (D'stream)	Vegetation adjacent tributary of Boundary Creek, d'stream of T4	Assess any difference in T4, away from track	2 – 5m	Riparian scrub/swampy riparian woodland complex	LTA	13,500 (15)
17	T5	Vegetation adjacent tributary of Boundary Creek, front of Gun Club	REFERENCE - vegetation monitoring sites in LTA	~ 10m	Riparian scrub/swampy riparian woodland complex	LTA	28,800 (32)
18	T6	Vegetation adjacent tributary of Boundary Creek, near Langdons Rd		1 – 5m	Riparian scrub/swampy riparian woodland complex	LTA	19,800 (22)
19	T7_riparian	Vegetation adjacent tributary of (upper) Ten Mile Creek		1 - 3m	Heathy woodland	LTA	4,500 (5)
20	T7_swamp	Vegetation within the drainage line, at "T7_swamp" site (above)	Compare within & outside drainage line	<1-2m	Riparian scrub/swampy riparian woodland complex	LTA	5,400 (6)
21	T8	Vegetation adjacent tributary of Dividing Creek, on Westwood Track	IMPACT - monitoring sites within the MTD	5 – 10m	Riparian scrub/swampy riparian woodland complex	MTD	25,200 (28)
22	T9	Vegetation adjacent tributary of Porcupine Creek, on Pipeline Rd		2 - 5m	Heathy woodland, sedgy riparian woodland	MTD	18,000 (20)
23	T10	Vegetation adjacent tributary of (upper) Dividing Creek, on Wares Rd		4 - 6m	Heathy woodland,	MTD	16,200 (18)
24	T11	Vegetation adjacent Porcupine Ck, on Colac - Olangolah Pipeline Rd	REFERENCE - vegetation monitoring sites in MTD	1 – 3m	Heathy woodland, wet heathland	MTD	29,700 (33)
25	T12	Vegetation adjacent tributary of Dividing Creek, on Gold Hole Road		2 – 5m	Lowland forest	MTD	28,800 (32)
26	T12_upslope	Vegetation upslope of T12		20-50m	Lowland forest	MTD	42,300 (47)

Site no.	Site name	Description	Purpose	Depth to water-table[1] (m)	Surface cover / vegetation cover	Outcrop Geology	Site area, m² (no. of pixels)
27	T13	Vegetation adj. tributary of Dividing Creek, on Parkes Lodge Road.		2 – 5m	Heath woodland	MTD	12,600 (14)
28	T13_upslope	Vegetation upslope of T13		20-50m	Lowland forest	MTD	11,700 (13)
29	T14a	Vegetation adj. Ten Mile Creek tributary of Dividing Creek, near bore	REFERENCE - vegetation monitoring site in LTA	1 – 5m	Riparian forest	LTA	30,600 (34)
30	T14b	Vegetation adj. Ten Mile Ck tributary of Dividing Creek (upstream of T14a)		1 – 5m	Riparian forest	LTA	17,100 (19)
31	U'Boundary Ck1	Vegetation adj. Boundary Creek (north of Gun Club)	IMPACT - Assess changes in bedrock outcrop area	5 – 10m	Heathy woodland	Bedrock	26,100 (29)
32	U'Boundary Ck2	Vegetation adj. Boundary Creek (north of Gun Club)		10 - 20m	Grassy forest	Bedrock	22,500 (25)
33	D/S McD.Dam, U/S Swamp	Vegetation upstream of Big Swamp, downstream of McDonalds Dam	IMPACT - Assess changes in area of suspected watertable decline	5 – 10m	Swampy riparian woodland, lowland forest	LTA	3,600 (4)
34	Upstream Dam	Upstream of McDonalds Dam	IMPACT - Assess changes in area of potential watertable decline	~ 5m	Damp sands herb-rich woodland, swampy riparian woodland	QA overlying LTA	21,600 (24)
35	Upper 10 Mile Ck	Vegetation adj. Upper Ten Mile Creek	REFERENCE - Assess any changes along 10 Mile Creek / reference point in LTA	2 - 5m	Riparian forest	LTA	39,600 (44)
36	Upper Dividing Ck	Vegetation near newly installed bore, on Westwood track	REFERENCE - Provide point of reference where watertable is known to be deep	20 – 50m	Lowland forest	LTA	8,100 (9)

1. Depth to watertable is based on a combination of the mapped DTWT (which used dates as close to 2014 as available for a given bore) and groundwater levels in new bores installed in 2014

Figure 3-3: Locality map - sites used in the NDVI analysis

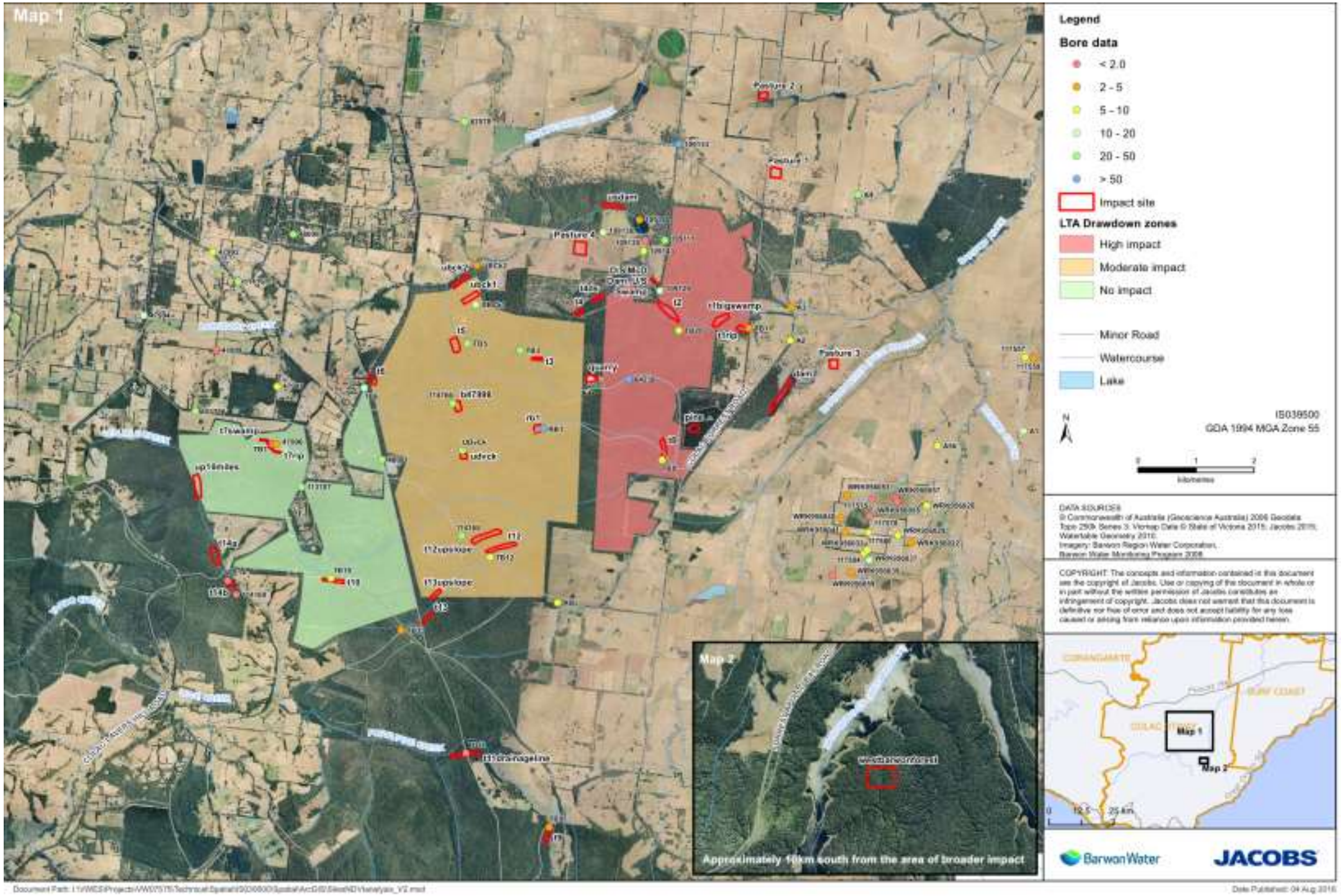
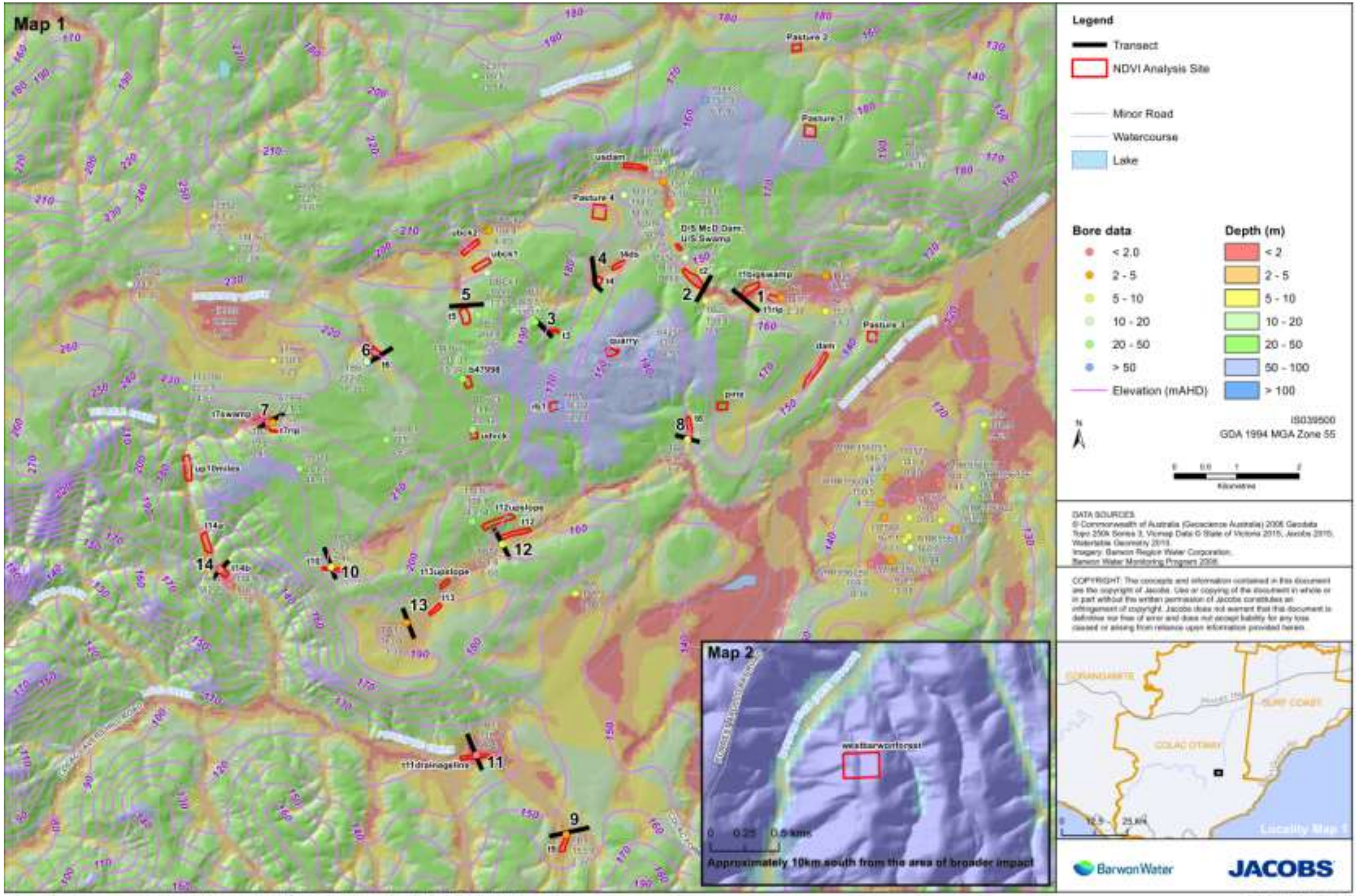


Figure 3-4: Depth to watertable map (upper most aquifer) used in the NDVI analysis



3.3 Results

The results of the NDVI assessment for the wet-dry seasonality assessment, the depth to watertable assessment and the temporal assessment are presented in the following sections. The NDVI results used for these assessments were based on the four time periods used to represent the following:

- Reference time period – August 1993 (wet) and March 1994 (dry)
- Impact 1 time period – August 1999 (wet) and March 2000 (dry)
- Recovery time period – September 2005 (wet) and February 2006 (dry)
- Impact 2 time period – November 2009 (wet) and February 2010 (dry)

The summer NDVI maps for 2010 and 1994 are shown in Figure 3-5 and **Figure 3-6** respectively. Two figures are shown for each time poeriod. One set presents the full spectrum recorded across the NDVI range (Figure 3-5 and **Figure 3-6**), the other set (Figure 3-7 and Figure 3-8) focusses on the 0.5 to 0.7 range, and results for areas of (mapped) native vegetation are shown. Healthy native vegetation of reasonable density plots within the 0.5 to 0.7 range, and hence this second image shows more contrast within the native vegetation.

In Figure 3-5 and Figure 3-6, the green colours (approximately above 0.5) represent areas of native vegetation, the orange and red colours represent dry land pasture (below 0.5) and the yellow areas (approximately 0.5) represent either areas of native vegetation of lower density and/or of poor condition (e.g. water stressed).

Some broad trends are readily visible, including the relatively low values for the annual pastures (which are inactive during this time of year) and the relatively high values for the areas of native vegetation. In the more elevated areas of the Otways Ranges the NDVI is higher than in the lower lying areas (attributed to higher rainfall and hence greater leaf area index and amount of biomass). Areas of irrigated pasture (e.g. west of Barwon River, downstream of confluence with Boundary Creek) and mature plantations (e.g. west of Colac-Forest Rd, north of bore 64230) exhibit relatively high NDVI. Water bodies return NDVI values around zero (e.g. West Barwon reservoir, south of Forrest).

In Figure 3-7 and Figure 3-8, the green and blue colours represent areas of native vegetation above an NDVI of 0.6 (indicative of healthy vegetation), whereas the brown colours represent vegetation in the range of 0.5 to 0.6. These values are on the margin in terms of range for healthy vegetation, which is typically 0.55 to 0.6. Hence values around 0.5 are indicative of either marginal reductions in the density of vegetation cover and/or photosynthetic activity due to some form of stress. In Figure 3-7 and Figure 3-8, the difference between the 2010 and 1994 images is particularly clear. Especially in the north eastern part of the study area (on either side of Boundary Creek) NDVI is lower in 1994 compared to 2010. Potential reasons for this difference are discussed later in this section.

The maps are useful for providing some background and wider context for the data, however the focus of this section is on a more quantitative assessment of the results, which is provided in the remainder of this section.

Figure 3-5: Summer NDVI 2010 (NDVI image for 19/02/2010)

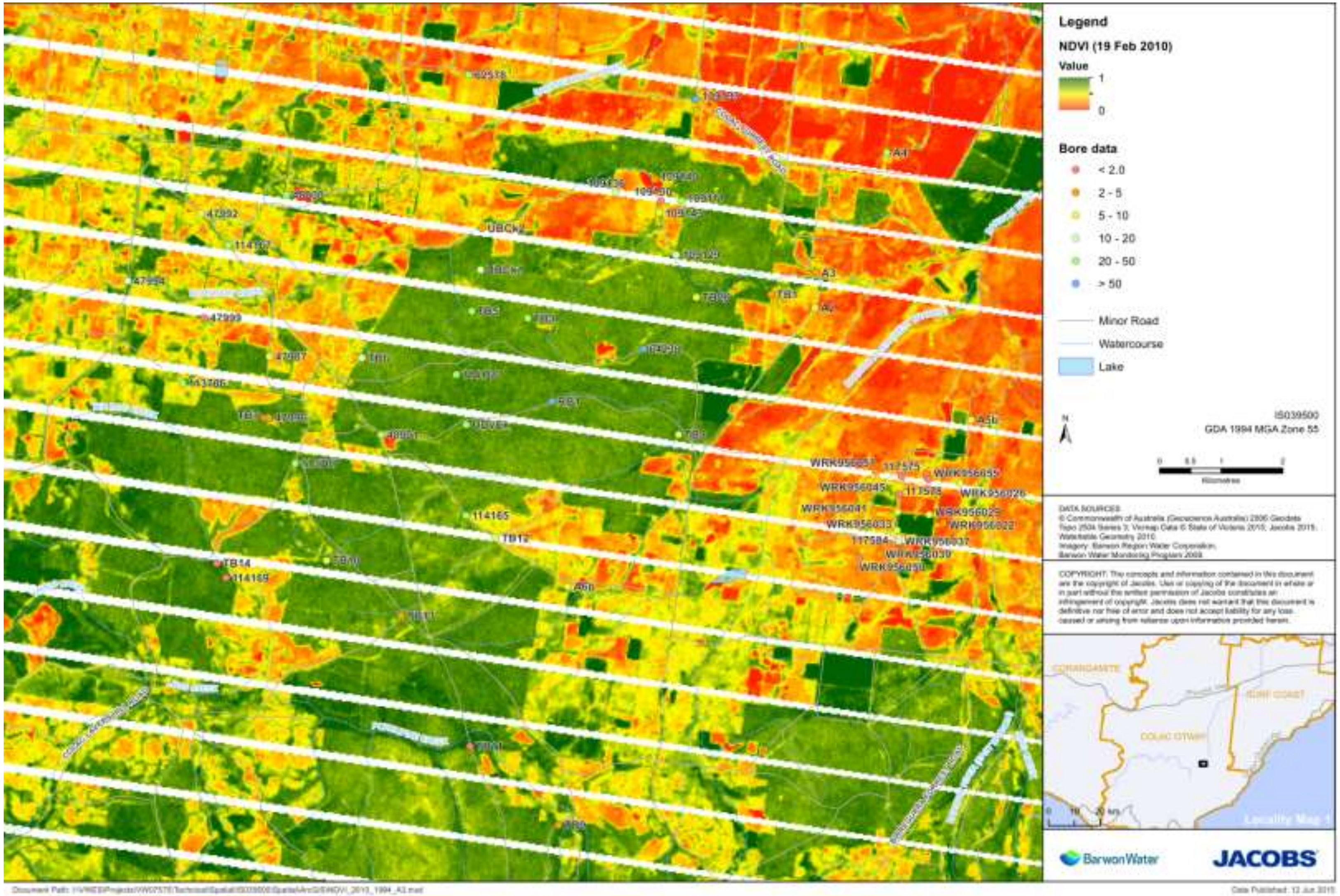


Figure 3-6: Summer NDVI 1994 (NDVI image for 18/3/1994)

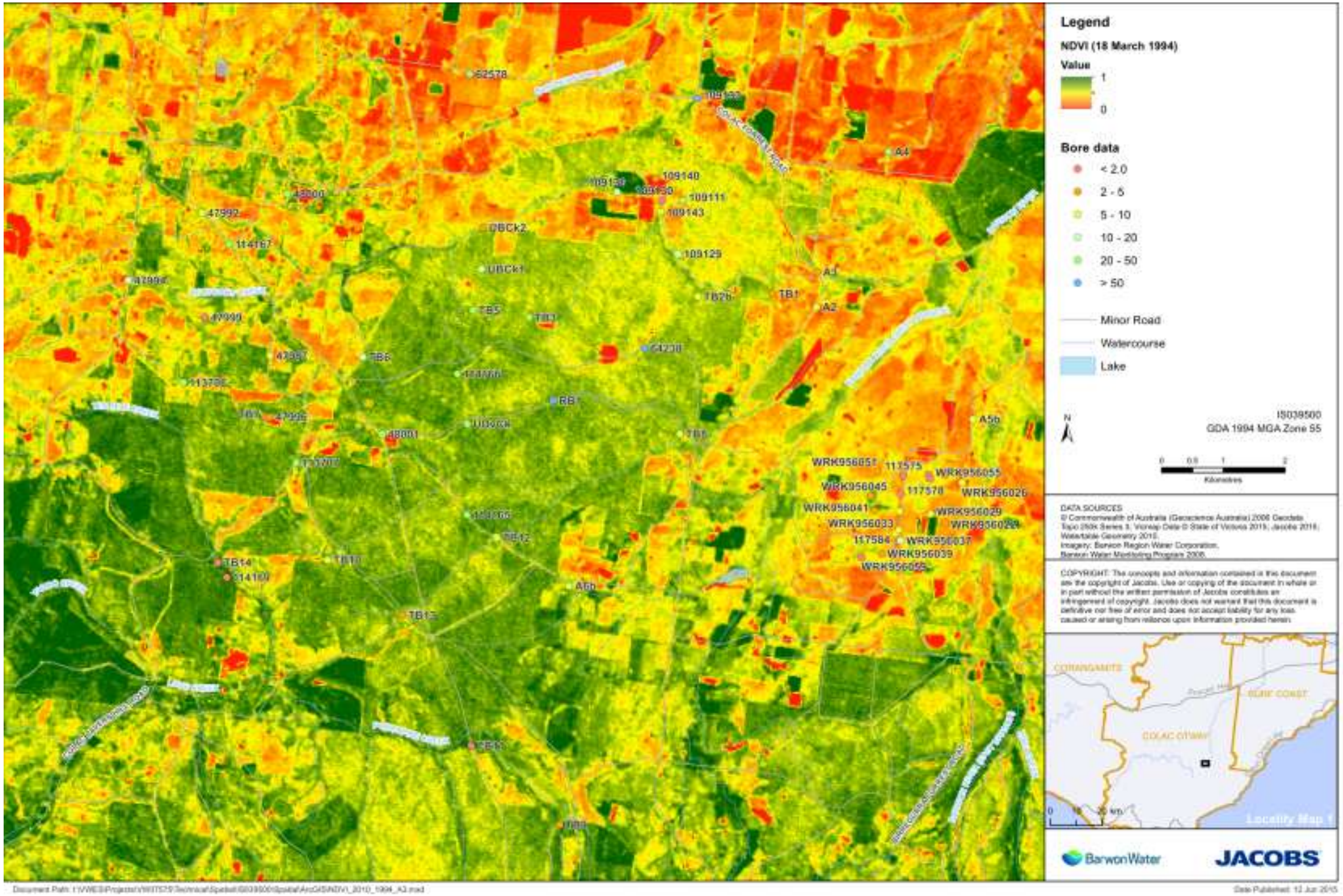


Figure 3-7: Summer NDVI 2010 for 0.5-0.7 range (NDVI image for 19/02/2010)

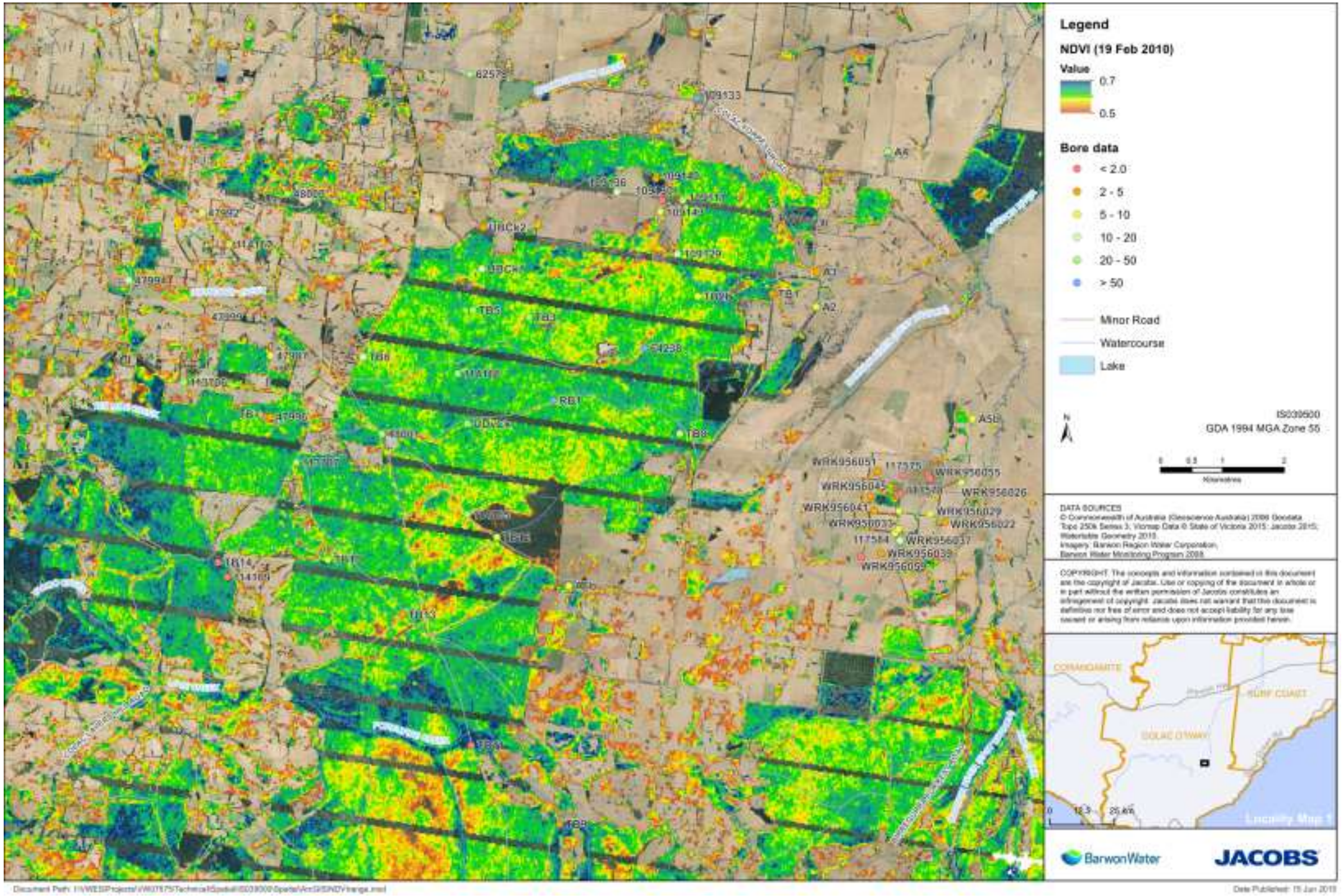
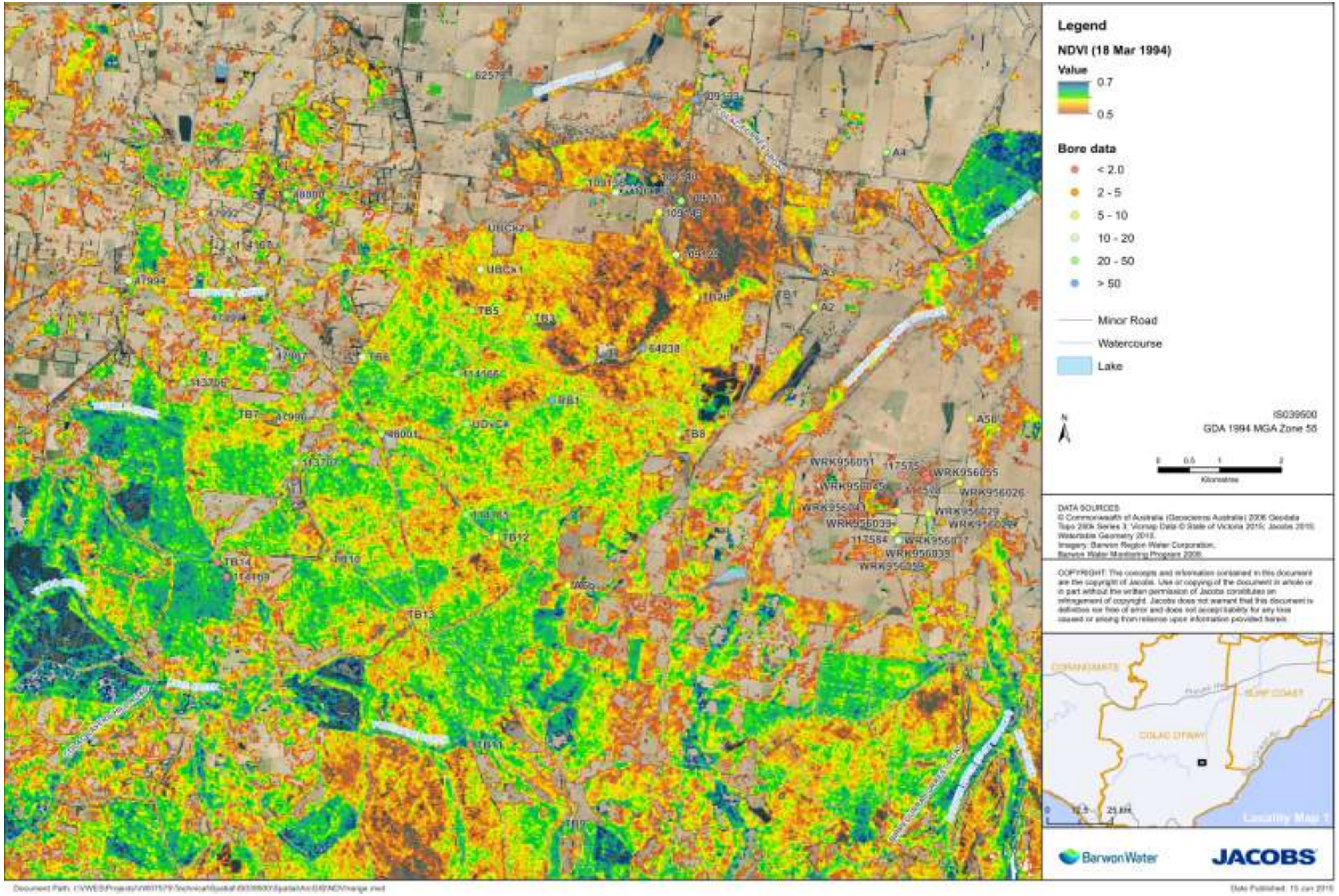


Figure 3-8: Summer NDVI 1994 for 0.5-0.7 range (NDVI image for 18/03/2010)



3.3.1 Wet-Dry seasonality assessment

Figure 3-9 plots each of the selected sites as paired data sets i.e. plot summer NDVI results against winter NDVI results for each site in each year. Hence for each site there are four data points representing each of the four time periods. The value is the average NDVI value within the selected area. The figure includes annotations, to assist with interpretation of the results. The following observations and conclusions are drawn from the plot.

Outliers

The outliers on the plot are useful for providing context to the sites of interest:

- **Water -** Water absorbs light in the near infra-red (NIR) range and hence has a consistently low NDVI value across both wet and dry seasons and plots in the bottom left hand corner of the figure (two results plot in the negative, and hence are not shown in the figure).
- **Sand quarry -** The sand quarry also plots in the lower left hand corner of the graph, although as sand does not absorb as much of the NIR as water it has slightly higher NDVI values than water. The winter 1994 point sits higher than the other three values. Given that this is the earliest date, the most likely explanation is that part of the quarry site had not being quarried in 1994 supported some shallow rooted winter/spring active vegetation when the image was captured.
- **Pine tree plantation –** When the pine plantation contained mature trees it plots in the far top right of the graph (1994, 2006 and 2010). When the plantation was harvested and replanted (sometime between 1994 and 2000) , the NDVI value in the year 2000 is seen to be substantially lower. The winter and summer NDVI value is lower because the canopy has not reached its full extent, however the summer is relatively lower for 2000, most likely because the root system is not yet sufficiently established in order to access year-round water and the vegetation activity is lower as a result. In contrast, the fact that the mature pine plantations have summer NDVI comparable to or higher than winter NDVI indicates that they have access to water deep in the soil profile, i.e. from the unsaturated zone or groundwater. Given the large depth to watertable at this location (approximately 20m), water from the unsaturated zone is the more likely source.
- **West Barwon forest –** This site is located approximately 10km south of the borefield, in forest near the West Barwon Reservoir (refer to the inset in Figure 3-3 for location). There is essentially no seasonal NDVI difference exhibited for this site, which plots in a tight band in the upper right hand corner of Figure 3-9. Like the mature pine plantations, this indicates a dense canopy and also all year round access to water. The site has been selected on ridge tops and not drainage lines and hence water use is considered to be from the unsaturated zone sourced directly from rainfall.
- **Pasture –** Non-irrigated pasture predominantly plots in the top left corner of Figure 3-9. This represents high winter NDVI values (similar and in many cases higher than the West Barwon forest and pine plantation winter NDVI values) but with low summer NDVI values. The fact that the summer NDVI values are only somewhat higher than the quarry summer NDVI values indicates the very low photosynthetic activity of these pastures during late summer/early autumn. This is typical of annual pastures. The fact that the 2006 values for the two dryland pastures plot much further to the right (i.e. had relatively high summer NDVI values) is indicative of the higher rainfall received in the two weeks prior to the summer 2006 image. The effect of recent rainfall on the NDVI values of pastures is much more pronounced due to the shallow roots and relatively quick response to rainfall compared to sites with tree cover.

  The irrigated pasture, in contrast to the non-irrigated pasture has some of the highest summer NDVI values, as the water application sustains high plant activity. It is noted that some of the irrigated pasture sites switch to non-irrigated at different dates (and vice versa) as not all the sites were irrigated for all the selected dates. Further one of the non-irrigated pasture sites was evidently watered for one of the dates.
- **T3 –** Site T3 is located in a sedge and rush dominated wetland in standing water (to 35cm at the vegetation transect but likely deeper toward centre of swamp) where Eucalyptus ovata trees occasionally encroach from the edges. It contains mainly sedges and rushes, as opposed to the relatively dense vegetation of other sites and hence this lower vegetative cover results in a lower NDVI value for the site. The regional groundwater level at this site is estimated to be a least 10m below the base of the swamp. The point of interest regarding this site is that in almost all cases the summer NDVI is similar or slightly higher than the

winter NDVI (with the exception of 1994), implying that the swamp and its vegetation may be sustained by a relatively permanent water source. Given what is known from surrounding regional groundwater levels (i.e. deep at this site), this is highly likely to be a perched watertable.

- **Big Swamp –** The Big Swamp site (*T1 Big Swamp* in Figure 3-9) has been affected by the acidification and fire that has occurred at the site (over the late 1990s and then late 2000s). The 2000, 2006 and 2010 values are clustered around the middle of the plot (with wet and dry season NDVI values between 0.4 and 0.5). The 1994 data point (before the fire and acidification) plots further up and to the right, and is located with many of the other sites investigated. The decrease in NDVI for the remaining three dates is due to tree death and decline in tree health due to the fire and acidification – this is discussed further later in this chapter. The riparian vegetation adjoining Big Swamp (*T1riparian* in Figure 3-9) does not show the same trends as in the swamp itself, and generally plots in the same cluster as the other native vegetation. This observation confirms our understanding, that a range of stresses to vegetation are reflected in the NDVI measure.

Reference Sites

Reference sites were selected where there is a high level of confidence that no watertable impact from the borefield has occurred. The West Barwon Forest site described above is a type of reference site, however it is a long way removed from the borefield compared to the other sites. It sits at a higher elevation in the Otways and will receive higher rainfall. More relevant reference sites closer to the bore field are T6, T7 and T14.

The T14 site (T14a and T14b) is located adjacent to Ten Mile Creek where the recently installed bore indicates shallow groundwater (less than 2m below ground at TB14b NDVI site) and the depth to watertable mapping indicates less than 5m below ground at TB14a NDVI site. These sites plot in a tight band in Figure 3-9 and are very similar to the West Barwon Forest site. This is due to a combination of the type of vegetation at this site which is likely to be similar to the West Barwon Forest site (over-storey is dominated by tall Manna gums), as well as the shallow watertable, which allows seasonally constant vegetation activity at the site.

The vegetation at T14a & b does not occur at any of the other terrestrial vegetation monitoring sites (T1 – T13). For this reason T14a & b has the highest NDVI of all of the 14 sites. The vegetation at T6 and T7 is more representative of the remaining vegetation monitoring sites. T6 and T7 plot with NDVI values from 0.5 to 0.6 for both wet and dry seasons. This seasonal consistency is again indicative of access to a permanent water source. The watertable is less than 2m below surface at T7. It is noted that 'T7 swamp' has some lower winter values compared to other sites – this is possibly due to the presence of standing water in the swamp, which will lower the overall NDVI value. For T6 the watertable is likely to be slightly deeper but still within the 2-5m range.

Impact Assessment Sites

One of the primary observations regarding the 'impact assessment sites' (sites where there may have been an impact from the borefield) which includes T1 – T4 overlying the LTA and T8 to T10 overlying the aquitard; is that they are grouped fairly tightly around the 0.5 to 0.6 NDVI range, with very similar wet and dry season values. The consistent seasonality of the results indicates access to a constant supply of water. Given the shallow depth to watertable at these sites, groundwater is considered the likely source. In fact, a number of the sites show a slightly higher summer NDVI value than winter NDVI value. This is likely due to the longer days and longer sunshine hours during summer, meaning greater potential for photosynthetic activity and plant growth. However this is only possible if accompanied by a reliable/constant water source.

The clustering of the sites in Figure 3-9 suggests that the impact assessment sites have not been affected by the borefield – however this is analysed further in the following section where the temporal change at the sites is more clearly plotted. The one site where there has been significant change is the site located near Boundary Creek downstream of McDonald's Dam and upstream of T2 (which in turn is upstream of the Big Swamp). The site is labelled "D/S McD. Dam, U/S Swamp" in Figure 3-9. This is not a terrestrial vegetation monitoring site, however the site was selected for NDVI assessment as it is likely that the watertable has declined in this area.

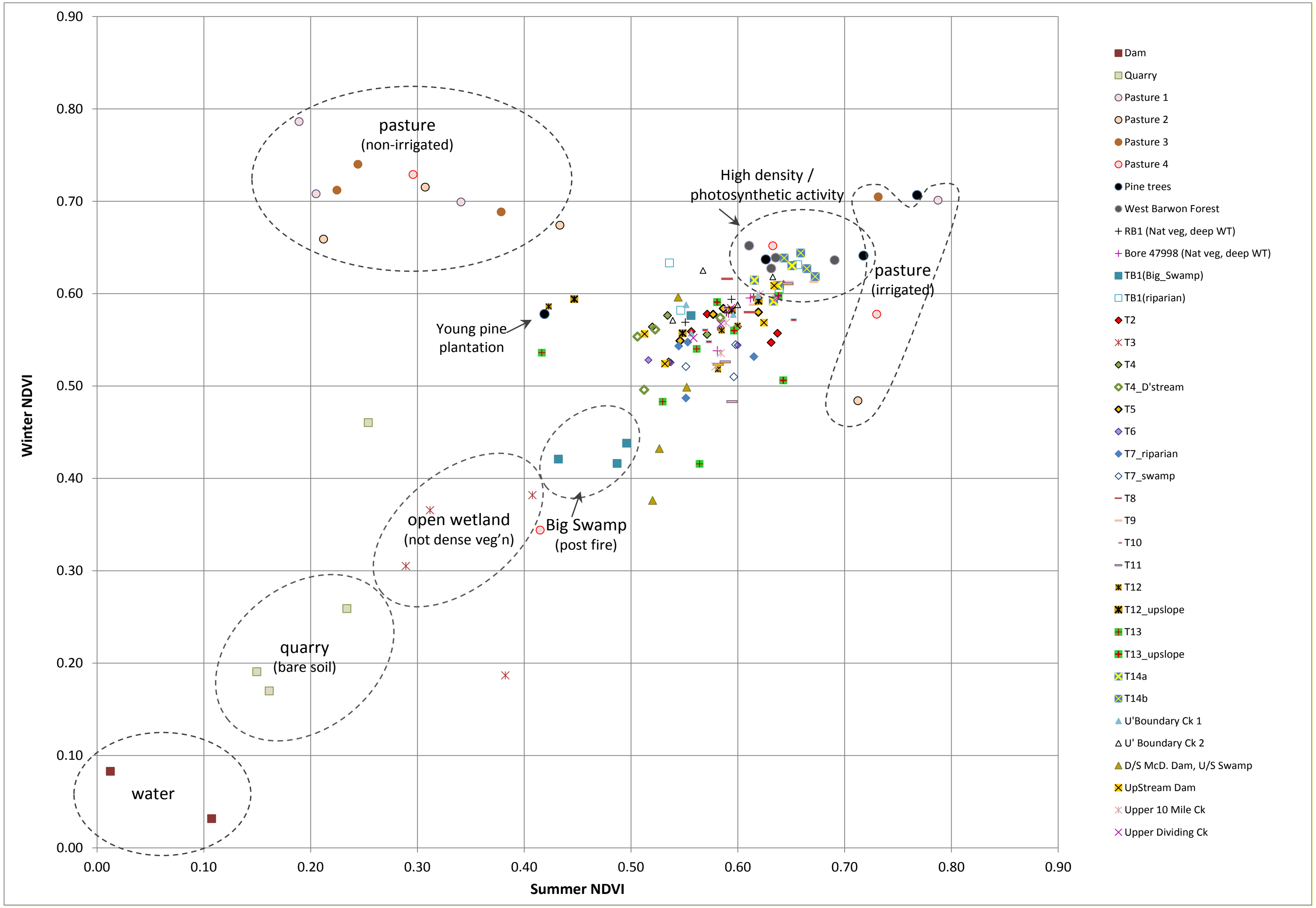
The site displays fairly consistent summer NDVI values, but winter NDVI values fluctuate from around 0.38 (in 2000) up to 0.6 (in 2010). The fact that the lowest winter value is recorded in the year 2000 implies possible impact from declining water levels, however the baseline 1994 (wet season) value is only slightly higher at 0.43.

The site is very small and its shape (aligned diagonal to landsat pixels rather than horizontally or vertically) means that the pixels that get calculated in the NDVI number will vary depending on where the pixels line up – which is different from year to year. This is likely to be, as least in part, the reason for this result. It is also possible that some change in land cover over the period of interest may have occurred. The site is a small patch of remnant vegetation on farmland, and some of this site could have been converted from relatively bare soil to tree cover during the period.

Importantly, any impact from declining water levels would most likely impact on summer NDVI which is not observed in the results. Also, the maximum impact would be expected in 2010 (representing the lowest water level), but the 2010 value in fact displays the highest winter NDVI value.

In summary, the wet – dry seasonality assessment shows a range of NDVI responses across the study area, which are all explained by their particular land use and surface cover. Most native vegetation are clustered in a range expected for healthy and dense vegetation; in general summer NDVI values are comparable to, or higher than winter NDVI values, indicating the vegetation is not water stressed during dry periods. There are no native vegetation areas which show any clear signs of stress or detereoration over time, but this is assessed in more detail in following sections. The exception is Big Swamp, where the die-back due to fire and acidification are evident in the data.

Figure 3-9 : Dry (late summer/autumn) vs Wet (late winter/spring) NDVI for selected sites



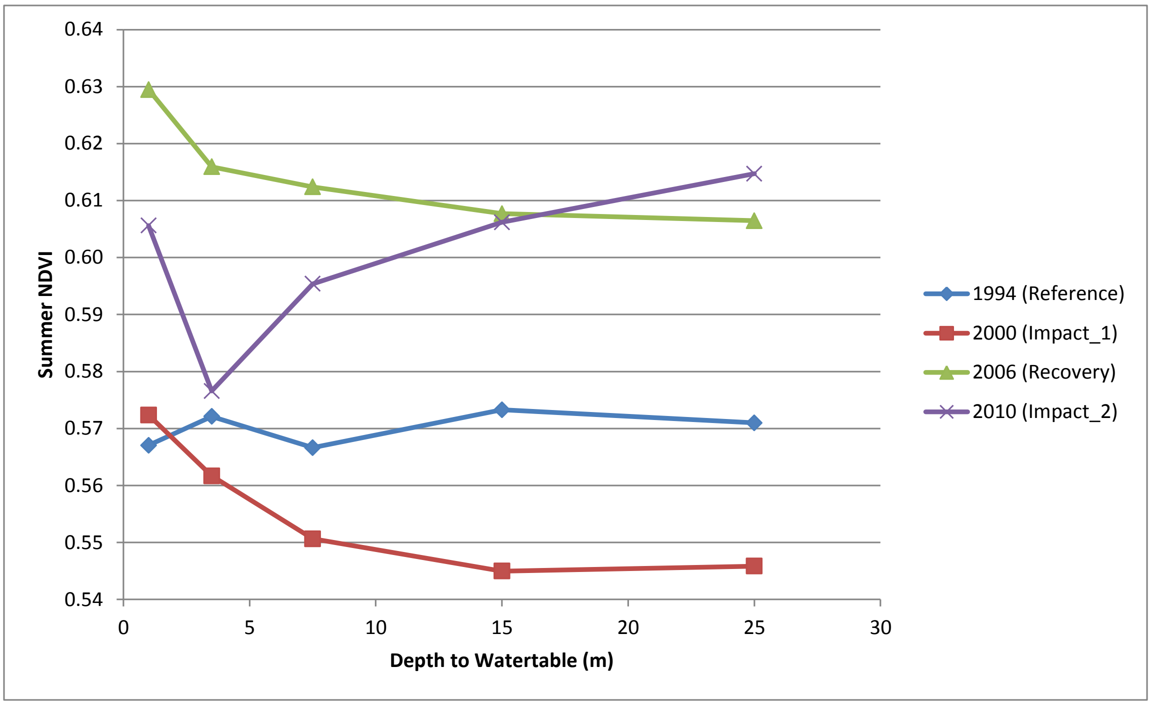
3.3.2 Depth to watertable based assessment

Figure 3-10 presents summer NDVI response versus depth to watertable (for all areas of native vegetation within the study area), and for each of the four analysis periods.

The 1994 NDVI values in Figure 3-10 are relatively consistent and show very little variability across depth to watertable. This implies that there was nowhere in the landscape that was water stressed at the time the image was captured, i.e. elevated areas show same NDVI as areas low in the landscape. This makes sense considering the significantly above average rainfall leading up to this date (refer Figure 3-2).

The 2000 and 2006 dates both show a clear and consistent trend of higher NDVI values for shallower depth to watertable. In particular where the depth to watertable is less than 2m and 2-5m from the surface are significantly higher than categories of deeper watertable. This suggests that the vegetation in the shallower depth to watertable categories had access to a more reliable source of water than the areas where the groundwater was deeper. A possible explanation is that the areas of shallow watertable tend to be located along drainage lines and therefore there is more surface water runoff and infiltration in these areas, and hence there is a more consistent source of water in the unsaturated zone. An alternate explanation is that the vegetation in these areas is accessing groundwater during these dry periods since it is relatively close the surface and more easily accessible. This is a possibly a more realistic explanation than the previous one, as during dry periods the unsaturated zone water store - particularly where the unsaturated zone is relatively thin – is likely to be exhausted more readily than areas where it is thicker. It might be argued that the differences in NDVI values between the depth to watertable categories is quite small and therefore not statistically significant (e.g. 0.63 compared to 0.605 for the upper and lower numbers of the 2006 curve in Figure 3-10). However it is known that the NDVI index suffers from a loss of sensitivity to changes in amount of vegetation at the high-cover/biomass end. This means that as the amount of green vegetation increases, the change in NDVI gets smaller and smaller (USDA-ARS, 2015). So at relatively high NDVI values, a small change in NDVI may actually represent a large change in vegetation. A further argument in support of the statistical significance of the results is the consistency of the trend across the depth to watertable categories.

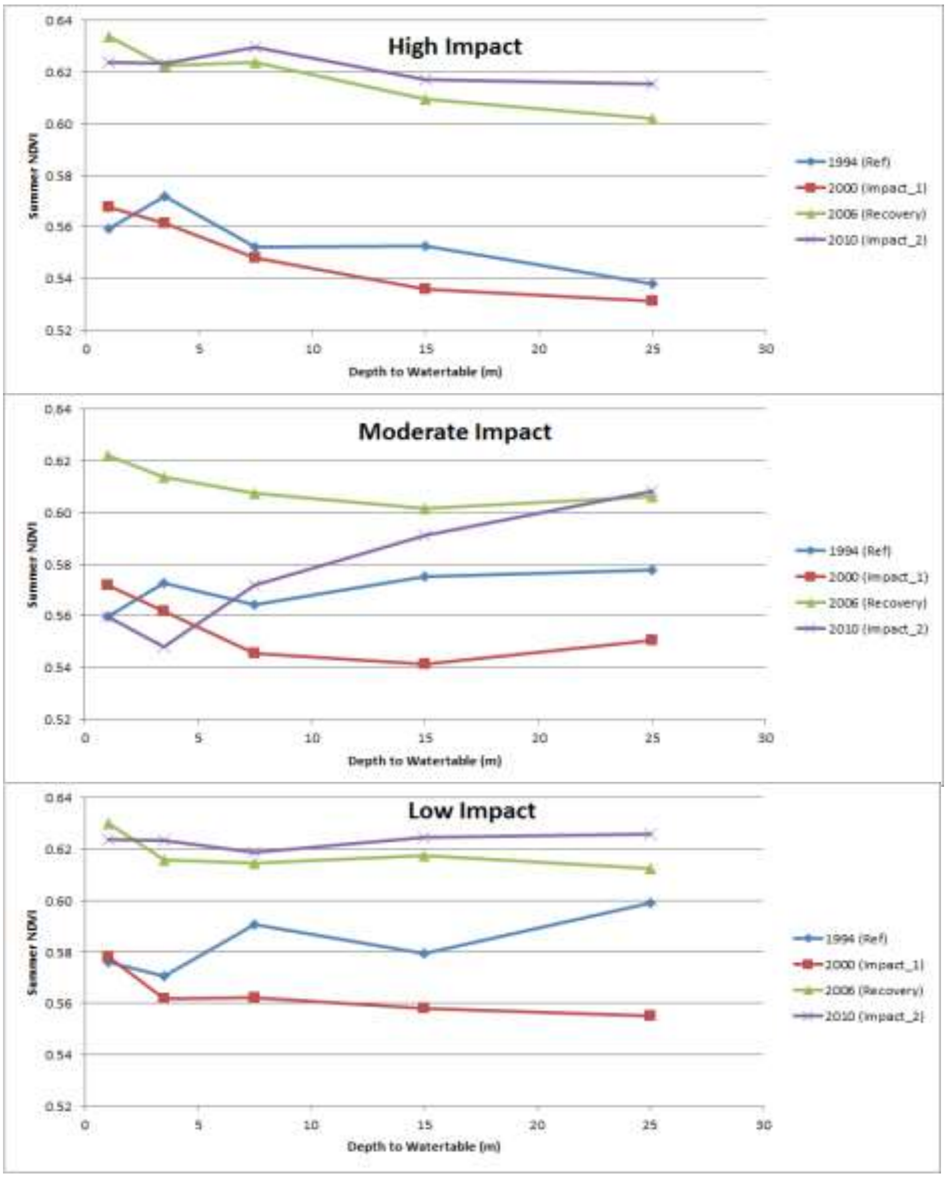
Figure 3-10 : NDVI (summer) response versus depth to watertable



The 2010 data does not show a clear trend, and possibly an opposite correlation with depth to watertable, i.e. increasing NDVI with increasing depth to watertable. The result is anomalous compared to the 1994, 2000 and 2006 results, which all have a feasible explanation for the data based on preceding rainfall. Given the dry conditions proceeding the 2010 analysis period, a similar downward trend with depth to watertable was expected. The anomalous NDVI results in 2010 are unlikely to be caused by declining groundwater levels which in turn causes a reduction the vegetation activity/density. The absolute NDVI values for shallow depth to watertable categories in 2010 are higher than in 1994 and 2000 when groundwater levels were higher. This suggests that the cause of the anomalous trend in the 2010 data is related to something other than groundwater level changes.

To investigate the cause of the anomalous 2010 results, additional spatial breakdown was conducted. The “High Impact”, “Moderate Impact” and “Low Impact” zones (as defined in Figure 3-3) were used for this purpose - Figure 3-11 presents NDVI versus depth to watertable for each of those three areas. For the “High Impact” area the results generally show a trend towards higher NDVI values for shallower depth to watertable (as per the 2000 and 2006 dates in Figure 3-10). For the “Moderate Impact” zone the trend is present for the 2000 and 2006 dates, almost neutral for the 1994 date and opposite for the 2010 date (i.e. NDVI increases with increasing depth to watertable). In the “Low Impact” category the trends are generally flat, although 1994 shows increasing NDVI with depth to watertable.

Figure 3-11 : NDVI (summer) response versus depth to watertable for three broad zones



Three conclusions can be drawn from this figure:

- The hypothesis raised above - that groundwater pumping has impacted shallow groundwater levels and in turn reduced vegetation activity / density in the 2010 image - is not supported by this further analysis, as the trend is not seen in the high impact zone but only in the moderate impact zone. If the hypothesis was correct the effect would be most significant in the "High Impact" area.

- There is a general trend that in dry periods (i.e. ignoring the 1994 data), that areas with shallower groundwater have a higher NDVI, suggesting that the vegetation in these areas may be accessing groundwater during these times. As described above, this is not conclusive as greater availability of water in drainage lines may be an alternate explanation.

- The trend of higher NDVI with shallower groundwater tends to weaken moving east to west (from high impact to low impact zone), a trend possibly explained by the rainfall gradient across the area. Rainfall is higher in the west than east, meaning greater water availability in the unsaturated zone in the west and hence less need to access groundwater.

To complete the assessment of the relationship between depth to watertable and NDVI, an assessment of the cause of the anomalously low result in the 2010 "Moderate Impact" area was undertaken. Figure 3-12 shows the 2006 and 2010 NDVI results for the moderate impact area. Visual comparison indicates that the NDVI is anomalously low in the south east corner in the 2010 image. However the area was still forested in 2010, which indicates a decrease in the greenness of the vegetation, i.e. rather than complete removal. This suggests that a fire has occurred in this area between the 2006 and 2010 images. A shortwave infrared false colour composite is shown on the right hand side of Figure 3-12. In this image the shortwave infrared is represented in red and near infrared represented in green. Therefore, any burned areas should look predominately red (i.e. predominately short wave infrared signal), which is indicative of a loss of photosynthesis and some dead vegetation. This is the case in the area of interest, and further suggests that a fire is the likely cause of the anomaly. Finally, the southern boundary of the anomaly follows Gold Hold Road, which adds weight to the theory that this is the remnant effect of a fire (either controlled or otherwise), and essentially rules out groundwater extraction being the cause of the low NDVI. DELWP planned burning history mapping confirms a planned burn was conducted in that area in November 2009 (DELWP Biodiversity Interactive Map – 3.2).

This issue highlighted the potential effect of fires on the outcomes of the NDVI assessment. To investigate this further, a "fire history" map was developed (using data from DELWP), and is presented in Appendix I. The map shows two categories of fires, planned burns and bushfire. There are four separate burns/bushfires of potential significance within the study area. Each is discussed below. For reference to the location of these areas, the below should be read in conjunction with the map in Appendix I. (The 2011 bushfire around Big Swamp has not been included in this discussion, as it is after the last NDVI assessment date (2010):

- 1998 bushfires north and south of Big Swamp – Examination of an NDVI difference map between the 2000 and 1994 summer data indicates some evidence of fires in these areas. However, the affected area is very small compared to the area mapped in Appendix I as bushfire affected. Most of that area in fact shows a marginally higher NDVI in 2000 compared to 1994. With respect to the actual fire affected area, it is noted that any negative affect due to the 1998 fire in this part of the study area actually adds a degree of conservatism to the assessment, as it reduces the average NDVI in the 'high impact' area.

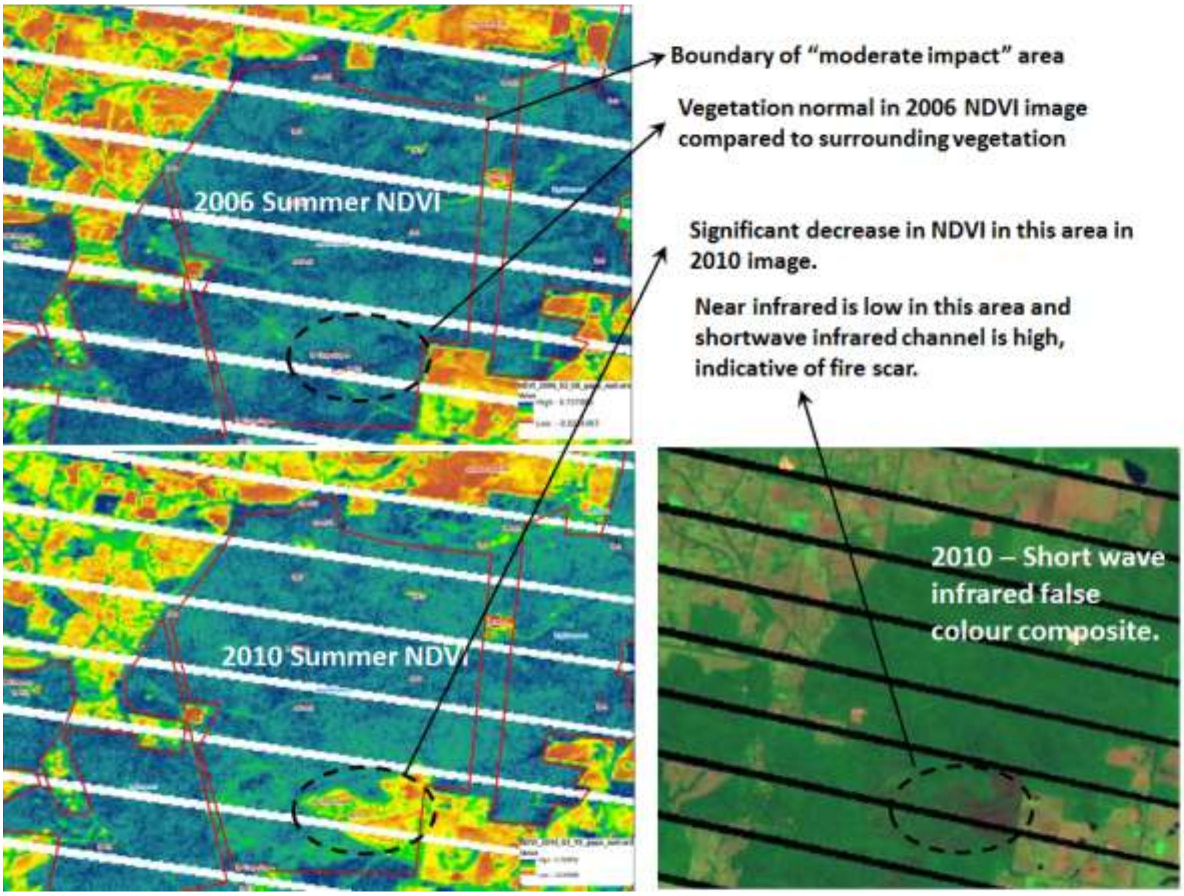
- 2003 planned burn between Westwood Rd and Westwood Track – this is a large area and hence potentially significant for the NDVI interpretation. However, there is no evidence in the NDVI data of the effect of this fire. An NDVI difference map between the 2006 and 2000 summer data shows no reduction in NDVI, as would be expected (and for example as observed in the 2010 NDVI for the area around Gold Hold Road). Either this planned burned did not proceed, or else the impact was so small as to not be noticeable in the NDVI data. Either way, it is considered to impact on the NDVI analysis.

- 2007 bushfire south of McDonalds Dam, and on the south side of Boundary Creek - There is evidence of a fire in the NDVI data. An NDVI difference map between the 2010 and 2006 summer data shows a reduction in NDVI in this area, although the affected area is much smaller than the "2007" polygon showing this area in Appendix I. Hence the impact on the overall NDVI will be small, and as described above, any negative affect due to this fire actually adds to the conservatism of the assessment, as it reduces the average NDVI in the 'high impact' area.

- 2009 and 2010 planned burn near Gold Hold Road in upper Dividing Creek catchment – the affect of these fires can be seen in the NDVI data. The area affected south of Gold Hold Road (2009 fire) is much smaller than the 2010 planned burn. This is the area discussed above, and when this area is excised from the moderate impact zone assessment, the results are consistent with the observed patterns.

In summary, the above assessment of planned burn and bushfire history in the area does not indicate any significant impact of such activities on the results, beyond the 2010 burn in the Gold Hold Road area. The effect of that burn has been allowed for in the interpretation of the results.

Figure 3-12 : Analysis of low NDVI in 'moderate impact' area in 2010 NDVI



Comparison of the location of the anomaly in the 2010 NDVI in the moderate impact area with the depth to watertable map (Figure 3-4) indicates that much of this area is located over relatively shallow groundwater, which also explains the reversal of the correlation observed in the NDVI and depth to groundwater seen in other areas.

3.3.3 Temporal assessment

Three approaches to examining NDVI trends across time are evaluated in this section:

1. Within the three broad zones of potential impacts (high, moderate, low/no impact)
2. Within different categories of depth to watertable
3. At some of the terrestrial vegetation monitoring sites

Each of these is discussed below.

NDVI across time for three broad zones of potential impacts (high, moderate, low/no impact)

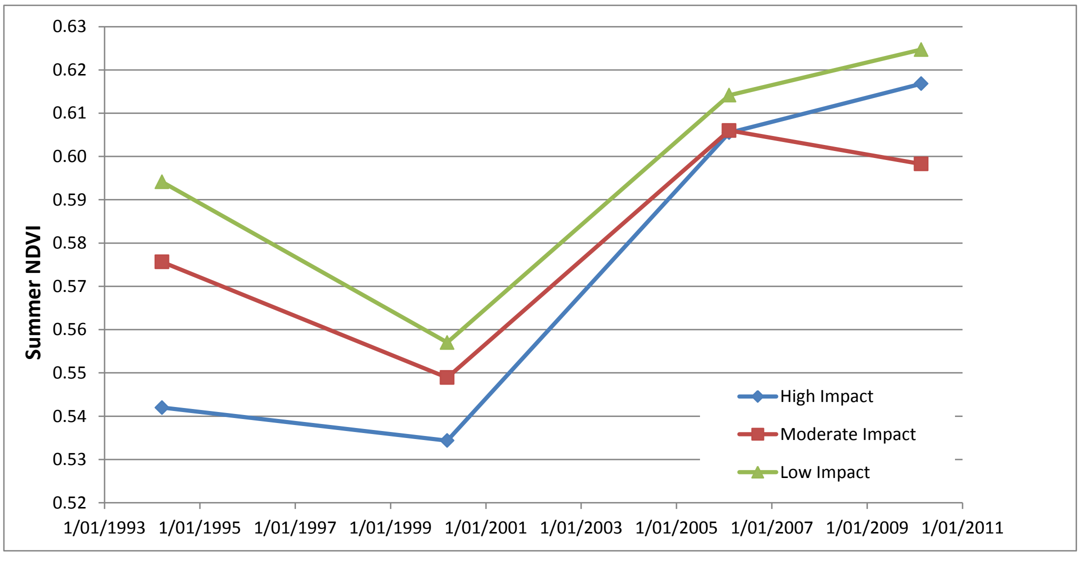
Figure 3-13 plots dry season NDVI for the three broad areas across the aquifer outcrop. As described earlier in this report, these zones are more accurately described as “potentially high impact” and “potentially moderate impact” as they simply refer to drawdown in the pumped aquifer, not to any impact on surface features such as vegetation:

1. “High impact” - where drawdown of approximately 10m or more has been estimated in the LTA aquifer
2. “Moderate impact” - where drawdown of between 2- 10m or more has been estimated in the LTA aquifer, and
3. “Low impact” - where less than 2m of drawdown has been estimated in the LTA aquifer.

The results imply that there has been no impact from the borefield on vegetation condition, as the 2006 and in particular the 2010 NDVI result is significantly higher than the baseline NDVI in 1994. This conclusion is based on the absolute NDVI data. A relative assessment indicates that the high impact area has increased relatively more in terms of NDVI than the low impact area over the assessment period. This is further evidence that groundwater extraction has not had a negative impact on vegetation condition/health.

The moderate impact category does however show a relative decline to 2010 compared to the baseline date (although is still higher in absolute terms than the baseline). This reason for the decline in this category was discussed in the previous section, and is considered due to the impact of a fire in the south east corner of the moderate impact area between 2006 and 2010, and is not related to groundwater extraction impacts.

Figure 3-13 : NDVI (summer) response across time for three broad ‘impact’ zones



2. NDVI across time within different categories of depth to watertable

Figure 3-14 plots NDVI across time within different categories of depth to watertable. For the purposes of the assessment, assuming that the depth to watertable categories of < 2m, 2-5m and 5-10m represent areas of potential groundwater use by vegetation, then a decline in NDVI in these categories may be indicative of a decline in vegetation condition. In absolute terms, NDVI numbers are higher in all categories in 2010 than 1994, implying no negative impact. However the relative shift between categories is also potentially informative. For the 2010 date, the shallower depth to watertable categories (in particular the 2-5m category) declines relatively more than the two deeper watertable categories. This could potentially be due to a lower watertable in these categories (due to either climate and/or groundwater pumping during the 2006-2009 dry period) leading to reduced water availability and associated decline in vegetation condition (relative to the vegetation overlying a deep watertable).

To investigate this further, the same plot was produced for the two key depth to watertable categories of interest (2-5m and 5-10m) but spatially aggregated into the low, moderate and high impact zones (refer Figure 3-15). The plot shows that in the low and high impact zones the relative trend between 2006 and 2010 is the same as for the deeper categories of depth to watertable. The figure shows that the anomaly is entirely derived from the moderate impact zone, and as discussed in the previous section is most likely caused by fire and very unlikely to be groundwater related.

Figure 3-14 : NDVI (summer) response over time for various categories of depth to watertable

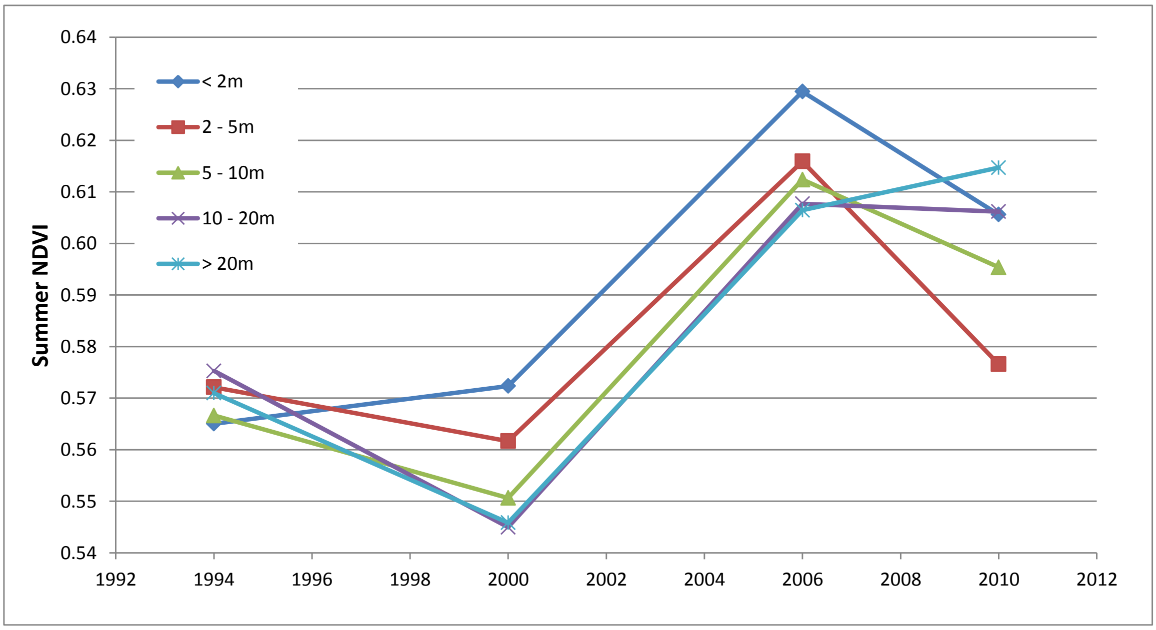
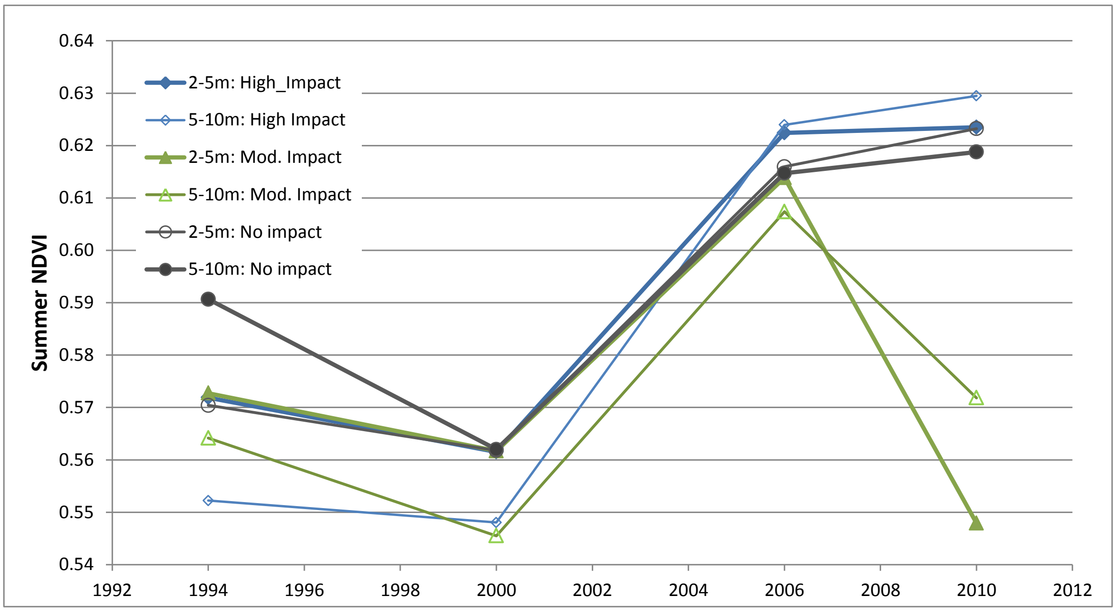


Figure 3-15 : NDVI (summer) response over time for various categories of depth to watertable within the three broad 'impact' zones



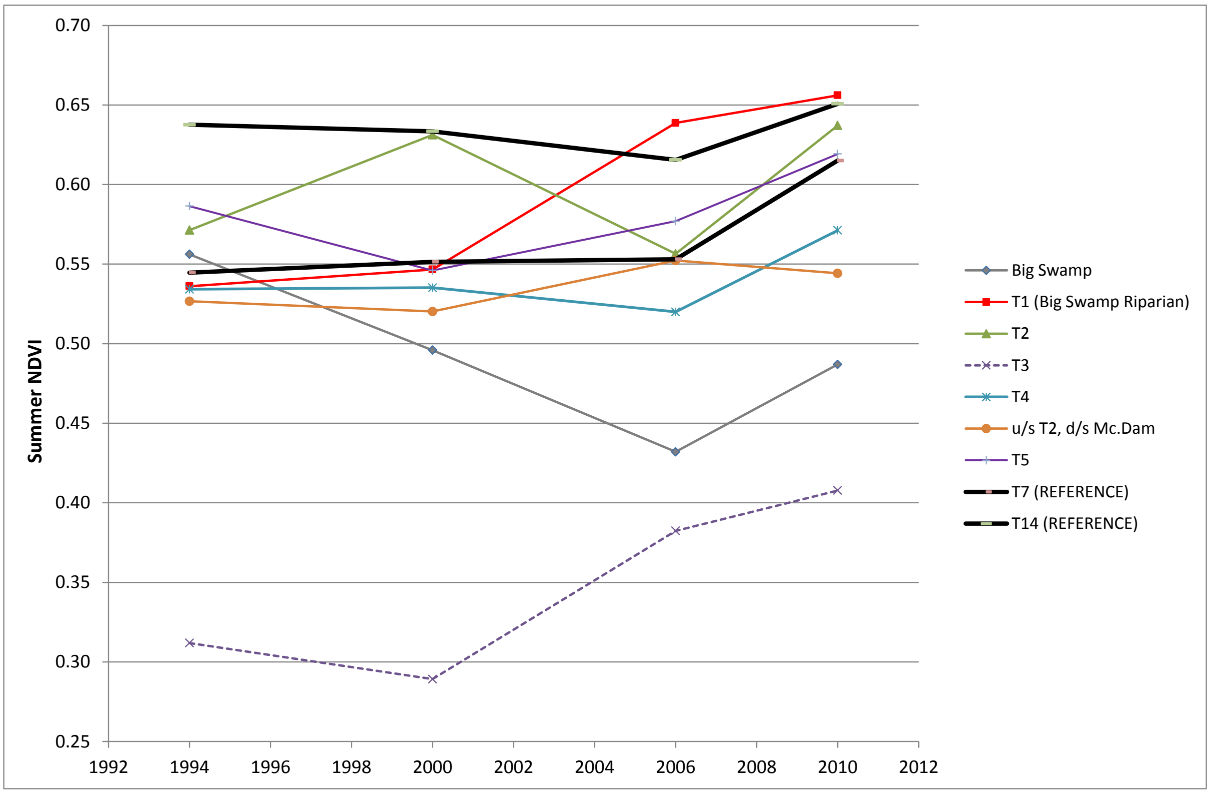
3. NDVI across time at selected terrestrial vegetation monitoring sites

Figure 3-16 plots summer NDVI values across time at the vegetation monitoring sites within the LTA outcrop. This assessment focusses on the aquifer outcrop area, because any significant decline in the aquitard (at the vegetation monitoring sites) related to the borefield operation is considered unlikely. Two additional locations - within Big Swamp and at a location upstream of the swamp but downstream of McDonalds Dam - are also included in the plot. The reference sites (T7 and T14) are shown for context and to assist in interpretation of the results.

The Big Swamp site shows a decline over the 1994 to 2006 period due to the effects of fire and acidification at the swamp, but with some recovery between 2006 and 2010. The T3 site is an outlier relating to the type of vegetation cover at this site which is dominantly a wetland type environment dominated by sedges and grasses, and hence has a significantly lower NDVI than the terrestrial vegetation sites. However the general trend at T3 is similar to the reference sites.

The trends at the remaining sites are very similar to the reference sites (T7 and T14), with NDVI values generally stable between 1994 and 2000, then either stable or slightly rising to 2006, and with all sites (except one) showing a rise in NDVI between 2006 and 2010. The exception is the site upstream of the swamp and downstream of McDonalds Dam, which shows a slight decline from 2006 to 2010, albeit still above the 1994 background value. The reason for this behaviour at this site has been explained in previous sections, and is related to the particular geometry of the site rather than change in vegetation condition. The consistent trend observed between the impact sites and the reference sites indicates that there has been no discernible impact on vegetation health at the monitoring sites over this timeframe and hence that the borefield does not appear to have negatively affected vegetation condition.

Figure 3-16 : Summer NDVI values at terrestrial vegetation monitoring sites



3.4 Conclusions

The following conclusions are drawn from the NDVI assessment:

- The seasonality assessment shows that native vegetation NDVI results are indicative of healthy and dense vegetation. In general summer NDVI values are comparable to, or higher than winter NDVI values, indicating the vegetation is not water stressed during dry periods. The consistent seasonality of the results indicates access to a reliable supply of water. The clustering of the impact and reference sites in Figure 3-9 suggests that the vegetation has not been affected by the groundwater extraction.

- The 2000 and 2006 summer images show a consistent trend of higher NDVI values for shallower depth to watertable. Excluding an anomalous area in the moderate impact zone (due to effect of fire) the 2010 results also exhibit the same relationship. In contrast the 1994 NDVI results show no trend with depth to watertable; this is attributed to the preceding years of above average rainfall, allowing areas where the watertable is deep to have similar levels of activity as the areas of shallow groundwater. The combination of these observations suggests that during extended dry periods vegetation in areas of shallower groundwater have access to a more reliable source of water, thus allowing greater vegetation density and photosynthetic activity. Two main possibilities are considered likely for the cause of the greater water availability in areas of shallow groundwater:

  - Areas of shallow watertable are usually located along drainage lines and therefore receive more surface water run off, which then infiltrates and is a more consistent source of water to fill the unsaturated zone.

  - The vegetation is accessing groundwater since it is readily accessible at shallow depths.

- The correlation of higher NDVI with shallower groundwater weakens moving east to west. This is possibly explained by the rainfall gradient across the area - higher rainfall in the west could provide greater water availability in the unsaturated zone and hence the capacity to match the activity of vegetation with access to shallow groundwater.

- Three lines of analysis of the NDVI data over time indicate that groundwater extraction has not had a negative impact on vegetation activity / condition:
  - The 2006 and 2010 NDVI results are on average higher than the 1994 NDVI baseline.
  - The NDVI data show no decrease within areas of groundwater drawdown – areas closer to the borefield have similar NDVI patterns as areas further away from the borefield, implying that there has been no impact from the borefield on vegetation condition. The high impact area (closer to the borefield) actually increases in NDVI by more than the low impact area (further from the borefield) over the 1994 to 2010 period.
  - Trends in NDVI at the vegetation monitoring sites T1 to T5 (within areas where groundwater drawdown has occurred) are very similar to the reference sites (T7 and T14), with NDVI values generally stable between 1994 and 2000, then either stable or slightly rising to 2006, and rising again between 2006 and 2010.

This assessment found no evidence of deterioration in vegetation condition over the assessed period, and therefore that groundwater extraction has not impacted the health or condition of terrestrial vegetation. Given that parts of this assessment suggest terrestrial vegetation may be using groundwater then the question as to why there has not been any impact on the NDVI results in areas where groundwater in the LTA is known to have declined needs to be considered. Three suggestions are proposed:

1. The evidence of groundwater use is not conclusive. The consistent seasonality between summer and winter NDVI could be due to the use of unsaturated zone water, which is readily available due to the high rainfall in the area. The correlation of shallow groundwater and NDVI could be explained by more readily available unsaturated zone water in drainage lines. However in areas of very shallow groundwater (e.g. less than 2m) it is unlikely that sufficient unsaturated zone water could be stored for use during prolonged dry periods, and hence some groundwater use is considered likely.

2. Vegetation has adapted to lower groundwater levels, with roots 'chasing' a falling watertable. This is possible (and has been documented elsewhere), however at a number of sites this is not the main explanation, as new groundwater bores indicate that the groundwater is currently still shallow (e.g. at T1, T2 and T4). Therefore in locations such as this, the following explanation is more likely.

3. Widespread areas of shallow upper layers of the LTA are being buffered from the groundwater level changes in the lower LTA, including on the LTA outcrop areas. The hydraulic separation between the shallower and deeper units within the LTA is evident in the shallow units that display seasonal influences compared to deeper units which respond to pumping from Barwon Downs borefield.

   At T1, T2 and T4 the watertable in 2014 was only 2-5m, 1-2m and 1-3m below ground level respectively, despite the fact that the LTA groundwater level was around 15-20m, 15m and 10m lower than pre-pumping levels at each of the sites respectively (based on drawdown mapping for 2012). This can only be the case if either the watertables at these sites are perched and hydraulically isolated from the underlying LTA or that the 'unconfined' LTA outcrop is actually acting as confined/semi-confined system. (i.e. clay layers within the LTA are buffering shallower units within the LTA such that they only experience a subdued decline compared to the deeper LTA pressure decline).

In summary, the NDVI analysis suggests that there is some groundwater use by vegetation during prolonged periods of below average rainfall, where the groundwater is shallow (e.g. less than 5m). There is no evidence that there has been a decline in vegetation activity / condition (as measured by NDVI), when comparing vegetation closer to the borefield versus further away, or when assessing changes in vegetation over time. While groundwater pressures in the LTA have declined in the outcrop area closest to the borefield, it is apparent that shallow groundwater has been buffered from the regional pressure decline and/or that vegetation has adapted to the decline in groundwater level.

4. Field assessment

4.1 Introduction

The objective of the field study is to use field based measurement of tree water use, soil moisture and groundwater levels and chemistry to determine if terrestrial vegetation uses groundwater.

4.2 Method

4.2.1 Approaches adopted

A number of tests can be used to evaluate the dependence of vegetation on groundwater (Eamus, 2009). Several of these tests have been chosen to provide a robust assessment in which multiple lines of evidence can be examined. The following tests were applied in this investigation to evaluate the groundwater dependence of vegetation.

- Stable isotopes of water: Stable isotopes are those that do not radioactively decay over time. In water these isotopes are deuterium (^{2}H) and oxygen - 18 (^{18}O). These isotopes contain either one or two extra protons respectively than the more common forms of these elements (hydrogen (^{1}H) and oxygen (^{16-}O)). The ratio of ^{2}H to ^{1}H and the ratio of ^{18}O to ^{16}O will vary for different bodies of water due to isotopic fractionation caused by transport processes and phase transitions through the atmosphere, lithosphere and biosphere (Barnes and Alison, 1988). Since the fractionation processes are likely to be different for groundwater, surface water and soil water, different sources of plant water will often, but not always, have a different composition of stable water isotopes that will be reflected in the $\delta^{2}H$ and $\delta^{18}O$ composition of plant xylem water (where δ is the measured ratio of the stable isotope relative to a known standard). Knowing the isotopic composition of these sources and within the plant can assist in conceptualising plant water uptake. These isotopes are collected by taking groundwater samples, soil samples from various depths and twig samples (from which the plant water is extracted) from trees close to the soil bore.

- Soil-plant water relations: Plants require water for photosynthesis and metabolic processes. Transpiration is the process in which plants take up water through their roots, passively transport it through the xylem, and regulate the diffusive evaporation of this water through the stomata in the branches and leaves. The rate of transpiration is controlled by solar radiation, the evaporative demand of the atmosphere (which is influenced by temperature, humidity, wind speed and incident sunlight), soil water supply, and by stomatal regulation. To enable plants to transpire, the Leaf Water Potential (LWP) must be maintained at a level which is more negative than the SWP (Soil Water Potential). When a soil is dry it has a highly negative SWP and the plant must then regulate the stomatal conductance in order to lower the LWP to a level which is more negative than SWP in order to continue to extract water. By contrast, a moist soil (maintained in a moist state by shallow groundwater or high rainfall) will not require plants to lower their LWP in order to extract water. Measurements of LWP are usually made pre-dawn when the difference between LWP and SWP is likely to be smallest because nocturnal transpiration is minimal (Ritchie and Hinckley, 1975). Thus, measuring pre-dawn LWP and SWP concurrently provides an indication of where in the soil profile plants are drawing their water from. It also provides an indication as to whether or not plants have access to groundwater.

  The total SWP is comprised of three components as shown in the following equation:

  $$SWP = \psi_z + \psi_m + \psi_o$$

  Where:

  ψ_z is the gravitational potential equal to the elevation above an arbitrary reference level (i.e. the elevation of the sample from the ground surface),

  ψ_m is the matric potential which is a measure of the capillary pressures acting on a water molecule and becomes increasingly negative as the soil dries out, and

ψ_o is the osmotic potential reflected by the presence of solutes in the soil and provides an indication of the pressure required to move soil water across the semi-permeable membrane of the root wall. ψ_o is negligible in the case of low soil salinity, however it becomes increasingly negative as the soil salinity increases.

All these components must be considered when comparing LWP and SWP. LWP and SWP are measured in the field using techniques and equipment described in the following sections.

- Soil profile analysis: an evaluation of the soil profile in terms of its physical and chemical properties that influence plant water availability is included to enhance and provide context to the assessment. Such characteristics include: soil texture, grain size analysis, water retention properties, salinity and pH.

In addition to the above considerations, it is ideal if the data collection occurs at a time when the target vegetation is most likely to be accessing groundwater. This is generally considered to be during or at the end of the dry season when lower rainfall combined with higher evaporation rates result in low soil moisture levels compared to other times during the year. These conditions combined with higher daily temperatures increase the level of moisture stress on the plant. As a result the plant may have to find alternate water sources (e.g. groundwater) to survive the dry season. For these reasons late summer was considered to be the best time to carry out the field component of the program.

4.2.2 Scope of field program

Fourteen sites have been selected for vegetation monitoring across the Barwon Downs region and these are named T1 – T14. Thirteen of these sites were selected for this field program. T3 was excluded on the basis of a large depth to watertable and the conclusion that it was therefore very unlikely to contain groundwater dependent vegetation. The scope of works undertaken by Jacobs at the 13 sites between 23rd of February and the 4th March 2015 included the following:

- Soil sampling;
  - Interpretation of soil core collected during drilling
  - Field analysis of Soil Water Potentials (SWP) at set intervals through the soil profile.
  - Sampling of soil at set intervals for laboratory analysis of physical and chemical properties and stable isotopes of water (deuterium (δ^2H) and oxygen – 18 ($\delta^{18}O$) from the core during drilling.
- Vegetation sampling;
  - Field analysis of both pre-dawn and mid-day Leaf Water Potentials (LWP) from three individual trees at each site.
  - Collecting twig samples from the same trees at the same time as the LWP analysis for laboratory analysis of stable isotopes of water (deuterium (δ^2H) and oxygen – 18 ($\delta^{18}O$).
- Groundwater Sampling
  - Collection of groundwater samples for laboratory analysis of stable isotopes of water (deuterium (δ^2H) and oxygen – 18 ($\delta^{18}O$).
  - Measurement of field parameters such as Electrical Conductivity (EC) and Standing Water level (SWL).

Further details of the sampling process are described below.

Soil sampling and analysis

All necessary clearances and permits were obtained by Barwon Water to undertake the drilling required for the soil sampling. This included sampling permits for working in the Great Otway National Park (around half of the sites were located in the National Park). The soil sampling was undertaken using hollow stem augers between Monday 23rd February and Tuesday 3rd of March 2015. This method was chosen as it enables the soil samples to be collected relatively undisturbed without the use of drilling fluids. For analysis of stable isotope composition and soil moisture it is paramount that no water is used during the drilling process as this would significantly alter the results obtained.

Push tube samples were taken at 40 cm intervals for the first four metres and then at one metre intervals until completion depth which was either when impenetrable material (e.g. hard rock) was encountered or when the sample became saturated. The soil samples for stable isotope analysis were packed tightly into glass jars with Teflon sealed lids with minimum head space. These samples were then stored in insulated coolers and freighted to the University of Western Australia (UWA) for soil water extraction and stable isotope analysis. A second set of samples were taken as intervals corresponding to significant changes in soil profile observed during drilling were sent to ALS and EP analysis to be analysed for soil chemistry and physical properties.

A third set of soil samples were collected in glass vials with Teflon lids to determine SWP using the WP4C Dewpoint Potentiometer (manufactured by Decagon Devices, REF). The measurements provided by the WP4C are the sum of the matric (ψ_m) and osmotic potentials (ψ_o). Following sampling each soil bore was rehabilitated by backfilling and restoring area to the same condition as it was prior to the sample being taken.

Vegetation sampling and analysis

Three trees comprised of the forest overstory were selected at each site for stable isotope sampling and moisture potential analysis. Where possible larger overstory trees were selected as they are considered to have larger root runs and therefore to be more likely have the ability to access groundwater. The tree species targeted for this study were the following:

- Manna Gum *(Eucalyptus viminalis).*
- Messmate Stringybark *(Eucalyptus obliqua),*
- Peppermint Gum *(Eucalyptus radiata),*
- Swamp Gum *(Eucalyptus ovata)*,

Twig samples were taken from each of the trees and sealed within cling wrap, foil and zip lock bags to prevent moisture loss. The samples were stored in insulated coolers which were freighted to UWA for the extraction of xylem water for stable isotope analysis. Pre-dawn and mid-day LWP measurements were taken from leaves from the same trees using a 1505D pressure chamber instrument manufactured by the Plant Moisture Stress (PMS) Company. The height that the leaves were extracted for the moisture potential sample was measured directly using a tape where possible, and where the sample was too high, height was estimated using the sampling apparatus. The plant water potentials were corrected for height thus removing the gravitational potential (ψ_z) portion of the measurement. Three replicates were taken from each tree at each site and the values averaged for greater accuracy. The LWP sampling data is included in Appendix H.

Groundwater sampling and analysis

Groundwater samples were taken from the existing monitoring bores at each of the sites using a disposable bailer. Field parameters such as EC and temperature were recorded. The samples were then sealed in amber glass bottles with Teflon sealed lids leaving no head space and shipped off in insulated coolers to UWA for stable isotope analysis.

An error during the transportation of the samples meant that the samples were stored in an un-refrigerated warehouse in Perth for around 1.5 days (against instructions). During this time there was the potential for evaporation of samples to occur. Due to the different methods of storing the samples, there was essentially no potential for evaporation of the groundwater samples, minor potential for evaporation of the soil samples and the relatively highest potential for evaporation of the twig samples. The effect of this on the results is discussed in the results of this section.

4.2.3 Sampling locations

The sampling locations were selected as the same locations as the vegetation monitoring sites identified in SKM (2013) and reported in SKM (2015). The vegetation monitoring sites were selected at locations where vegetation is most likely to be using groundwater, which is where the watertable is shallow.

A field reconnaissance of the 13 sites was carried out in late December 2014 to ensure the locations were accessible and contained vegetation amenable for sampling. The location of the sites is shown in Figure 1-6.

The sites were all located along or close to known watercourse / drainage lines within sclerophyll forest near an existing groundwater monitoring bore and vegetation transect. To minimise vegetation disturbance, the sites were located adjacent to roads or tracks. Where possible, care was taken to place the soil sampling bores up gradient of these features. This was to reduce the likelihood of altered hydrology which may occur from track construction and use, such as preferential flow from wheel ruts and compaction. These factors may unduly affect soil moisture content and/or the isotopic signature. The location and details of each site are presented in Table 4-1 and photographs of the sites are shown in Appendix G.

The sampling locations (soil bore and trees) in this study were generally located as close to the drainage line as possible. However, there were some exceptions where the sampling location was deliberately moved some distance upslope of the drainage line. This was undertaken at selected sites because it was known that the groundwater was very shallow at the drainage line, and hence there was a very strong likelihood that the field assessment would show groundwater use by the trees in the drainage line. For some sites a more informative location for investigation was therefore considered to be upslope of the drainage line to assess how far away from the drainage line the trees were using groundwater. Locations where the sampling location was deliberately upslope of the drainage line included:

- T4 – The soil bore was located approximately 4m above the drainage line. Depth to watertable at the drainage line is around 2-3m, and hence groundwater use by trees in the drainage line is considered likely. Depth to watertable at the location 4m above the drainage line is estimated to be 4m below ground level.

- T11 – The soil bore was located approximately 6-7m above the drainage line. Depth to watertable at the drainage line is around 1m, and hence groundwater use by trees in the drainage line is considered very likely. Depth to watertable at the location 6-7m above the drainage line is estimated to be 5-6m below ground level.

- T14 - The soil bore was located approximately 5m above the drainage line. Depth to watertable at the drainage line is around 1m, and hence groundwater use by trees in the drainage line is considered very likely. Depth to watertable at the location 5m above the drainage line is estimated to be 4m below ground level.

At other locations, it was not possible to locate the site at the drainage line due to access constraints, including at T1, where the bores was located around 4m above the drainage line, and notably at T5 where the bore was located 7 to 8m above the drainage line.

The location of the soil bore and sampled trees relative to the drainage line and watertable are key factors when considering the results from, and conclusions about, the field results.

Sites were divided into ‘impact’ or ‘reference’ sites. Impact sites were areas likely to have been impacted by declining groundwater levels (at least for the deeper part of the LTA aquifer), from the Barwon Downs borefield. Reference sites were selected where watertable drawdown from the borefield was considered very unlikely. Finally, impact and reference sites were selected to contain approximately half of the sites within areas of LTA (aquifer) outcrop and half within aquitard outcrop.

Table 4-1 Sampling site details

Soil Bore	Sampling Date	Soil Bore Easting (m)	Soil Bore Northing (m)	Elevation (mAHD)[1]	Soil bore depth (m)	Associated groundwater monitoring bore	Target tree species
SB1	26/2/2015	735316	5743753	152.98	2.8[2]	TB1	*E. radiata, E. ovata,& E. obliqua*
SB2	3/3/2015	734639	5743993	153.21	2.8[2]	TB2	*E. radiata*
SB4	26/4/2015	732955	5744156	181.72	6	TB4B & TB4C	*E. radiata*
SB5	2/3/2015	731011	5743996	219.47	3.2[2]	TB5	*E. radiata*
SB6	23/2/2015	729425	5743269	228.90	3.6[2]	TB6	*E. radiata*
SB7	24/2/2015	727544	5742302	223.06	2.8	TB7	*E. radiata*
SB8	25/2/2015	734226	5741587	152.71	6	TB8	*E. obliqua & E. radiata*
SB9	27/2/2015	731968	5735446	155.73	4	TB9	*E. obliqua & E. viminalis*
SB10	24/2/2015	728385	5739951	215.46	5	TB10	*E. radiata & E. ovata*
SB11	2/3/2015	730561	5736699	140.54	5	TB11	*E. radiata*
SB12	27/2/2015	731130	5740159	172.83	2	TB12	*E. ovata*
SB13	25/2/2015	729600	5738929	189.02	5	TB13	*E. radiata*
SB14	28/2/2015	726683	5740005	147.78	6	TB14	*E. obliqua*

Notes:

1. Elevation at surface of soil bore

2. Hole terminated at this depth due to refusal on impenetrable material.

The following provides a brief description for each site:

- SB1 – Located near the middle of Big Swamp, on the southern side about 700m west of T1 monitoring bore. It was not possible to locate this site adjacent to TB1 due to a large number of fallen trees in the vicinity preventing drill rig access.
- SB2 – Located several hundred metres upstream of Big Swamp near to the vegetation transect. The location of the soil bore is not adjacent the TB2 bore as this is located on a tributary of Boundary Creek and not Boundary Creek proper.
- SB3 – No soil sampling was undertaken at this site due to the very deep watertable indicating that it is unlikely the vegetation at this site is accessing groundwater.
- SB4 – Located on a tributary of Boundary Creek with an elevation approximately four metres above the drainage line. There are three groundwater wells at this site screened at different depths. The middle depth bore was dry at the time of sampling.
- SB5 – Located on a tributary of Boundary Creek adjacent to the Gun Club. This site is located approximately five metres above the drainage line on the eastern side of the road.
- SB6 – Located on a tributary of Boundary Creek off Langdons Rd. The soil bore was not located near the observation bore (TB6) but in a location closer to the tributary on the northern side of the drainage line.
- SB7 – Located on an upper tributary of Ten Mile Creek approximately ten metres from the observation bore TB7.
- SB8 – Located on a tributary of Dividing Creek on Westwood Track approximately 50 m uphill from the TB8 monitoring bore. The only suitable site for this soil bore was on the down gradient side of the track.
- SB9 – Located on a tributary of Porcupine Creek on Pipeline Road approximately 100 m north of the TB9 bore on the eastern side of the road.
- SB10 – Located on an upper tributary of Upper Dividing Creek approximately 1 m from the TB10 monitoring bore. The initial site selected for the soil sampling was intended to be further up the hill however due to the potential for interaction with services in the area it was moved.
- SB11 – Located on Porcupine Creek on the Colac-Olangolah Pipeline Track. This site was originally proposed to be located to the north of the observation bore TB11 however due to the high possibility of intercepting services associated with the pipeline the site was moved to another location 200m south with a vertical elevation approximately 5-6 m above the observation bore and drainage line.
- SB12 – Located on a tributary of Dividing Creek on Gold Hole Road on the opposite side of the road from the observation bore TB12 approximately 3m above the drainage line.
- SB13 – Located on Dividing Creek on Parkes Lodge Road approximately 200 m from the observation bore just outside the swamp area.
- SB14 – This site is targeting a tributary very close to Ten Mile creek. The soil bore location is approximately 200 m uphill from the monitoring bore with an approximate elevation 5 m above the bore and drainage line.

4.2.4 Climate data

The sampling program was undertaken between the 28th February and 4th March 2015.

Figure 4-1 shows rainfall conditions for the 14 months prior to the sampling event. The graph shows that at the time of sampling there was a deficit in cumulative rainfall of approximately 170 mm from the preceding winter. As mentioned in Section 3.1 it is ideal if the sampling is undertaken following a dry spell at the end of the dry season in order to have the greatest chance of sampling vegetation whilst it is using groundwater. The 170 mm deficit indicates near ideal conditions leading up to the sampling event.

Figure 4-2 shows temperature and rainfall data for the Mount Gellibrand weather station over the duration of the sampling program. Although Mount Gellibrand is not in the direct vicinity of the sampling sites it is the only weather station recording temperature and rainfall data during the sampling program. With the exception of the 28th February, daily maximum temperatures ranged between 20°C and 25°C during the sampling program. Daily minimum temperatures ranged between approximately around 8°C to 15°C. On the 28th February the daily maximum rose to 31°C followed by a rain event that night. There were two rainfall events over 5 mm during the sampling program. However observations by field staff indicate that these events were patchy as they were the results of thunderstorm activity; this may have resulted in some of the sample sites receiving rainfall whilst others did not.

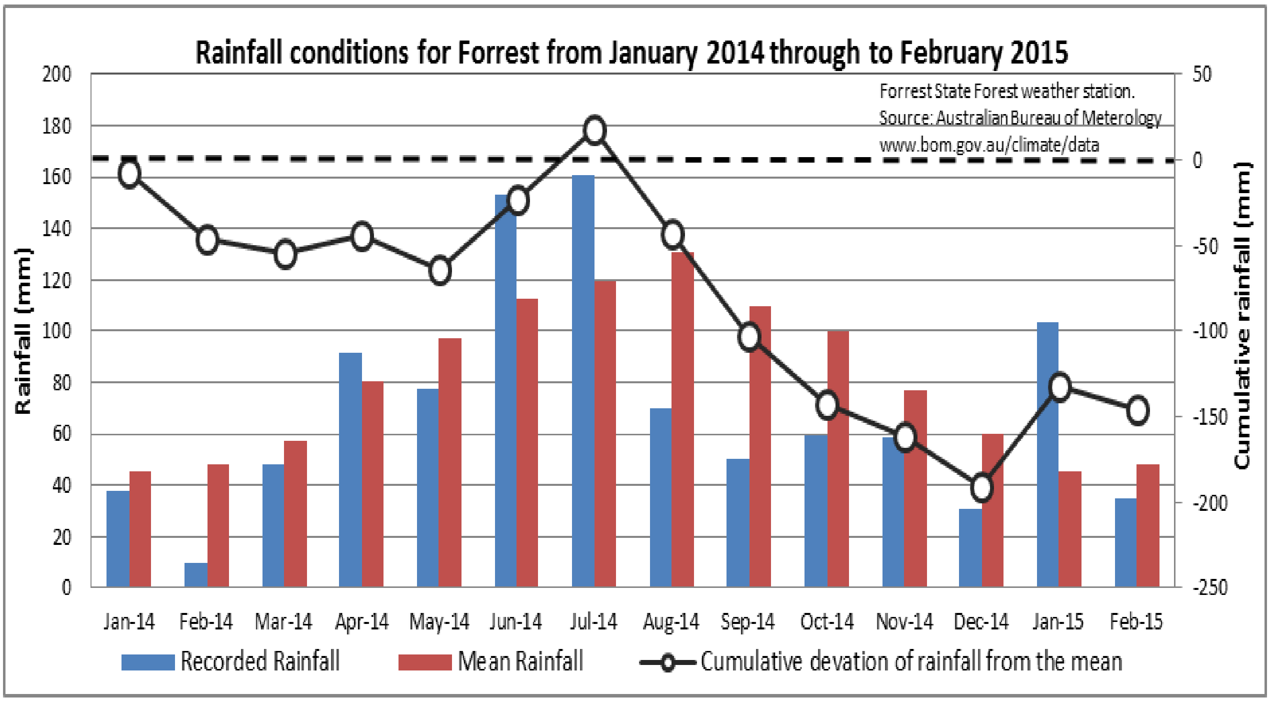


Figure 4-1 Recorded, mean and cumulative deviation rainfall for Forrest State Forest weather station

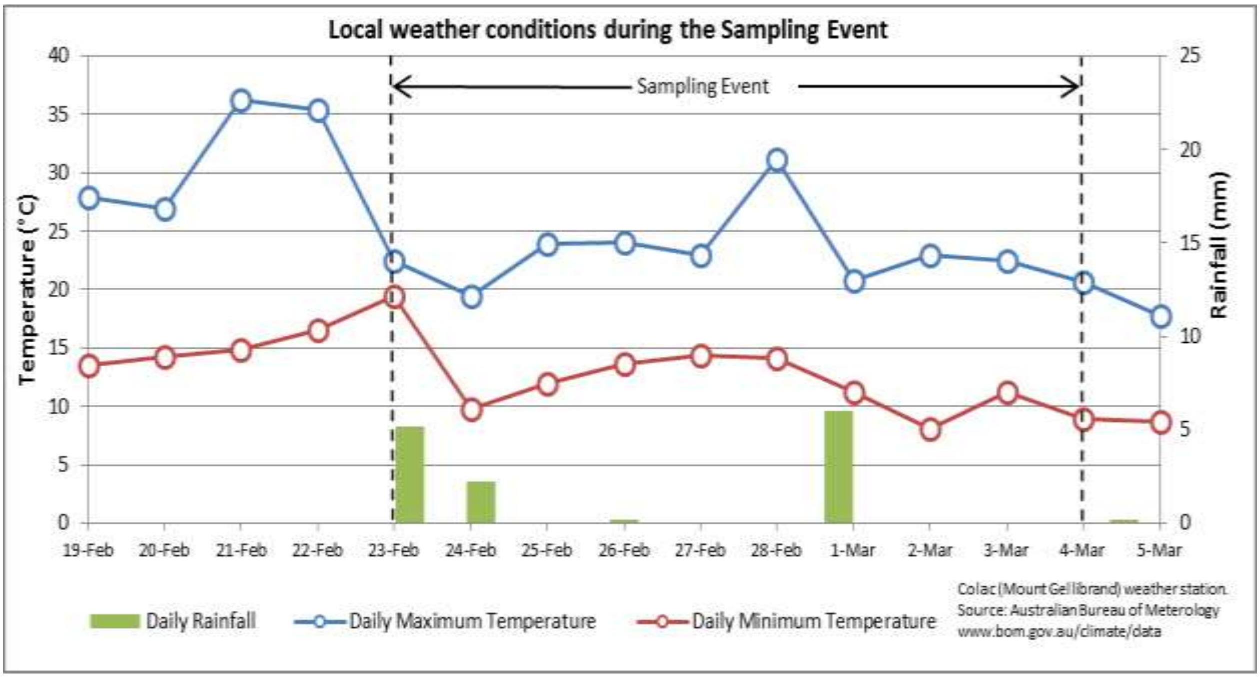


Figure 4-2 Recorded rainfall and temperature during the sampling event (2015)

4.3 Results

4.3.1 Soil physical properties

Soil particle size analysis was carried out to determine the texture (% sand, % silt and % clay) of the soil sampled. This analysis was undertaken using the Pipette method (Makenzie et.al, 2002) at the EP Analysis Laboratory in South Australia. The results of the analysis are presented in the soil bore logs (refer Appendix D) and the clay percent versus depth is shown in Figure 4-3.

The percentage of clay within the soil profile has a strong effect on hydraulic properties of the soil, including the water retention, drainage and permeability. Soils with high clay content generally have a greater ability to retain soil moisture than soils with low clay contents. However due to the small pore sizes, recharge is restricted due to the lower permeability and more energy is required by the plant to access this water.

With respect to soil texture with depth, the sites sampled can be categorised into four groups:

- Type 1: Low clay content - SB2, SB6 and SB14. SB2 and SB6 of these sites have soils with low clay and high sand contents throughout soil profile. These soils would likely dry out rapidly only holding significant water following rainfall events or if they are near or within the saturated zone. Although SB14 has a band of soil with higher clay content at a depth of around 1 m, the rest of the soil profile displays a low clay content. Compared to the other three soil types, this soil profile may be less likely to support tree water use from the unsaturated zone.

- Type 2: Decreasing clay content with depth – SB1, SB4 and SB9. These two sites have higher clay contents in the upper soil profile compare to at depth. Although the clay at the surface may have higher water holding capacity it has a lower infiltration rate which may inhibit infiltration to the lower layers by causing soil water loss through runoff and evaporation before recharge can occur.
- Type 3: Increasing clay content with depth – SB5, SB7, SB8 and SB12. Sites of this type have soil profiles showing low clay percentages in the surface soil and higher clay percentages at depth. The lower clay content in the shallower soil would facilitate recharge into the deeper sections of the profile with higher clay percentages. These two factors coupled together would tend to create a soil profile with both a good recharge rate and good storage capacity deeper down i.e. with good potential for unsaturated zone storage. Compared to other categories, this soil profile is more likely to support tree water use from the unsaturated zone.

- Type 4: High clay content – SB10 and SB11. These sites have soil with high clay contents throughout the profile. The water holding capacity of this soil would be high but the infiltration rate would be low. These soils are likely to hold moisture for long periods of time between rainfall events, however due to the small pore spaces, the plant would use more energy to extract the water from the soil.

Figure 4-3 shows the percentage of clay with depth for the four groups.

4.3.2 Soil chemistry and field observations

All soils sampled from the 13 sites have low salinity values ranging from 2 to 650 µS/cm electrical conductivity EC). Plants prefer salinity levels to be less than 1,000 µS/cm EC. In general the soils sampled are leached, with salinity increasing slightly throughout the profile. This is attributed to the high rainfall (~1000 mm/yr) received in this area which pushes the salts down the soil profile.

With the exception of one sample, all of the soils sampled (excluding one) were acidic, with pH values ranging from around 3.5 to 6 pH units. The only anomaly was one sample from SB13 at four metres depth where the pH is alkaline (8.3). This site is accompanied with significantly elevated exchangeable calcium (13.3 Meq/100g) when compared to the other samples. This also coincided with the presence of roots at the same depth in the soil core.

During drilling at SB12 iron staining was noticed surrounding the roots within the soil profile at a depth of approximately one metre, which could be the result of acidic soils. Soil acidification occurs in areas of higher rainfall (over 500 mm/year) and in the Otway Ranges pH levels less than 5 are considered normal (Slattery and Hollier, 2002).

At two of the sites (SB9 and SB12) plant roots were observed within the perceived saturated zone of the soil profile showing that it is likely that vegetation accesses groundwater at these sites during dry periods. These were detected at depths of 2.2 to 3.7m and 2.5 m respectively. These roots may have been put down deeper due to seasonal groundwater fluctuation or historical drought events.

A complete record of soil chemistry and physical properties is listed in Appendix C and drill logs of the soil bores are presented in Appendix D.

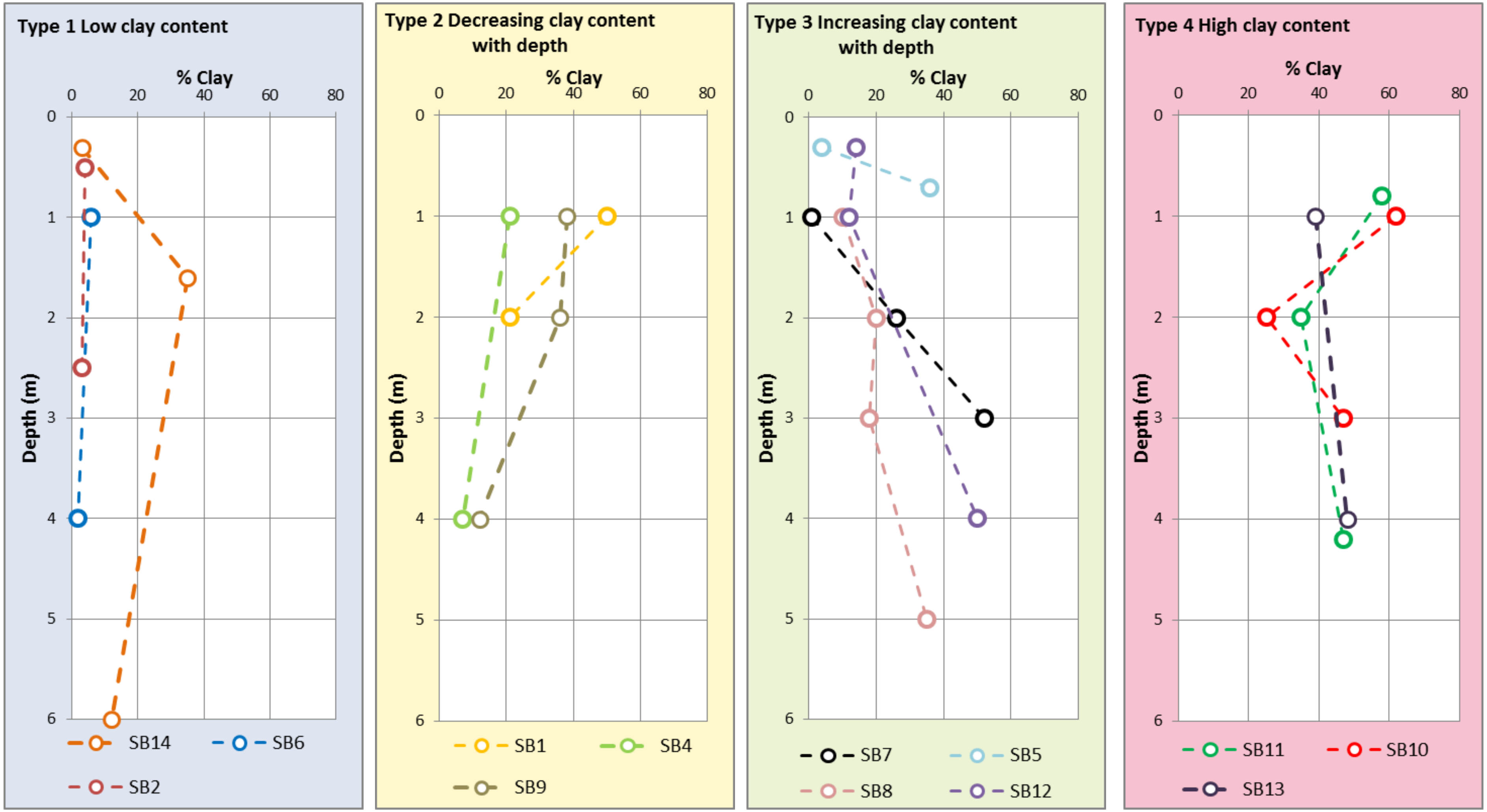


Figure 4-3 Profiles of percentage clay with depth

4.3.3 Groundwater properties

Table 4-2 presents the field measurements taken during the field program. The watertable is relatively shallow at sites situated along the drainage lines. The field measurements of salinity show that the groundwater is very fresh ranging from 39 to 270 µS/cm for shallow waters. TB4C has a salinity of around 400 µS/cm, however this monitoring bore is screened in deeper groundwater than the other bores. The low salinities are attributed to the high rainfall in the area, and the fact that the bores are screened in the upper-most part of the watertable – bores screened deeper in the aquifer would have higher salinities due to longer residence time. The low salinities are indicative of relatively rapid recharge through the unsaturated zone. Combined with the 2014 measurements from the same bores, the results show that there is significant temporal variability in the salinity of the upper part of the watertable.

Table 4-2 Groundwater field data

Monitoring bore	Sample Date	SWL (mTOC)	Groundwater EC (µS/cm)	Estimated depth to groundwater in soil bore (mBGL)	Additional comments
TB1	26/02/2015	2.08 (from TB1)	70	> 2.8m	Drilling refusal prior to watertable intersection. Based on transect (refer Appendix J), watertable is expected to be around 4-5m bgl at SB1. (Note: TB1 is not a good indicator of DTWT at SB1 due to distance from the site and different elevations above Big Swamp).
TB2b TB2c	03/03/2015	TB2b: 5.27 TB2c: dry	TB2b: 65	1.2m	Based on SWP at time of drilling soil bore. However TB2c (bore installed near SB2) has been dry since installation in May 2015
TB4a	26/02/2015	dry	N/A	~5-6m.	Could be as shallow as 4m, (based on soil moisture potentials). It was difficult to identify the point where saturation occurs in the soil sample. In nearby drainage line (3m vertically below the SB4), the watertable is around 2.8m bgl.
TB4b	26/02/2015	3.27	63		
TB4c	26/02/2015	29.44	400		
TB5	02/03/2015	21.5	270	> 3.2m	Drilling refusal prior to watertable intersection. Note, the TB5 monitoring bore is significantly elevated above the drainage line. Cross section in Appendix J indicates groundwater likely to could be ~ 15m bgl at this siteSB5.
TB6	23/02/2015	17.7	198	~2 m	SWP data suggests watertable around 2m, nearby bore suggests ~ 1-2m and bore log ~ 1.5 -2m > 3.6m (Drilling refusal prior to watertable intersection). Note, tThe TB6 monitoring bore is elevated 3-4m above the drainage line. Based on transect using TB6 data, watertable is estimated to be around 4-5m bgl.
TB7	24/02/2015	3.73	39	1m	
TB8	25/02/2015	4.26	142	~6 to 6.5m	It was difficult to identify the point where saturation occurs in the soil sample. Based on nearby TB8 (refer transect in Appendix J) it appears the depth to groundwater at SB8 is around 6 to 6.5m
TB9	27/02/2015	4.77	55	3m	
TB10	24/02/2015	5.68	40	4.5m	

Monitoring bore	Sample Date	SWL (mTOC)	Groundwater EC (µS/cm)	Estimated depth to groundwater in soil bore (mBGL)	Additional comments
TB11	02/03/2015	4.22	90	~5-6m	It was difficult to identify the point where saturation occurs in the soil sample. The SWP suggests saturated conditions may occur around 1m. However, based on slight drying at 3m, and expected WT based on T11 transect, WT around 5-6m is more likely
TB12	27/02/2015	7.5	79	6m	The SWP suggests saturated conditions may occur ~ 1m. However, the observation bore is in close proximity (TB12) and considered the more reliable indicator of watertable depth. Note that this is considered to be a perched water level rather than the actual watertable. The groundwater level in nearby TB12 suggests that actual watertable is probably around 3-4m bgl (refer transect in Appendix J)
TB13	25/02/2015	4.24	75	4.8m	
TB14	03/03/2015	2.28	70	4.5m	

4.3.4 Comparison of soil and leaf water potentials

To make an approximation of the trees primary water source, measurements were made of the pre-dawn leaf water potential (LWP) for each of the sites within 24 hours of the soil sampling taking place. The exception was SB14 where logistical constraints meant that measurements were taken 48 hours following soil sampling. The elevation adjusted LWP measurements vary from site to site and range between -0.78 MPa and -0.01 MPa for pre-dawn and -0.35 MPa and -1.99 MPa for mid-day. A comparison of pre-dawn LWP and SWP through the soil profile at each site is shown in Figure 4-4, Figure 4-5, Figure 4-6 and Figure 4-7.

At all sites and depths sampled the soil displayed a moisture potential greater than wilting point (-1.5MPa) which is considered to be the point at which plants can no longer extract water from the soil. This indicates there is sufficient water within the soil profile for vegetation use even after a period of below average rainfall. The gravitational potential of the soil does not play a major role in the SWP as the gravitational component will only increase by 0.01 MPa per metre of depth below the reference point which is generally set at the soil surface. The influence of osmotic potential within the SWP is minimal due to the very low salinity of the soil. Seven of the sites display a general trend of increasing soil moisture potential, indicating a drier surface soil, with moisture increasing with depth.

More information on water sources for vegetation at each site is described in the following section.

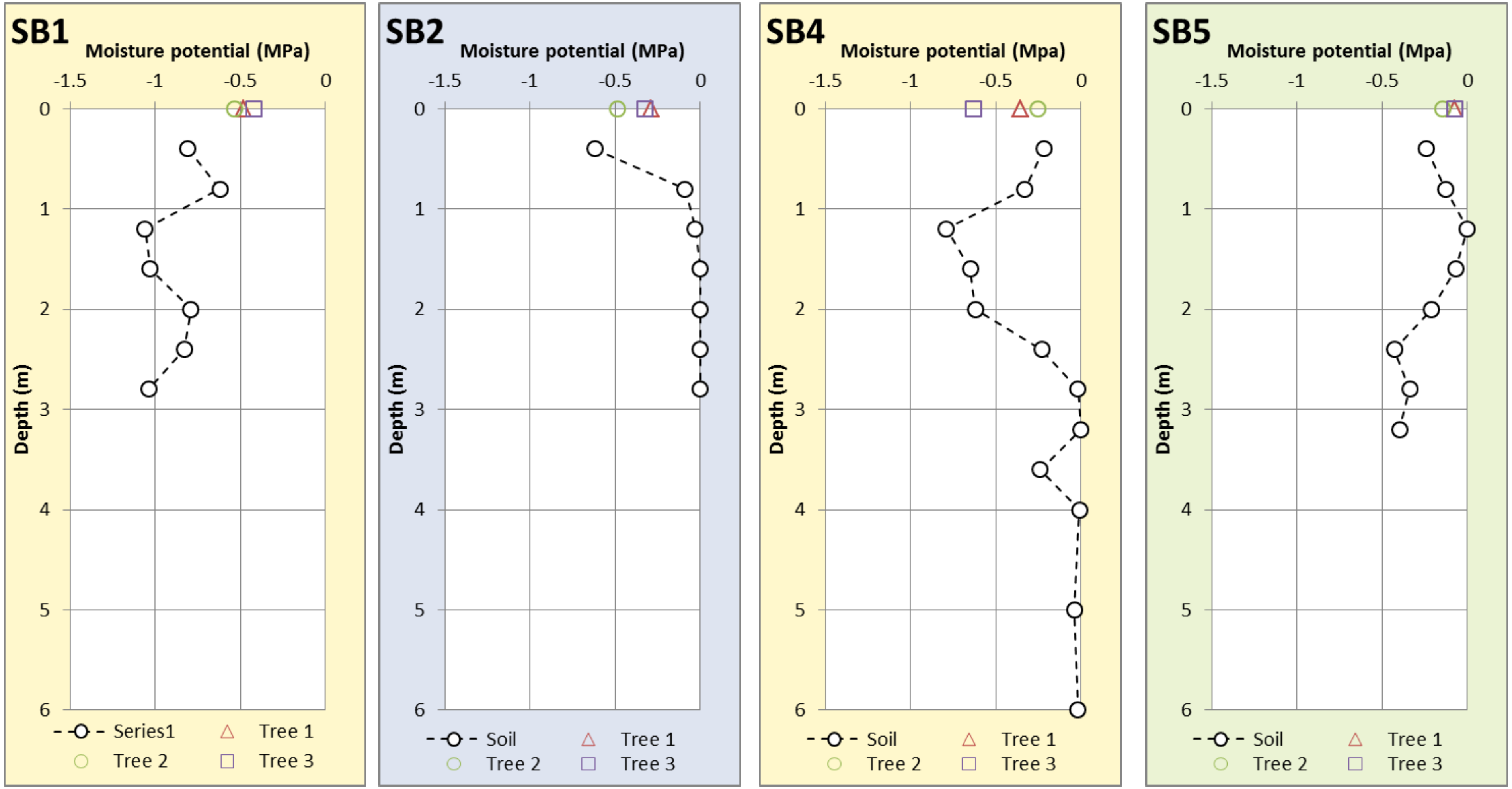


Figure 4-4 Pre-dawn LWP and SWP for SB1 to SB5

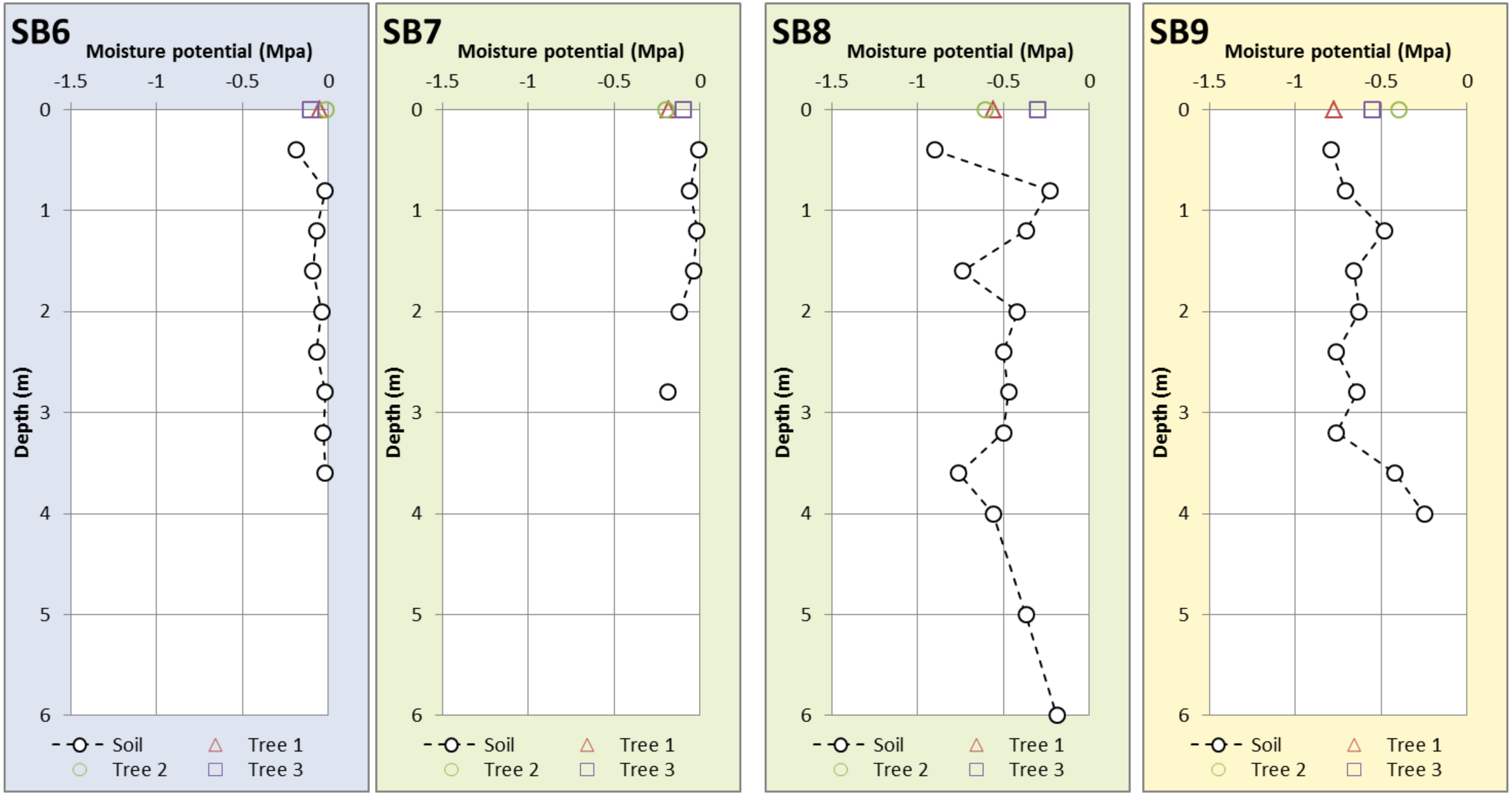


Figure 4-5 Pre-dawn LWP and SWP for SB6 to SB9

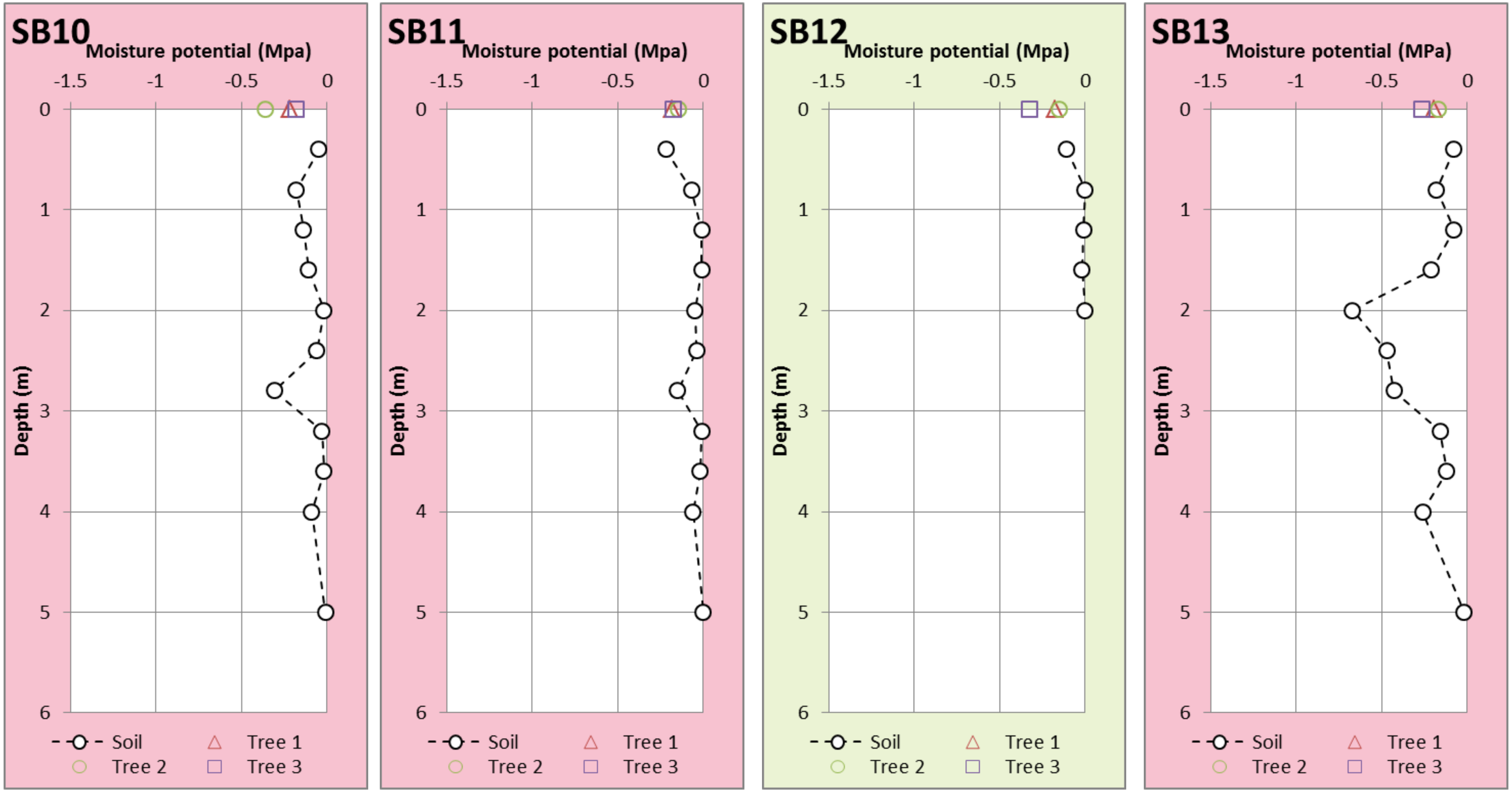


Figure 4-6 Pre-dawn LWP and SWP for SB10 to SB13

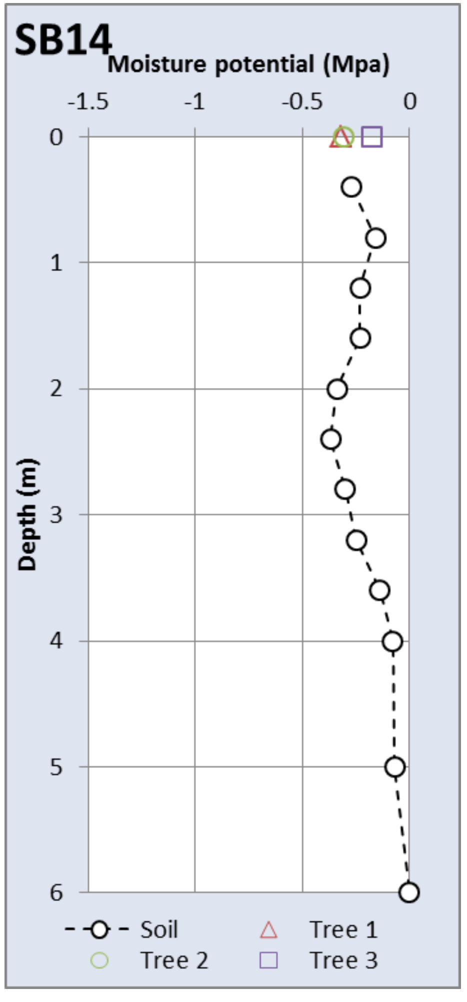


Figure 4-7 Pre-dawn LWP and SWP for SB14

4.3.5 Summary of leaf water potential and soil data

The measurement and sampling of SWP and LWP occurred during relatively cool conditions and even though there were rain events during sampling, the soil moisture potentials within the top layers of the soils remained at similar levels when comparing measurements taken prior to and after the rainfall event.

As pre-dawn LWP is considered to be more or less in equilibrium with the SWP (at the point within the soil profile where the tree is drawing water), the following inferences can be drawn regarding likely water use:

- At the SB1 site the LWP is less negative than SWP measured in the soil profile. This indicates the vegetation is likely to be accessing water from an area in the profile deeper than the interval sampled. This may possibly be groundwater, however as groundwater was not intersected in this soil bore (due to drilling refusal on hard material), deeper and possibly damper soil water cannot be ruled out by LWP alone. However, when considering a transect of the site (refer Appendix J), the watertable is likely to be around 4m below surface at SB1. Hence it is considered likely that trees access groundwater to meet at least some of their water requirements.

- At SB2 the soil bore log and SWP show the watertable to be close (approximately 1.2 m) to the surface. The pre-dawn LWP indicate the vegetation is accessing water from the drier sandy layer above the watertable, which is supported by the presence of a large number of roots only seen within these shallower sandy sediments. However, with groundwater at only 1.2 m below surface, it is likely that the shallower soil water is derived in part from the capillary fringe of the watertable.

- At the SB4 site, for 2 trees water use is implied around 0.4 - 0.8 m depth (i.e. soil water) and for 1 tree water use implied around 1.6 – 2 m depth (i.e. also soil water). With an estimated watertable at the site of 4m, soil water is the likely source. Roots were observed in the soil core at 1 to 2 m which coincides with these results. Just below this the soil water potentials indicate the watertable (or at least the capillary fringe of the watertable) is at a depth of around 4m, and possibly extends as high as 2.8 m. It is likely that in this area of the soil column the moisture content is supported by the downward infiltration of rain water meeting with the capillary fringe associated with the shallow watertable. The watertable in TB4c is considered too deep to be a water source for this vegetation, this is also supported by the dry bore TB4a (which is screened at an interval between TB4b and TB4c) indicating a separation between the shallow and deep groundwater. In summary, the results suggest soil water as the main source (at the time of this study), however the capillary fringe appears to extend a long way above the watertable at this site, and hence some role for groundwater cannot be dismissed. Vegetation located closer to the drainage line where the depth to watertable is shallower is considered very likely to be using groundwater.

- Water used is implied at 1.2 m in the profile in SB5. The log shows evidence of perching of soil water at a depth of 1.2 m on top of a clay layer in the soil profile. The soil profile becomes drier below this depth, indicating that this water is not part of the regional groundwater system but local minor perching or delayed infiltration of rainwater. The near zero pre-dawn LWP at this site indicates that this depth (around 1.2 m) is likely to be the source of water for the vegetation sampled (i.e. soil water, rather than groundwater). However, it is important to note that (due to drilling access constraints) this site is located significantly higher above the drainage line than other sites (refer cross section in Appendix J), and hence this result does not preclude groundwater use by vegetation closer to the drainage line.

- The SWP in SB6, SB7 & SB12 is near saturation throughout the soil profile suggesting that groundwater is close to the surface and that this moisture is likely present due to the capillary fringe above the groundwater. The near zero pre-dawn LWP at the SB6 and SB7 sites combined with the shallow watertable indicate that this vegetation is likely accessing groundwater simply due its close proximity While SB6 did not intersect the watertable, but the low soil moisture potential indicates the likely influence of the capillary fringe.

  At SB12, while the SWP results imply a shallow watertable, TB12 is located in close proximity to SB12 and the observation bore is considered the more reliable indicator of the actual watertable - around 6 m below ground level. The near zero pre-dawn LWP for trees 1 and 2 indicate water use at around 0.5 m.

The pre-dawn LWP for tree 3 is more negative than that of tree 1 and tree 2, indicating a higher level of water stress. Overall, with a watertable at 6 m, the SWP data indicate soil water as the tree water source at SB6 at the time of the field study.

- The soil profile at SB8 shows two depths where drying is evident, one at 1.6 m and the other at 3.6 m. These are accompanied by the presence of roots and pre-dawn LWP of a similar magnitude and indicating recent water use from these depths, i.e. soil water as the source. However it should be noted that roots were observed in the soil core at 6.5 metres (near to where the watertable is likely to be located), indicating the vegetation is likely have access to groundwater but does not appear using it as a major water source at the time of the sampling program, as water was available is the soil profile.

- At SB9 the pre-dawn LWP implies one tree using water from below 3.6 m (i.e. groundwater), one tree using water from around 0.5 m (i.e. soil water) and one tree probably using water between 1 - 1.5m (soil water or capillary fringe of groundwater). Hence the results indicate a mixture of soil and groundwater use. Tree roots were observed at a depth down to 3.7 m within the soil bore which confirms the trees at the site can access groundwater.

- The SWP at SB10 and SB11 show the soil profiles are damp throughout with a watertable at around 4 m and 5-6 m depth respectively. The high water content is likely due to the high moisture holding capacity relating to the clay content throughout the profile. At SB10 there is evidence of drying in the soil profile between 0.8 and 1 m depth coinciding with roots being observed in the soil core. This combined with pre-dawn LWP of a similar magnitude suggests water use from this depth and not groundwater use. At SB11 the moisture content is driest within the shallowest portions of the soil profile associated with the presence of roots within the top 0.8 m. This combined with pre-dawn LWP of a similar magnitude to SWP at these depths indicates water extraction from the top 0.8 m of the soil profile at the time of sampling. The results imply soil water use at both sites.
- The SWP and LWP at SB13 suggest water use at the time of the sampling at 0.5 – 1 m below surface (i.e. soil water). The watertable is estimated to be at around 5m depth. Further, significant drying of the soil profile observed between 2 and 3 m depth, with a smaller magnitude of drying at a depth of 4 metres, both imply recent plant water use at these intervals. The presence of roots at 4 m combined with pre-dawn LWP of a similar magnitude to the soil at 4 m depth also indicate recent water use from this interval. This depth (4m) coincides with the only alkaline soil sample (pH 8.3) found across the sites, however the reason for this is unclear from the available data .

- The SWP and LWP at SB14 imply water use in the upper 1.5 m of profile, i.e. soil water. Further, drying at a depth of around 2 to 3 m in the profile, coupled with pre-dawn LWP of a similar magnitude, indicate recent plant water use from this depth. The watertable is estimated to be at 4-5m depth.

4.3.6 Stable isotopes of water

Stable isotopes and the biosphere

The compositions of stable isotopes of water can vary throughout the biosphere due to differences in the fractionalisation processes as a result of the effects of evaporation and chemical interactions. These differences can often provide a useful tool for linking target vegetation to its possible source water giving a measurement of plant water use at the time of sampling. For example, if the proportions of each stable isotope analysed found within the vegetation are similar to the proportions found in local groundwater and different to those found in local soil water, it is likely that the vegetation in question is using ground water at the site (refer to section 4.2.1). This section presents the results of the stable isotopes of water ($\delta^{18}O$ and δ^2H) that were sampled at the 13 sites in order to quantify variations throughout the vegetation xylem water, soil pore water and groundwater.

Figure 4-8 presents all collected stable isotope data plotted together to highlight associations and general processes that drive isotope fractionation for waters in the area. The local meteoric waterlines (LMWL) for Melbourne and Adelaide are also plotted to show the isotopic composition of the likely precipitation sources for the study area. Of note is the relatively restricted range for groundwater samples, the significant variability for soil samples (which is not correlated directly with depth or soil type) and the relatively tight trend for the twig samples that is offset from the groundwater samples. This is discussed further in the sections below.

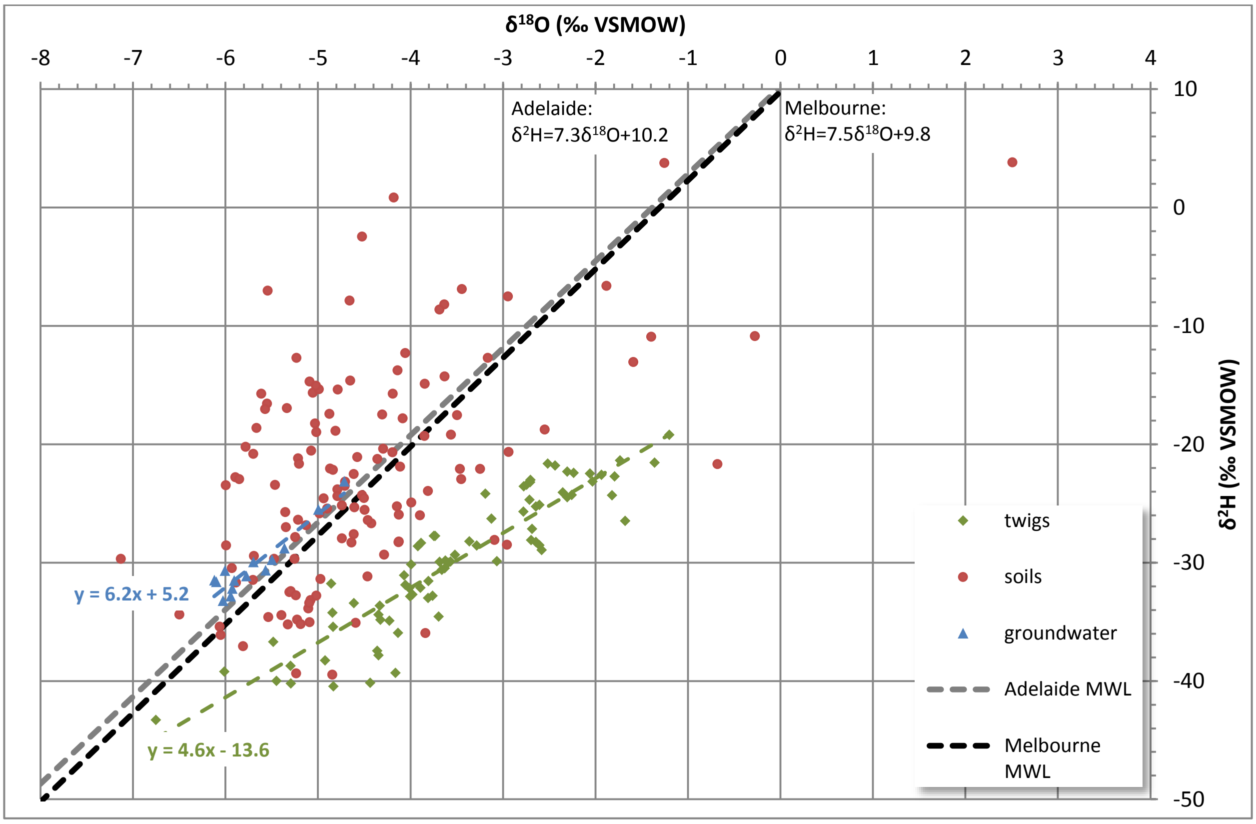


Figure 4-8 Compiled stable isotope data for groundwater, soil water and twig water

Groundwater

The isotopic signatures for the groundwater all plot within a tightly confined area slightly above, and to the left of the LMWL for Adelaide and Melbourne at the depleted (more negative) end of the rainfall trend. The depleted signature indicates the majority of recharge being received by groundwater is likely to occur during large, high intensity rainfall events. The slight shift of the isotopes to the left (slightly above) of the LMWL indicate interactions between the recharging water and soil particles during infiltration. This occurs when oxygen and hydrogen atoms within the infiltrating water interact with clay particles in the soil profile. The heavier oxygen isotope (^{18}O) and the lighter hydrogen isotope (^{1}H) preferentially adsorb onto clay particles during infiltration. This reaction results in the isotopic signature of the residual water (in this case groundwater) showing a depletion of ^{18}O combined with an enrichment of ^{2}H when compared to the initial rainfall source. The fact that the groundwater isotope trend line plots so close to the LMWL indicates that the water has undergone relatively little alteration in terms of evaporation or soil interaction during recharge, and therefore the recharge is implied to have occurred rapidly. This is a conclusion also supported by the low EC of the groundwater.

Soil water

Stable isotope profiles from all sites are presented in Appendix E. There are two general types of isotopic profiles observed across the sites. The profiles for two sites representative of these types are presented in Figure 4-9 (SB8 and SB9). The first type (observed at SB1, SB2, SB4, SB6, SB7, SB8 and SB14) exhibits a generalised evaporation profile with enriched isotopic signatures for both stable isotopes near the surface which gradually become more depleted with depth. The isotopic enrichment in the surface sediments indicates fractionalisation caused by evaporation and diminishes with depth as is overtaken by capillary action within the soil profile. The soil logs show that sites with this type of isotopic profile generally have higher proportions of sand within the upper areas of the soil profile than the other sites. The larger pore spaces found in sandier soils results in higher levels of evaporation and faster infiltration through these sections of the soil profile. This combined with lower levels of capillary action results in a faster drying of the soil at these locations between rainfall events, giving an enriched isotopic signature. This data is also supported by the SWP results in section 4.3.4.

The second type (SB5, SB9, SB10, SB11 and SB12) shows an isotopic signature which does not vary significantly depth. The soil bore logs and physical analysis show these soils have higher clay content compared to the other sites. Soils with higher clay contents have smaller pore spaces and as a consequence much slower rates of infiltration coupled with higher levels of capillary action. Importantly, the water is more tightly held to the soil in these profiles and hence subject to significantly less evaporation. This results in little change in the isotopic signature of the soil water throughout the soil profile and the resulting groundwater.

It is noted that the first type of isotopic signature is dominantly comprised of sites in the aquifer (LTA) outcrop area, while sites displaying the second type of signature are mainly overlying the aquitard (MTD). This concurs with the higher sand content in the upper part of the profile which is the main factor giving rise to the two different isotopic signatures.

In both profile types the isotopic signature becomes near vertical below around one to three metres depth which suggests a strong recharge gradient where groundwaters are reflecting an averaged soil profile signature caused by continual mixing of discrete rainfall events as the water percolates through the soils.

Displacement in the isotopic profile towards the right (less negative) reflect changes in soil texture and relate to discrete sandy horizons that undergo greater evaporative fractionation, likely due to preferential extraction of water by plants. This is evident in the ^{18}O profiles for SB8 at around 2.8 m, SB9 at around 2 m and SB14 at 2.4 m. These zones also correspond to lower water potentials, as expected. (See compilation plots in Appendix E).

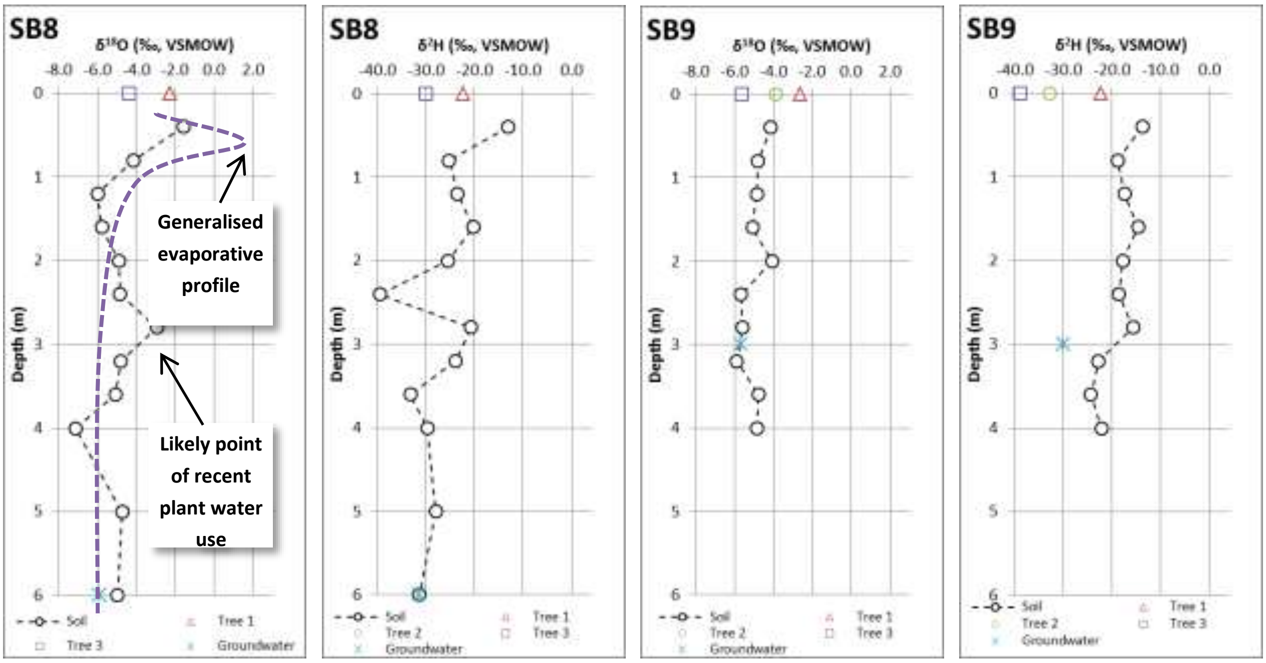


Figure 4-9 Representative stable isotope profiles - SB8 is typical of sites showing increased depletion with depth (in the upper profile); SB9 is typical of sites showing little variation in isotopic signature with depth)

Plant water

The water sampled from the trees (twig samples), as shown in Figure 4-8, indicates an isotopic trend consistent with the evaporation of meteoric water. In contrast, groundwater samples plot along the meteoric water line, indicating the absence of significant groundwater evaporation. As the process of transpiration does not fractionate oxygen or hydrogen isotopes, it is likely that the evaporation trend in Figure 5-6 is symptomatic of evaporation during sample holding. As described earlier, an error during the transportation of the samples meant that the samples were stored in an un- refrigerated warehouse in Perth for around 1.5 days (against instructions). During this time there was the potential for evaporation of samples to occur. Nonetheless the results are useful to the study.

Assessment of the isotopic results from the twig samples generally resulted in one of three categorisations:

- TYPE A - The trees were likely using groundwater, as the extrapolated evaporative trend placed the samples either at a similar place to the groundwater isotope results, or left/below the groundwater isotope results. Two examples of this are shown in Figure 4-10.

- TYPE B – The results were inconclusive, as the groundwater isotopic signature and the soil water isotopic signature were too similar to enable differentiation. Two examples of this are shown in Figure 4-11.

- TYPE C – The results were inconclusive, as the twig samples could be matched with a particular depth in the soil profile, or the groundwater isotopic signature. The difference between this and Type B is that there is differentiation between the groundwater isotopic response and the bulk of the soil samples, but some of the soil samples plot along the evaporative trend line for the vegetation samples. Hence the conclusion from this type of response is either groundwater, or soil water from the particular depths plotting on the vegetation evaporative line.

A summary of the isotope analysis and interpretation is presented in Table 4.3, including classification of the sites into the above three categories.

Four sites have been classified as Type A, where the isotope data indicates that the trees are using groundwater. This was the case at T2, T4, T7 and T9 (Figure 4-10 : Type A isotope grouping – indicative of groundwater use by sampled trees. Trees plot closer to groundwater than soil water, therefore interpreted as groundwater use.).

Six of the thirteen sites were classified as Type B (T5, T8, T10, T11, T13 and T14) where the isotopic signature for the groundwater and soil were too similar to enable any differentiation. While the isotope results were inconclusive at these sites, the soil and leaf water potential data can be used to determine vegetation water use.

Three sites were assigned Type C classifications, being T1, T6 and T12. At T1 it is concluded that groundwater was the more likely source, however there is some uncertainty.

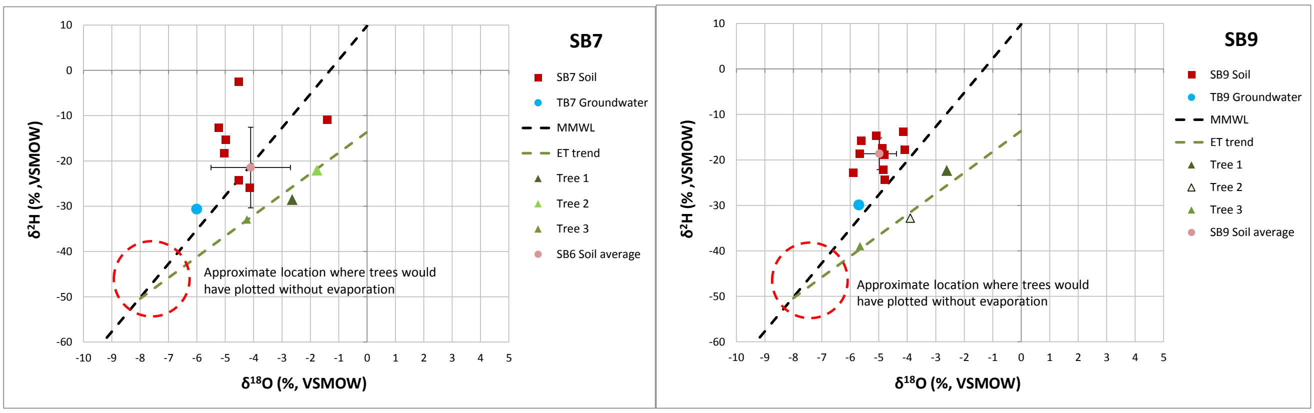


Figure 4-10 : Type A isotope grouping – indicative of groundwater use by sampled trees. Trees plot closer to groundwater than soil water, therefore interpreted as groundwater use.

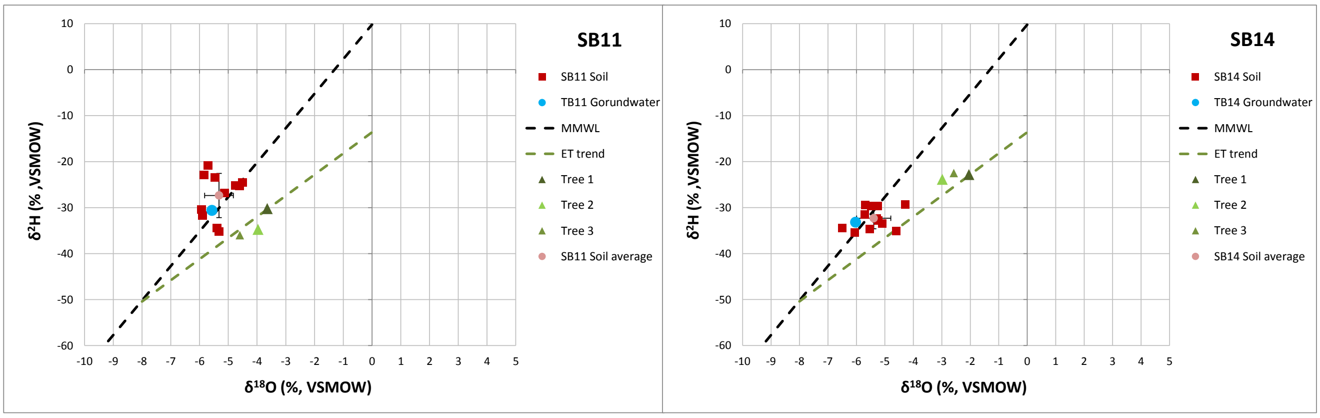


Figure 4-11 : Type B isotope grouping – soil water and groundwater isotope signature too similar to enable differentiation between sources

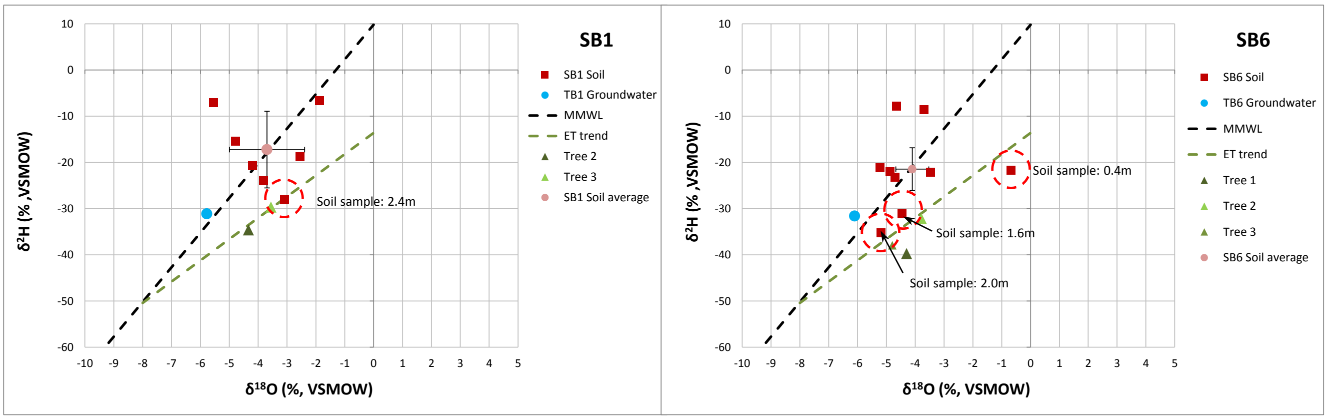
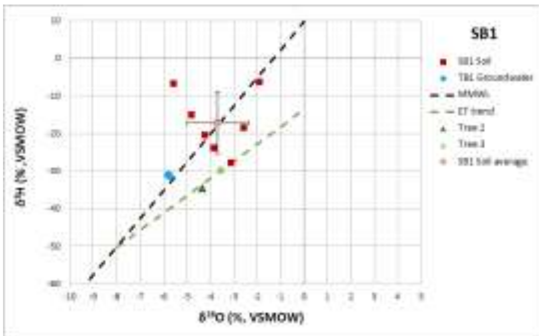
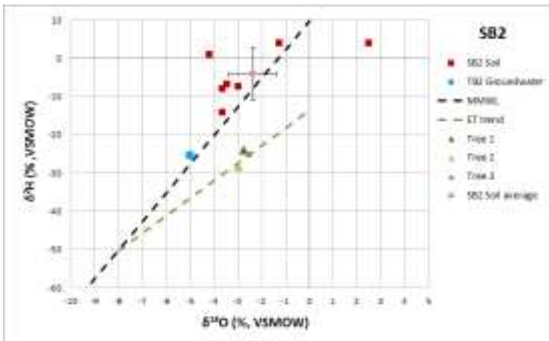
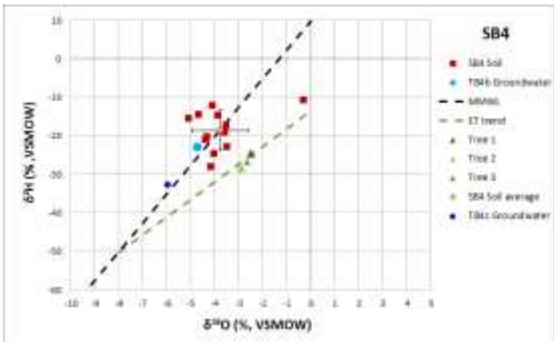
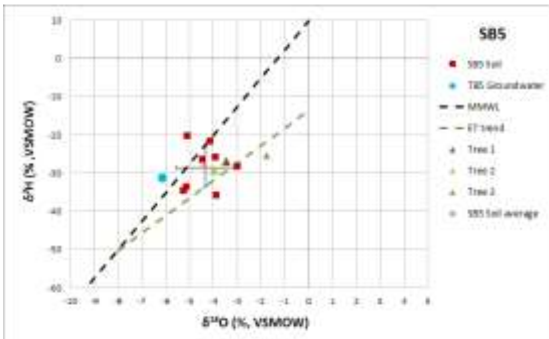
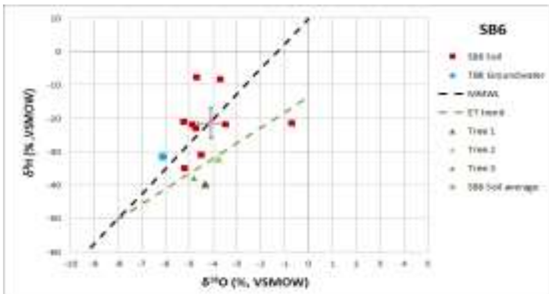
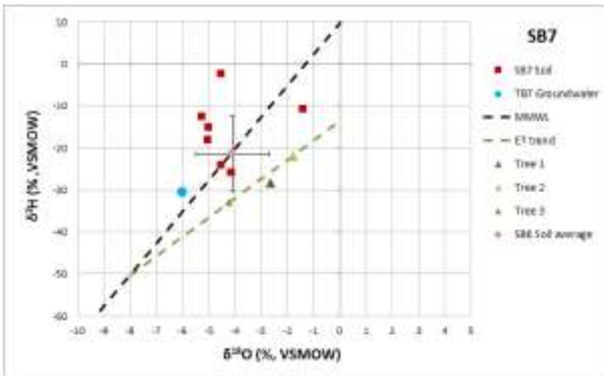
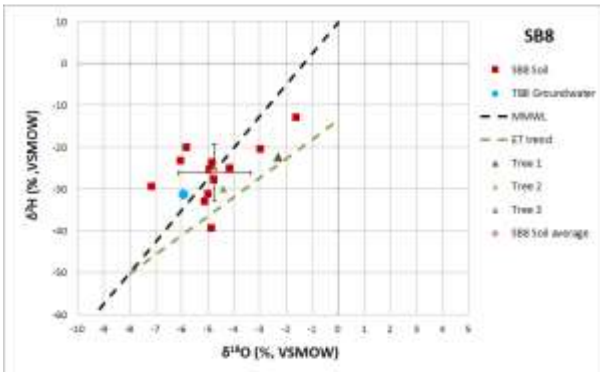
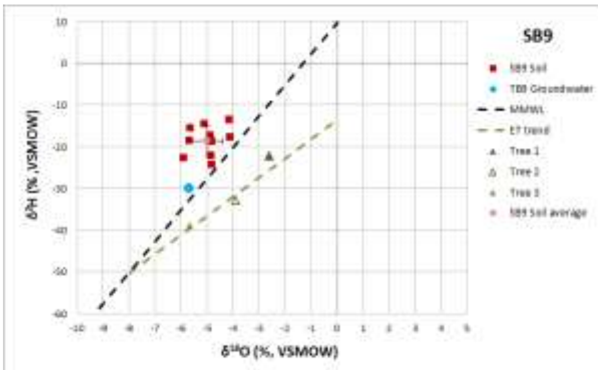
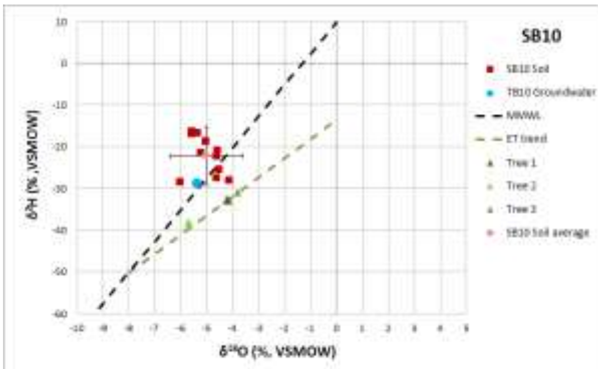
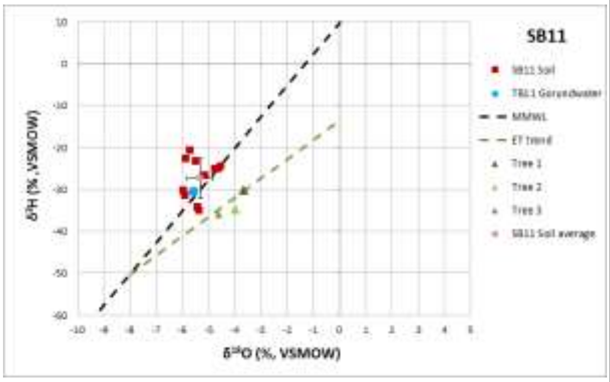
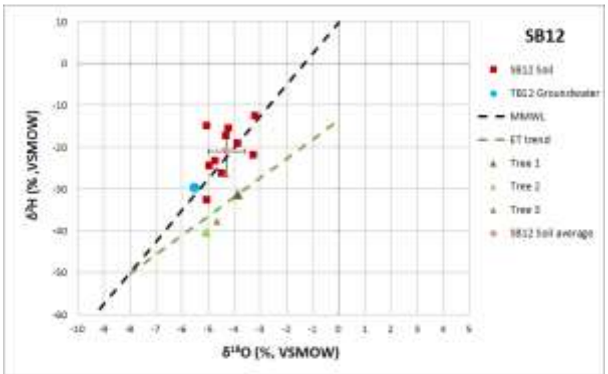
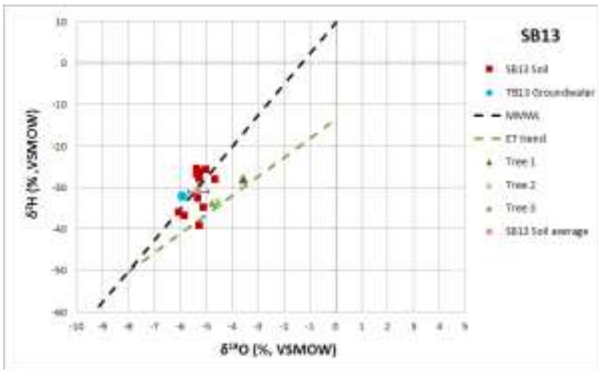
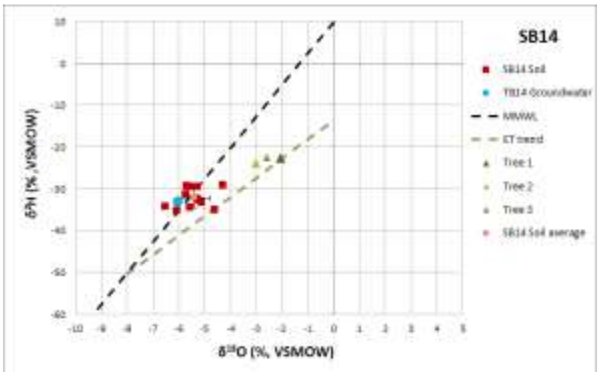


Figure 4-12 : Type C isotope grouping – some soil water samples plot on evaporated twig samples line; could be groundwater or soil water from those corresponding depths

Table 4.3 : Summary interpretation of isotope results

	Site ID	Group	Plot	Comments
	SB1	C		Could be soil water from 2.4m, or groundwater. More likely to be groundwater given most soil water is away from vegetation ET trend line
	SB2	A		Strongly implies groundwater use. Soil samples plot long way from groundwater and ET trend for tree samples.
	SB4	A		Most likely groundwater, as most soil water plots well away from ET samples trend line. However soil water from 0.4m has an evaporated signature too – source water could be a mixture of groundwater and soil water from around 0.4m.
	SB5	B		Inconclusive - Could be either or a mixture of soil and groundwater.
	SB6	C		Some support for conclusion of groundwater use, however soil water from 0.4m, 1.6m and 2m has an evaporated signature along the vegetation ET line too, and hence could be either soil water or groundwater or both.

<table>
<tr><th>Site ID</th><th>Group</th><th>Plot</th><th>Comments</th></tr>
<tr><td>SB7</td><td>A</td><td>
</td><td>Consistent with groundwater use. Soil samples plot long way from groundwater and ET trend for tree samples.</td></tr>
<tr><td>SB8</td><td>B</td><td>
</td><td>Inconclusive: Groundwater and soil water signature is very similar and hence differentiation of source water is difficult.</td></tr>
<tr><td>SB9</td><td>A</td><td>
</td><td>Consistent with groundwater use. Soil samples plot long way from groundwater and ET trend for tree samples</td></tr>
<tr><td>SB10</td><td>B</td><td>
</td><td>Inconclusive: Groundwater and soil water signature is similar and hence differentiation of source water is difficult. (Probably more indicative of groundwater use, but some ambiguity).</td></tr>
</table>

Site ID	Group	Plot	Comments
SB11	B		Inconclusive: Groundwater and soil water signature is very similar and hence differentiation of source water is difficult.
SB12	C		Inconclusive - could be groundwater or soil water from 0.4m.
SB13	B		Inconclusive: Groundwater and soil water signature is very similar and hence differentiation of source water is difficult.
SB14	B		Inconclusive: Groundwater and soil water signature is very similar and hence differentiation of source water is difficult.

1. Type A – Implies groundwater use, Type B – Soil water and groundwater signature too similar to enable differentiation, Type C - Some soil water samples plot on evaporative trend line for twig samples, could be groundwater or soil water from those corresponding depths

4.3.7 Combined analysis of tree source water

This section combines the results of different aspects of the field investigation to provide an overall interpretation of the source of water used by the trees at each site. The information used to make this evaluation includes:

- Soil and leaf water potentials
- Soil water, groundwater and leaf water isotope results
- Depth to watertable
- Bore log information, including depth of tree roots, where observed

Table 4.4 presents this information and the final column summarises the likely water source for the trees. Where applicable this includes discussion on the likely source at the time of the field investigation and whether this may have been different in the past. For example, at some sites soil use was concluded at the time of the field investigations, but evidence of tree roots at depth suggests historical groundwater use. This is an important result which emphasises the ‘point in time’ nature of this study.

The final column also provides important commentary regarding water use relative to the location of the site within the profile of the drainage line. As described earlier in this report, at some sites a decision was made to locate the assessed trees and soil bore some distance away from the drainage line, as groundwater use in the drainage line was considered very likely, and hence not a particularly useful conclusion. And at some sites access at the level of the drainage line was not possible, so the assessment location was by necessity some metres above the drainage line. At these locations commentary on the likely water use of trees in the drainage line is also provided in the table.

Appendix J presents conceptual cross sections through the drainage lines at each of the thirteen sites. The surface topography is based on the digital elevation data and the soil bore and groundwater bore elevations are based on survey data of these features. The vegetation survey transects for the sites have also been included, for information. The NDVI results across the transect are included at the top of each figure. The alluvial thickness and extent has been estimated from the soil logs and geology map, but given the scale of the geology map relative to the section, and the use of only one bore in estimating the alluvial thickness and extent, the area of mapped alluvium has a reasonable degree of uncertainty. Hydrographs of the groundwater levels in the observation bores are included in the figure (where available and where the bore is located in reasonable proximity to the transect).

The figures provide a summary of the tree water use at the site, based on the conclusion outlined in Table 4.4. Importantly, the figures indicate the location of the site (soil bore and nearby trees sampled) in relation to the profile of the drainage line. These sections help to put into context the elevation of the sampled trees and soil bore with respect to the elevation of the drainage line and watertable. For example, the figures quickly illustrate the influence of the location of the sampling sites along the drainage lines on the outcome of the field results, including T5, T8, T11 and T14, which are elevated significantly above the drainage line. The greater depth to watertable at these sites is readily apparent compared to other sites.

Figure 4-13 provides a visual summary of the results across all sites. The symbol in the foreground for each site shows the interpreted water source for the trees sampled in the February 2015 field investigation. The symbol indicates either soil water (brown), groundwater (blue) or a combination of both (half brown – half blue). Some of the sites also show a background symbol, which has been used to indicate either:

- the strong likelihood of historical groundwater use at the site even though the conclusion was soil water use for the sampled trees at the time of the survey
- the strong likelihood of groundwater use lower in the drainage line even though soil water was concluded as the source for the sampled trees above the drainage line

The figure shows six sites where groundwater use was inferred from the field work (T1, T2, T4, T6, T7 and T9). Three sites were considered very likely to have groundwater use by trees closer to the drainage line (T8, T11 and T14) and at two sites there was good evidence of historical groundwater use (T8 and T13). It is important to note that at three of the six sites where groundwater use was inferred from the field work, that soil water use was also inferred for those trees, i.e. groundwater was meeting a part of their water requirements. While the field component of this study was undertaken at the end of a short term dry period (-150mm below average rainfall from August 2014 up to time of the field program) there have been and will be periods of greater water stress than measured in this study. At these times it is likely the use of groundwater would increase, i.e. the proportion of groundwater use at sites already using groundwater would increase and would commence at some sites currently not interpreted to be accessing groundwater.

In total ten sites were considered to have present or historical groundwater use for at least some of their water requirements. Conversely, there were only three sites (T5, T10 and T12) where groundwater use by trees has not been inferred either in the February 2015 field work, in the drainage line down-gradient of the sampled trees and/or historically at the site. At T5 groundwater use in the drainage line is possible but there was not sufficient evidence to make the conclusion with the same certainty as at other sites. Overall the study has confirmed fairly widespread groundwater use by trees on the Barongarook High, at least within and near drainage lines. This is something that has been previously surmised but has been confirmed in this assessment.

Table 4.4 : Summary assessment of tree water use

Site ID (location)	Depth to watertable	Soil profile	Indicators of water use from SWP and LWP	Indicators of water use from water isotopes	Summary
SB1	>3m Drilling refusal at 3m. Based on profile, WT expected to be ~ 4m	Sandy silt: 0 -0.7m Sandy clay: 0.7-1.5m Clayey sand 1.5 - 3m	SWP more negative than LWP, indicating water use below depth of soil bore. Given estimate of gw depth (~4m), some groundwater use very likely.	Slightly ambiguous - could be soil water from 2.4m, or groundwater. However, more likely to be groundwater given most soil water plots away from veg (particularly tree 2)	**Summary** – Groundwater use. SWP/LWP – Result is clear, below depth of bore and therefore very likely groundwater used Isotopes – Most likely groundwater.
SB2	1.2m (based on SWP at time of field program but TB2c, immediately adjacent SB2 is 3m deep and has been dry since installation in May 2015)	Sand to 3.2m Roots up to 0.8m	Tree water use implied between 0.5 – 1m (which could be soil water or groundwater from capillary fringe)	Strongly implies groundwater use.	**Summary**: Groundwater use Chemistry results strongly imply groundwater use. To reconcile SWP indicating use from 0.5-1m, water at this depth must be from capillary fringe. With watertable at 1.2m this is quite feasible. (Note - site is complex due to shallow watertable implied at time field program, but subsequent watertable in obs. bore at the site > 3m.
SB4	~4m (based on SWP)	Clayey sand / sandy silt to 2.8m Sand, fine grained from 2.8-6.5m, with clay layer 3.3 - 3.7m Minor roots to 2m depth.	For 2 trees, water use implied around 0.4 - 0.8m (soil) For 1 tree, water use implied around 1.6 – 2m (soil) Estimated watertable at site is ~ 4m – hence most likely soil water but for tree 1 could be capillary fringe of perched system	Most likely groundwater, most soil water plots away from it. However soil water from 0.4m has an evaporated signature too – source water could be a mixture of groundwater and soil water from 0.4m.	**Summary**: Soil water and groundwater use. Likely soil water supported by groundwater from capillary fringe. *A higher proportion of groundwater use closer to the drainage line is considered very likely, as the depth to watertable becomes shallower.*
SB5	>3.2m (likely ~ 10m)	Clayey sand to 1.5m Sandy clay to 3.3m	Water use implied at 1.2m depth. Given watertable is > 3.2m (and probably 10m+ at this location), soil water is source of tree water.	Inconclusive - Could be either or a mixture of soil and groundwater.	**Summary**: Soil water use. However, trees may use groundwater closer to the drainage line.

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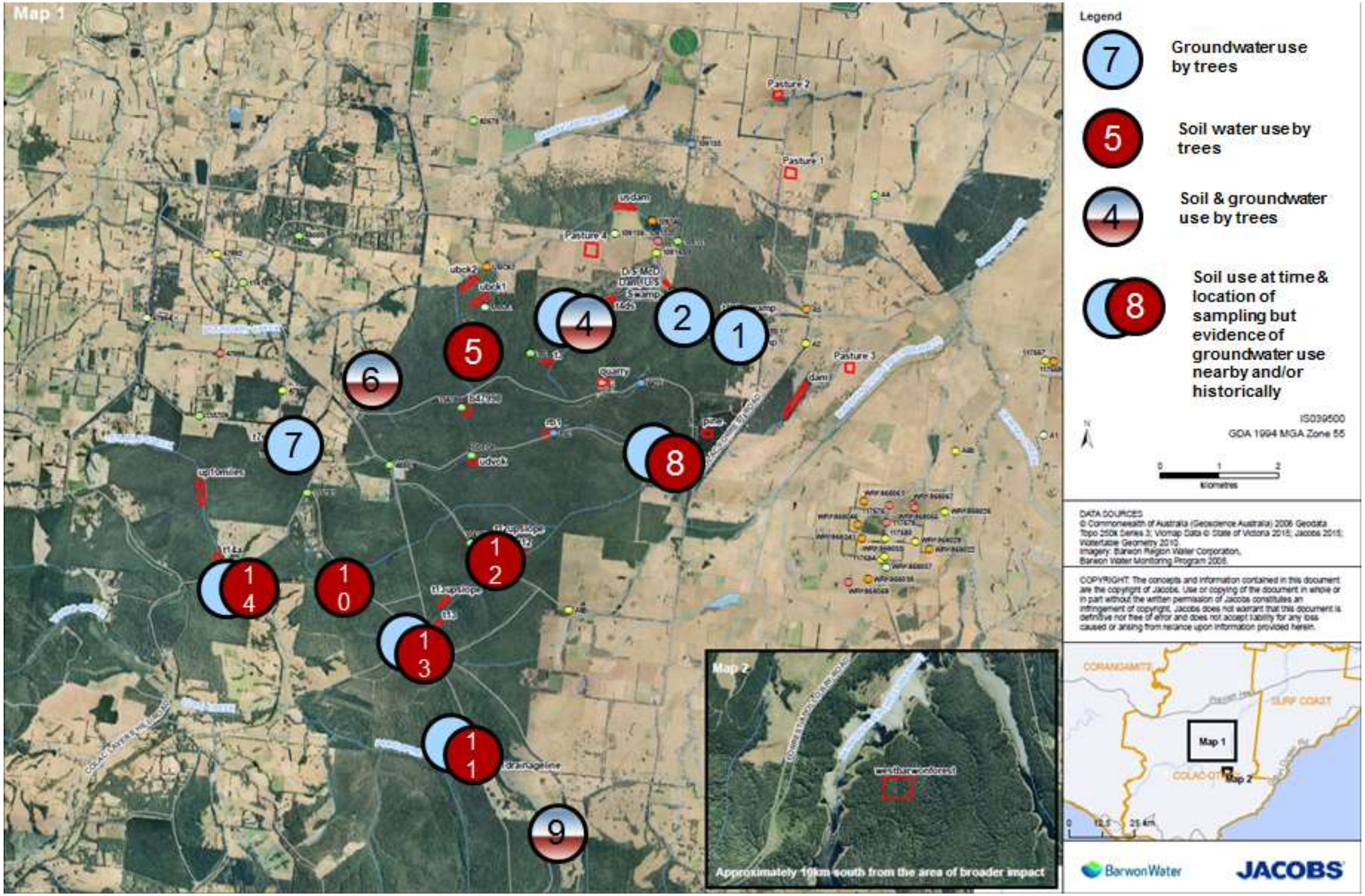
Site ID (location)	Depth to watertable	Soil profile	Indicators of water use from SWP and LWP	Indicators of water use from water isotopes	Summary
SB6	~ 2m (SWP data suggests watertable around 2m, nearby bore suggests ~ 1-2m and bore log ~ 1.5 -2m)	Dominantly sand to 4m	Indicates water use around 1-2m in the profile. Based on estimated depth to watertable this could be groundwater from capillary fringe, but could also be soil water.	Some support for conclusion of groundwater use, however soil water from 0.4m, 1.6m and 2m has an evaporated signature along the vegetation ET line too, and hence could be either soil water or groundwater or both.	**Summary**: Soil water and groundwater use. SWP and chemistry data indicate water use from between 0.4 to 2m, however it is not conclusive if this is soil water or groundwater (from capillary fringe). Given shallow groundwater (~ 2m), some groundwater use is very likely.
SB7	1m	Mainly sand to 2.4m Sandy clay 2.4 – 3m	Indicates shallow water use from 0.5m – 1m. With very shallow groundwater, this is the capillary fringe. Hence this is groundwater use.	Consistent with groundwater use.	**Summary**: Groundwater use.
SB8	~6.5m	Silty sand to 3.4m. Silty-sandy clay from 3.4 – 6.5m Roots observed down to 6.5m	Implies shallow use from soil from around 0.5 – 2m bgl.	Groundwater and soil water signature is similar and hence differentiation of source water is difficult. Conclusion: Inconclusive	**Summary**: Soil water use & evidence of historical groundwater use Tree roots were observed regularly through the profile down to 6.5m (approximate depth of current watertable), strongly suggesting historical groundwater use. While tree water use at the time of the survey is considered to be soil water, there are two important caveats: • *Groundwater use closer to the drainage line is considered very likely (based on section and associated depth to watertable through the site)* • Groundwater use in the past (within the lifetime of current trees) is considered very likely. Trees have needed to access water from at least 6.5m below ground, and this is most likely groundwater.

Site ID (location)	Depth to watertable	Soil profile	Indicators of water use from SWP and LWP	Indicators of water use from water isotopes	Summary
SB9	3m Sample described as wet from 3m, but SWP suggest WT around 4-5m. However nearby TB9 supports WT at approx. 3m.	Clayey silt to 2.2m. Silty clay: 2.2 to 4m Roots observed down to 3.7m	Implies 1 tree groundwater use, 1 tree soil water and 1 tree is ambiguous. Above interpretation assumes that the watertable is at 3m. SWP suggests lower than this, although nearby groundwater bore indicates 3m is likely at the soil bore.	Consistent with groundwater use. Soil samples plot long way from groundwater and ET trend for tree samples	**Summary** – Groundwater and soil water use Even with some ambiguity as to whether the watertable is at 3m or close to 4m, based on the isotope data alone the conclusion of groundwater use still stands. The SWP also indicates at least one tree using groundwater. Tree roots down to 3.7m also suggest groundwater use.
SB10	4.5m (based on soil bore log and also consistent with TB10)	Silty clay to 1.8m Clayey sand to 3m Silty clay to 5m Roots observed to 2m depth	Tree 1 & 3 suggest use around 0.5 – 1m. Tree 2 suggests use around 3m depth. With watertable at around 4.5m all trees likely to be using soil water.	Soil and groundwater isotope results are similar and hence differentiation based on isotopes is difficult. (Probably more indicative of groundwater use, but some ambiguity).	**Summary** – Soil water use. Based on SWP/LWP (isotope result inconclusive).
SB11	~ 6 - 8m (The SWP suggests saturated conditions may occur around 1m. However, based on slight drying at 3m, and expected WT based on T11 transect, WT around 6-8m is more likely)	Sandy silt: 0 - 0.4m Silty clay / clay : 0.4 - 5m	Implies water use in the 0.5 – 1m range, i.e. soil water.	Isotope results are inconclusive - soil and groundwater isotope results are so similar that no differentiation based on isotopes is possible.	**Summary**: Soil water use. Based on SWP/LWP tree water use is considered to be soil water in the 0.5 – 1.25m range. *However, groundwater use closer to the drainage line is considered very likely.* (Seasonal groundwater response also supports this conclusion)
SB12	~ 6m (The SWP suggests saturated conditions may occur ~ 1m. However, the observation bore is in close proximity and considered the more reliable indicator of watertable depth)	Silty sand: 0 - 1.2m Silty clay / sandy clay : 1.2 - 4m Roots observed to 2.5m depth	Implies use in the upper 0.5m of the profile (soil water)	Inconclusive - could be groundwater or soil water from 0.4m.	**Summary**: Soil water use. Conclusion is based largely on the SWP data, but is not inconsistent with the isotope data (where shallow soil water is a potential source)

Site ID (location)	Depth to watertable	Soil profile	Indicators of water use from SWP and LWP	Indicators of water use from water isotopes	Summary
SB13	4.8m	Sandy silt: 0 - 0.6m Clayey silt: 2-3m Silty clay/clay to 3 - 5.5m Roots observed to 4m depth	Suggest current use around 0.5 – 1m, but drying in the profile at around 2-3m suggests recent historical use at that depth. SWP/LWP indicates soil water use.	Inconclusive - could be groundwater or soil water from 2.4m and/or 3.6 to 5m. However, the results more closely support a soil water source rather than groundwater source.	**Summary**: Soil water use & evidence of historical groundwater use The combined of evidence of recent use at 2-3m (from SWP/LWP data) combined with the evidence of soil water use at 2.4m from the isotope data, is the basis of this conclusion. *However, tree roots are observed down to 4m in the profile (within capillary fringe of current watertable). Hence trees at the site have needed to access from this depth in the past, and hence likely to have used groundwater in the past*.
SB14	4.5m	Abundant roots observed 0 – 0.7m	Implies use in upper 1.5m of profile, i.e. soil water.	Isotope results are inconclusive - soil and groundwater isotope results are so similar that no differentiation based on isotopes is possible.	**Summary**: Soil water use. Based on SWP/LWP soil water (shallow) is considered most likely source. *However, the site is around 6-7m of the drainage line of Ten Mile Creek and groundwater use closer to the drainage line is considered very likely.*

Figure 4-13 : Summary of tree source water for all sites



5. Combined analysis and conclusions

5.1 Discussion

This section considers the combined findings of both the NDVI assessment and field program. The discussion is focussed around the two main objectives of the study, which were to determine whether terrestrial vegetation in the study area is using groundwater (and to what extent) and to assess whether there is any evidence of impact from historical groundwater pumping on vegetation condition.

5.1.1 Groundwater use by trees

The study involved two very different approaches to assessing groundwater and tree interaction; NDVI analysis across a wide area and a field study involving direct physical and chemical measurements of soil, groundwater and vegetation at thirteen sites. The NDVI analysis provides a broad spatial assessment of tree cover and condition with the potential to assess trends across time. Spatial analysis of the NDVI data can be used to infer groundwater use. This relies on the well accepted assumption that groundwater use by vegetation is more likely where the watertable is shallow. Hence during periods of water stress, relatively healthier (i.e. more photosynthetically active) vegetation would be expected where the watertable is shallow, as the vegetation has access to a reliable source of water compared to vegetation overlying a deep watertable. And in fact this trend is observed in the NDVI data, in that during periods of water stress there is higher NDVI where the watertable is shallow, compared to deep. Conversely, this trend is not observed in the 1994 NDVI data which represents a time of relative water abundance.

This conclusion could be attributed to concentration of runoff in drainage lines and associated replenishing of unsaturated zone soil moisture. However it is considered unlikely that unsaturated zone water in areas of shallow watertable would be of sufficient volume to sustain trees during severe drought - groundwater use is considered the best explanation for this observed trend in the NDVI. Further, the conclusion of groundwater use by the trees is also supported by the field study:

- At six sites groundwater use by trees was inferred (for meeting at least some of their water requirements) from the field work: at sites T1, T2, T4, T6, T7 and T9,
- At three sites it was considered very likely that trees closer to the drainage line were using groundwater: sites T8, T11 and T14), and,
- At two sites there was evidence of historical groundwater use: T8 and T13.

In total ten out of thirteen sites were considered to have evidence for present or historical groundwater use.

Hence the field program supports the hypothesis of groundwater use by trees developed from the NDVI analysis. While the field program was undertaken during a relatively dry period, it was not as dry as the two periods assessed in the NDVI assessment, during 2000 and 2010. Hence if groundwater use is demonstrated at a number of locations in February 2015, then a geographically wider extent of groundwater use by vegetation is likely in 2000 and 2010. Further, sites using groundwater in 2015 could have had an increased proportion of their water needs met from groundwater during historical periods of higher water stress.

Indeed as described above, there were two sites in the field program where current (February 2015) water use is inferred to be soil water, but there is strong evidence of water use from deeper in the profile historically. At these sites tree roots were found around the depth of the current watertable, but water use at the time of the field study was from soil water higher in the profile. This highlights two important factors regarding the field program:

1. While the study is a ‘snap-shot’ in time, the field program revealed evidence of changing water use trends across time at some locations. This is a finding supported by the NDVI analysis, where groundwater use is implied at some times but not at others. This highlights the capacity of trees within the area to adapt to changing levels of water availability.

2. The field program, based solely on the isotope and water potential results, underestimates groundwater use by vegetation compared to the historical record, i.e. during periods of greater water stress than February 2015.

The results suggest a greater reliance by trees on groundwater in areas of outcropping aquifer (LTA). For example, at each of the sites located on LTA outcrop where the watertable was less 10m from the surface, groundwater use by trees at the time of the study was indicated, which was at six of seven sites. The exception was site 5 and the absence of use here is attributed to a deep watertable; >10m below surface at the selected trees. In contrast, at two of the five sites overlying alluvium/aquitard there was no evidence of current groundwater use, and at a further site only historical evidence of groundwater use, but not current use. This is probably due to the fact that the outcropping aquifer represents the sandier profiles where there is less water held in the pores in the unsaturated zone (water drains more quickly/easily and less volume is retained) compared to the clayey sites of the aquitard / alluvium where the water holding capacity in the unsaturated zone is higher. In periods of greater water stress however, even at these more clayey sites, there is evidence of historical groundwater use (e.g. T8 and T13).

5.1.2 Impact of borefield pumping on trees

Despite the evidence of groundwater use described in this assessment, there is no evidence that groundwater extraction from the Barwon Downs borefield has had a negative impact on vegetation activity or condition (as measured by NDVI). There is no difference observed across time in vegetation closer to the borefield, where greater levels of drawdown in the aquifer have occurred, versus further away. This is based on both assessment of areas of shallow groundwater where groundwater use is more likely and on vegetation generally.

While groundwater pressures in the pumped aquifer (LTA) have declined in the aquifer outcrop area near the borefield, it is apparent that shallow groundwater has been buffered from the regional pressure decline and/or that vegetation has adapted to the decline in groundwater level. There is evidence of both of these factors at play in the study area. For at least two sites there is firm evidence of aquifer perching or buffering, based on data from nested bore sites (TB1 nest and TB4 nest). This means that drawdown in the watertable is either unaffected (if true perching is present – as shown at TB4) or reduced (where a low permeability material separates the two units – as seen at TB1 nest) compared to pressure declines in the pumped (LTA) aquifer. It is very likely that other sites also have a watertable aquifer that is to some degree buffered from regional LTA fluctuations. This is supported by the patterns observed in the groundwater hydrographs at the terrestrial vegetation sites. These hydrographs generally show seasonal variations against a slightly declining trend over the period of mid-2014 to end of 2015, responding to short to medium term rainfall patterns. In contrast deeper groundwater bores within the LTA show an overall recovering trend from the 2007 to 2010 borefield pumping.

It is also possible that vegetation has adapted to lower groundwater levels, with roots following a falling watertable. This is possible (and has been documented elsewhere), however at a number of sites new groundwater bores indicate that the groundwater is currently still shallow (e.g. at T1, T2 and T4), implying that buffering is the more likely reason for vegetation's resilience. Further, the ability of tree roots to follow a falling watertable is much more viable if the watertable change is small and slow (i.e. buffered compared to regional change). Hence at some sites both of these factors may combine to explain the resilience of vegetation to any impact from historical groundwater pumping.

An assessment of planned burns and bushfire history in the area does not indicate any significant impact on the NDVI results within the study area, beyond the 2010 burn in the vicinity of Gold Hold Road. The effect of that burn has been allowed for in the interpretation of the results.

5.2 Conclusion

The wider implications of this study for the overall assessment of the Barwon Downs groundwater system, updating of the conceptual model and planning towards licence renewal are summarised below:

- Trees within the area of influence of the borefield do use groundwater to meet some of their water requirements. Groundwater use (by trees) is considered likely at the majority of the vegetation survey sites. This is an important progression, because historical vegetation surveying was conducted at sites where groundwater use at the survey sites was unknown. The results of this study should be considered when reporting on future vegetation surveys at the site.

- Evidence of changing patterns of water use to adjust to varying levels of water availability were observed in both the NDVI data and the field study.

- The use of deeper cut off levels for ET extinction depth should be considered in the new groundwater model (e.g. up to 5-6m below ground level) in areas covered by native vegetation.

- Based on the NDVI data, tree health and condition has not been impacted by operation of the Barwon Downs bore field.

- Trees using groundwater have not been affected by groundwater pressure decline in the LTA due to:

  - The presence of perched aquifers which may be more widespread in the study area than previously considered

  - The hydraulic separation between shallow and deeper units within the LTA – this was a concept first raised in the SKM (2013) scoping study. This is now supported by the 1.5 years of groundwater level monitoring data at the terrestrial vegetation sites which show groundwater levels reflecting shallow and seasonal influences rather than the recovering trend observed in bores screened deeper in the LTA across the Barongarook High.

  - The ability to adapt to changing lower levels (e.g. by sinking deeper roots). While there is no direct evidence of this in the field study, there is anecdotal evidence that this has occurred in the past at some sites

  The exact contribution of each of these factors in trees maintaining ecological condition despite the regional decline in the LTA pressure is not known.

5.3 Recommendations

This study recommends two actions to continue to monitor potential impacts of groundwater extraction on vegetation include:

- Annual vegetation monitoring at the vegetation survey sites whilst the bore field is operating, as recommended by Jacobs 2016 vegetation survey report.

- Review of NDVI data at some after each period of borefield use. This will build on the baseline established in this study, and enable a regional assessment of vegetation changes that is not possible in the site by site assessment.

Now that data loggers are installed at each vegetation monitoring site, consideration should also be given to using diurnal watertable fluctuations to directly measure groundwater consumption by vegetation. This would be useful to inform conceptualisation of different areas of relative groundwater use, but would also yield quantitative estimates of ET that could be useful in numerical modelling.

6. References

Barnes. C., Allison G., (1988), *Tracing of water movement in the unsaturated zone using stable isotopes of hydrogen and oxygen*. Journal of Hydrology, 100:143−176.

Bureau of Metrology, Climate data online, viewed online 01/05/2015: http://www.bom.gov.au/climate/data/index.shtml?bookmark=136

Crosbie R., Morrow D., Cresswell R., Leaney F., Lamontagne S., Lefournour M., (2012) *New insights to the chemical and isotopic composition of rainfall across Australia*. Water for a healthy Country Flagship, CSIRO, 2012.

Eamus, D. (2009), *Identifying groundwater dependent ecosystems: A guide for land and water managers*. Published by Land and Water Australia; PN30129.

Makenzie N., Coughlan K., Cresswell H., (2002), *Soil physical measurements and interpretation for land evaluation*, CSIRO publishing, 2002.

Ritchie, G.A., and T.M.Hinckley. (1975), *The pressure chamber as an instrument for ecological research*. Advanced Ecological Research 9, 165-254

Roderick, M., R.C.G. Smith, and G. Ludwick. (1996). Calibrating long term AVHRR-derived NDVI imagery. *Remote Sensing of Environment*. 58:1-2

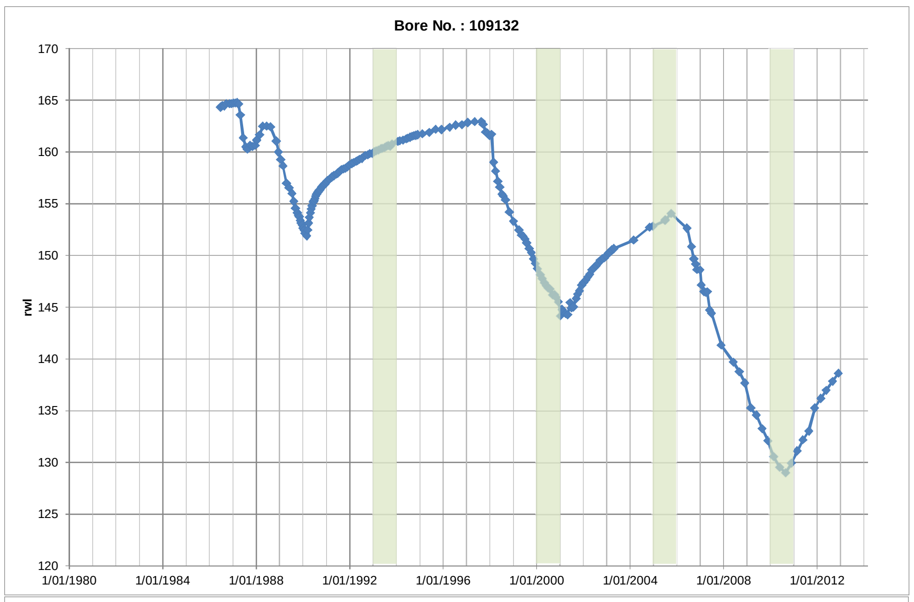
Slatery B., Hollier C., (2002) *The Impact of Acid Sulphate Soils in Victoria*, Department of Natural Resources, 2002 Available on line at: http://vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_mgmt_acid.

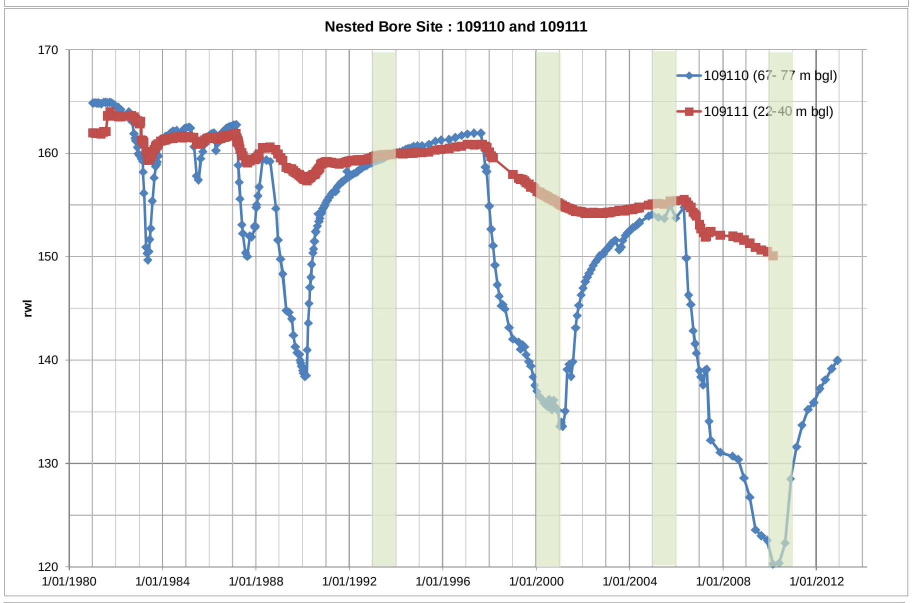
SKM & EA (2009). Barwon Downs Flora Study 2008. Final1. VW04550. 14 April 2009.

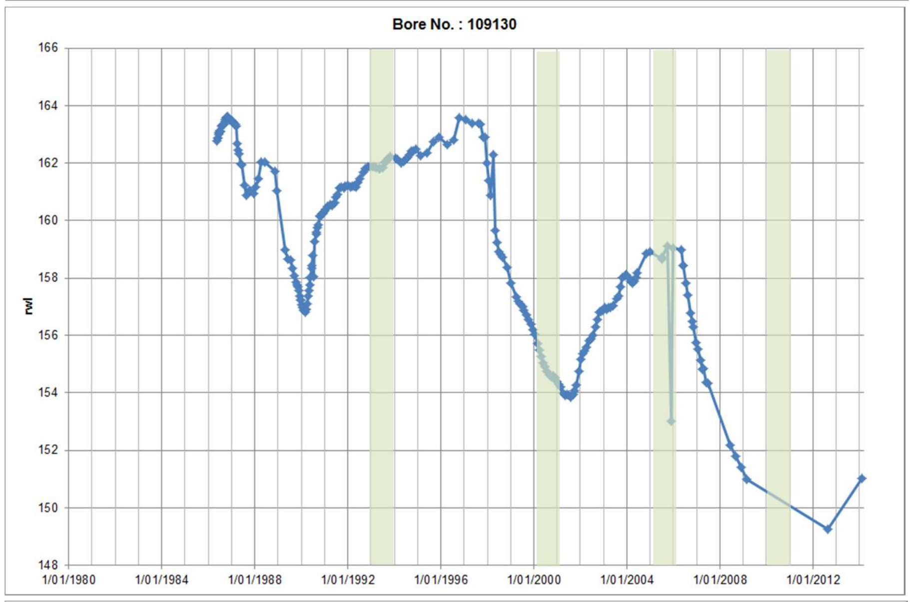
SKM (2013) Barwon Downs Monitoring Program. Stage 1 – Field investigations and monitoring program scope.

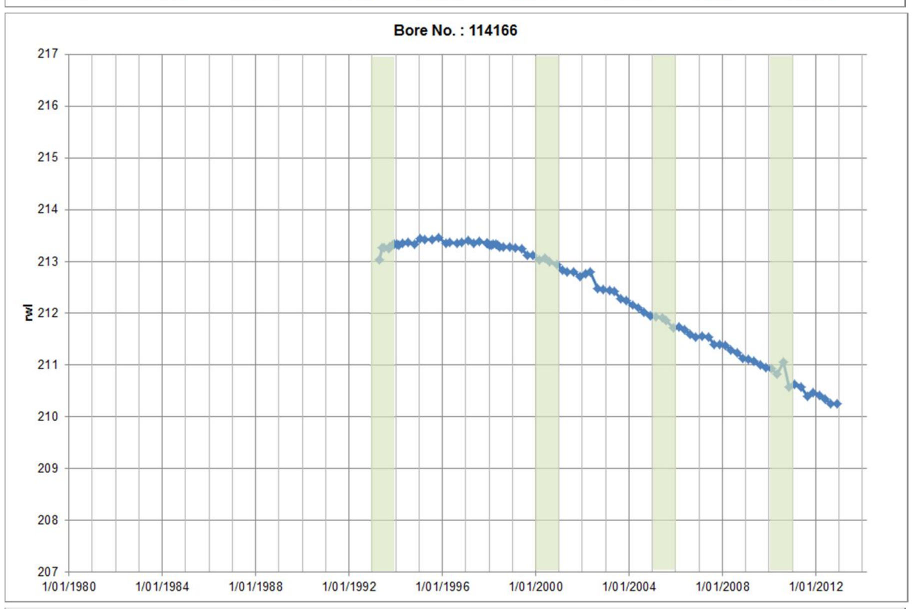
USDA-ARS Jornada Experimental Range, BLM-AIM Program, and Idaho Chapter of The Nature Conservancy (2015). The Landscape Toolbox – Tools and Methods for Effective Land Health Monitoring. http://wiki.landscapetoolbox.org/doku.php/remote_sensing_methods:normalized_difference_vegetation_index Accessed: 18 April 2015.

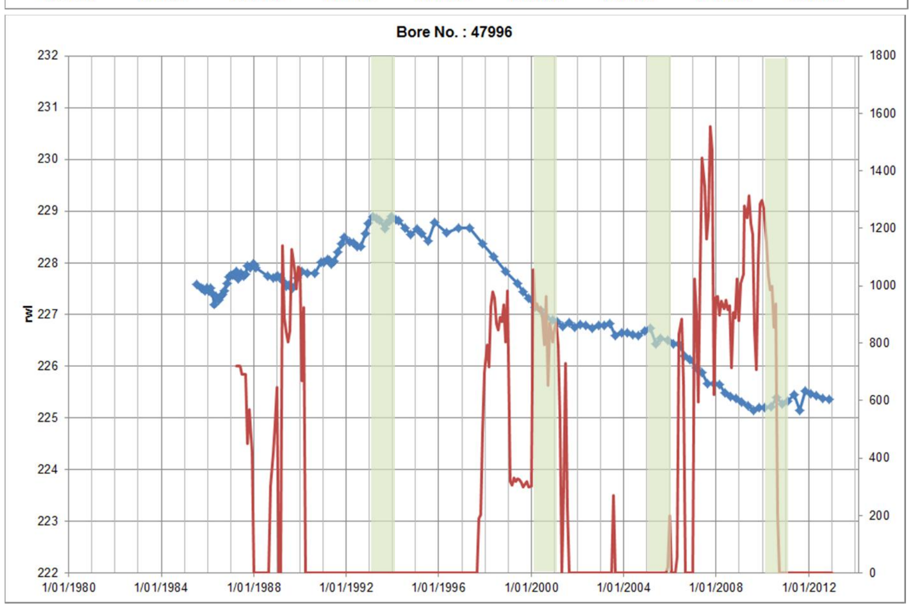
Appendix A. Groundwater hydrographs used in selection of NDVI analysis periods











Broad date selection for NDVI analysis overlain with key hydrographs for groundwater bores in the analysis area

Green years in the hydrographs indicate the target dates for NDVI analysis.

The red line in the bottom hydrographs indicates use of the borefield (units are ML/month).

The bores are in the following locations:

- Bore 109132 is located in the LTA outcrop area, approximately 5km from the borefield.
- Bore 109110 / 109111 is located in the LTA outcrop area, approximately 6km from the borefield - east of McDonalds Dam)
- Bore 109130 is located in the LTA outcrop area, approximately 6km from the borefield – downstream of McDonald's Dam, adjacent Boundary Creek
- Bore 114166 is located in the LTA outcrop area, approximately 8km from the borefield
- Bore 47996 is located (on the margin of) the LTA outcrop area, approximately 10km from the borefield

Appendix B. Rainfall conditions preceding NDVI analysis dates

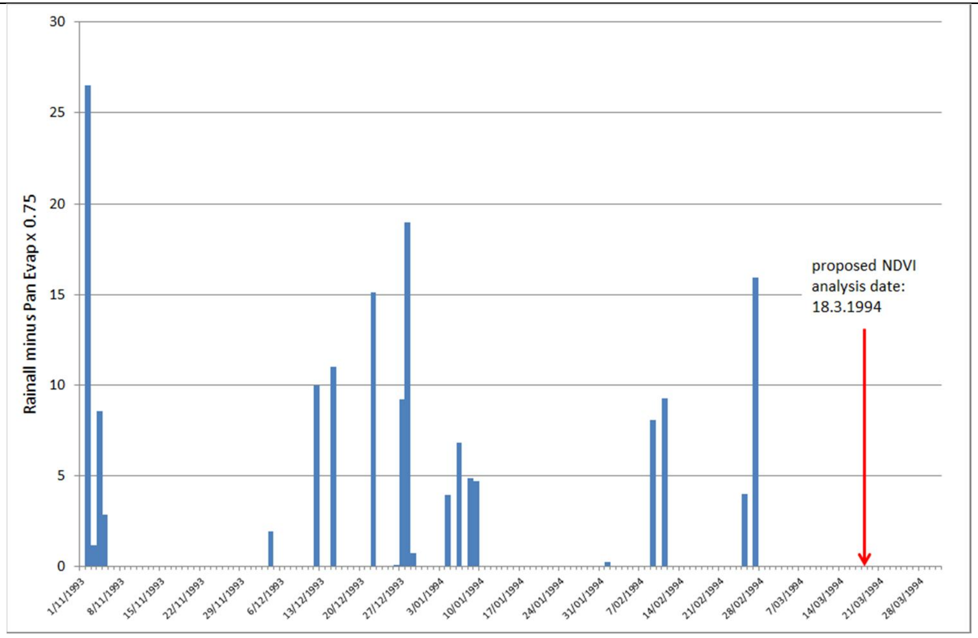
Table B-1 Summary of dates selected for analysis and rationale

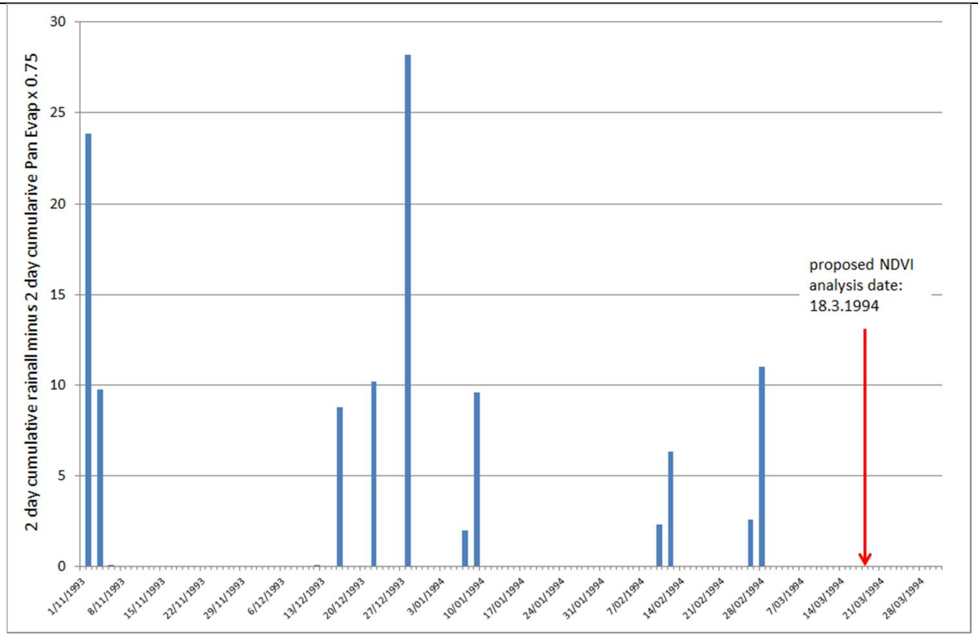
Broad time period targeted	Rationale for broad time period	Date selected and discussion of preceding rainfall
1984 - 1987 or 1993 to mid-1997	To obtain vegetation activity data representative of pre-pumping / pre-change in groundwater level condition (i.e. essentially no impact from pumping / change in groundwater levels) The mid to late 1980s date was not preferred due to the coarser data resolution for NDVI imagery at that time, which would have made comparison with later dates more difficult.	'Dry season' date: **18/03/1994** (some cloud cover in the regional image but over the area of interest was OK) *Rainfall conditions prior to selected date*: As shown below, 18 days prior to the selected date there was a rainfall event of around 16mm. Given the number of days between the event and the NDVI analysis date, any significant influence on the results is considered unlikely. At a wider-time scale, it can be seen below and from Figure 3-2 that there was above average rainfall during December 1993. There is around 2.5 months after this date for this effect to be ameliorated. However even if there is a residual 'abnormal' influence on the NDVI result due to the rainfall, given that this is the background date, this will tend towards producing a conservative result in terms of comparison with impact dates (i.e. it will increase the NDVI and enhance vegetation activity at this time). 'Wet season' date: **22/08/1993**
Jan – March 2001 or Jan – March 2000	Impact Assessment 1. – To assess potential impacts on vegetation activity associated with changes in groundwater levels related to drought and groundwater extraction over the 1997 – 2001 period The 2000 date was selected over the 2001 date due to issues with the available images for 2001 (data gaps, cloud cover etc).	'Dry season' date: **11/03/2000** (complete coverage but some dark shadows from cloud over area of interest; less than 5% of area). *Rainfall conditions prior to selected date*: As shown below, there was very little rainfall in the period leading up to the NDVI analysis date, and what did occur is expected to have quickly evaporated. 'Wet season' date: **23/08/1999** (time periods in Spring had too much cloud cover to be useful. Otherwise the closest date with no cloud cover was 13/12/99, which is too far out of the 'wet season')
Jan – March 2006	Recovery Assessment – If there was any impact on vegetation activity associated with decline groundwater levels in the previous assessment, this date will be used to assess the extent of any recovery in the following 4-5 year period.	'Dry season' date: **8/02/2006** (Some gaps present but less than approx. 5% of the area) *Rainfall conditions prior to selected date*: As shown below, there was relatively very little rainfall in December 2005 and January 2006 (both months are below long term average). This is supported by the declining trend in the rainfall residual curve prior to the data (refer Figure 3-2). The exception was 29th and 30th January, where around 12mm and 16mm respectively occurred. The majority of this is expected to have evaporated and not impact tree water use, however some effect is possible. 'Wet season' date: **8/09/2005** (complete coverage but some dark shadows from cloud over AOI which affects <5% of area).
Jan – March 2010 or Jan – March 2011	Impact Assessment 2. - To assess potential impacts on vegetation activity associated with changes in groundwater levels related to drought and groundwater extraction over the 2006 – 2010 period. This represents conditions at close to lowest groundwater levels on record (i.e. highest possible impact).	'Dry season' date: **19/02/2010** (Some gaps present but less than approx. 5% of the area) *Rainfall conditions prior to selected date*: The rainfall residual curve shows that in the preceding two years there was an overall declining rainfall trend, followed by a wetter than average spring (2009), and then average summer rainfall. As indicated below, there were 3 rainfall events (each around 10mm) in the 15 days preceding the analysis date. This also shows that most of this rainfall would be evaporated (from vegetation or soil surfaces) within several days of each rainfall event, meaning relatively little would be expected to be available to deep rooted plants and any impact on results is expected to be minor. 'Wet season' date: **7/11/2009**

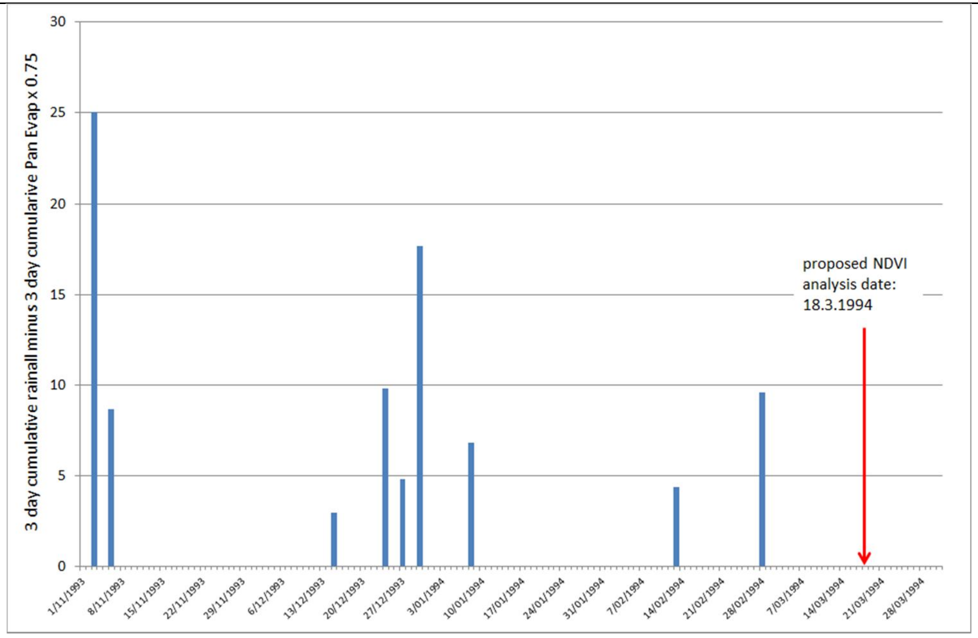
Rainfall (less evaporation) prior to selected NDVI analysis

Note: the plot in the left hand column is daily rainfall minus pan evaporation (x 0.75) for the same day, the middle figure is of 2 day cumulative rainfall minus 2 day cumulative pan evaporation (x 0.75) and the plot in the right hand column is 3 daily cumulative rainfall minus 3 day cumulative pan evaporation (x 0.75)

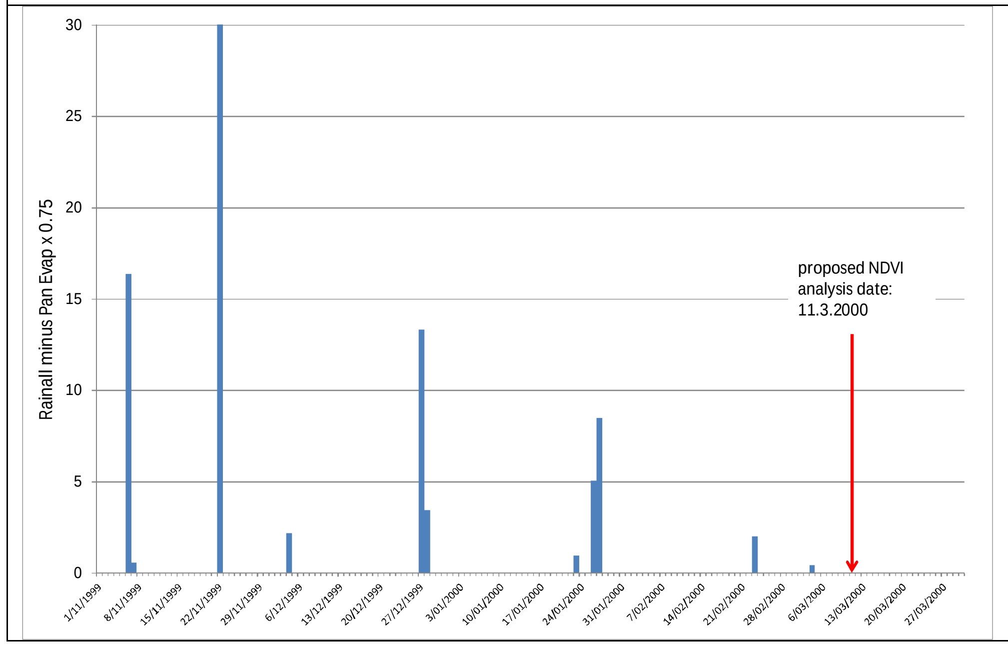
Background Date (18 March 1994)

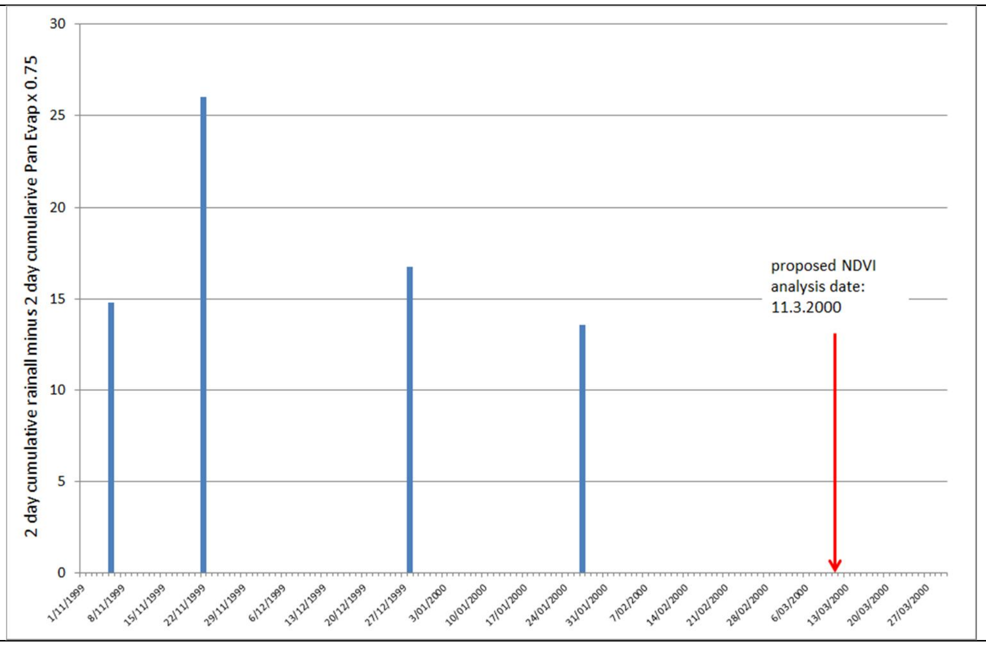


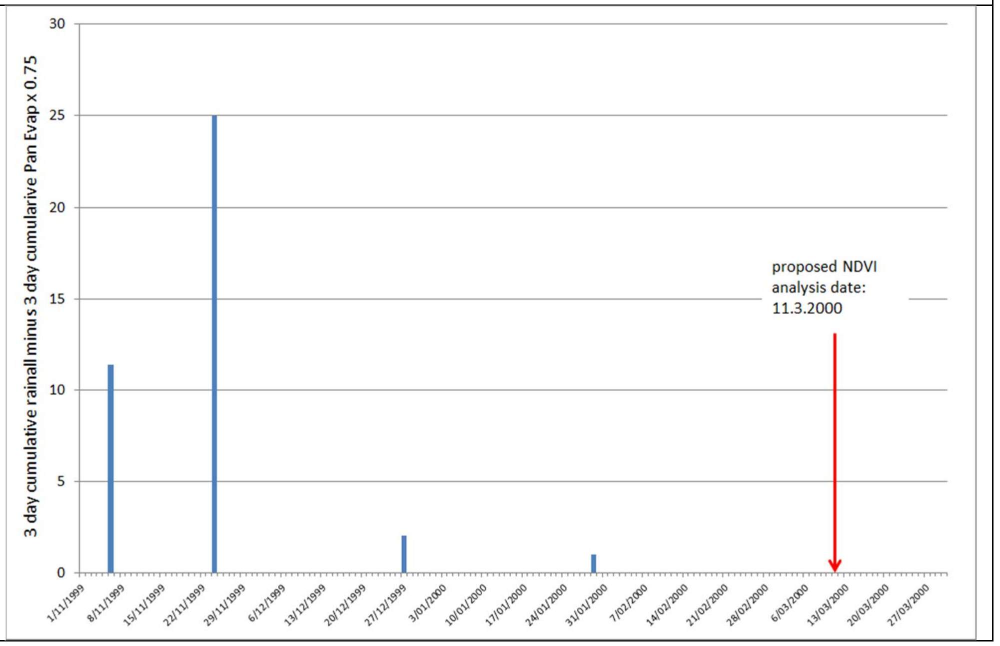




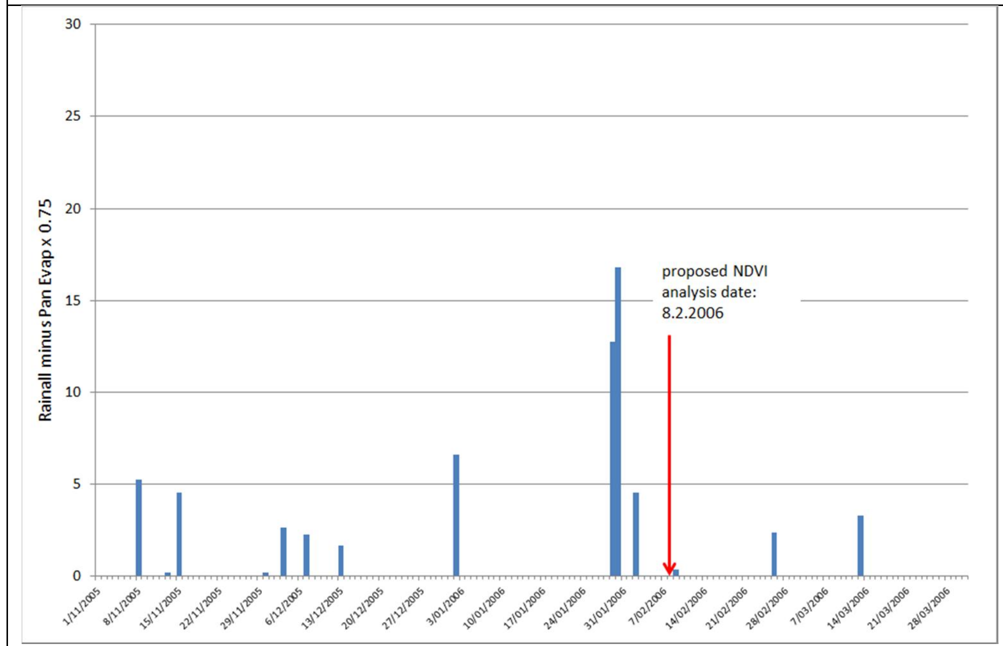
Impact Date 1 (11 March 2000)

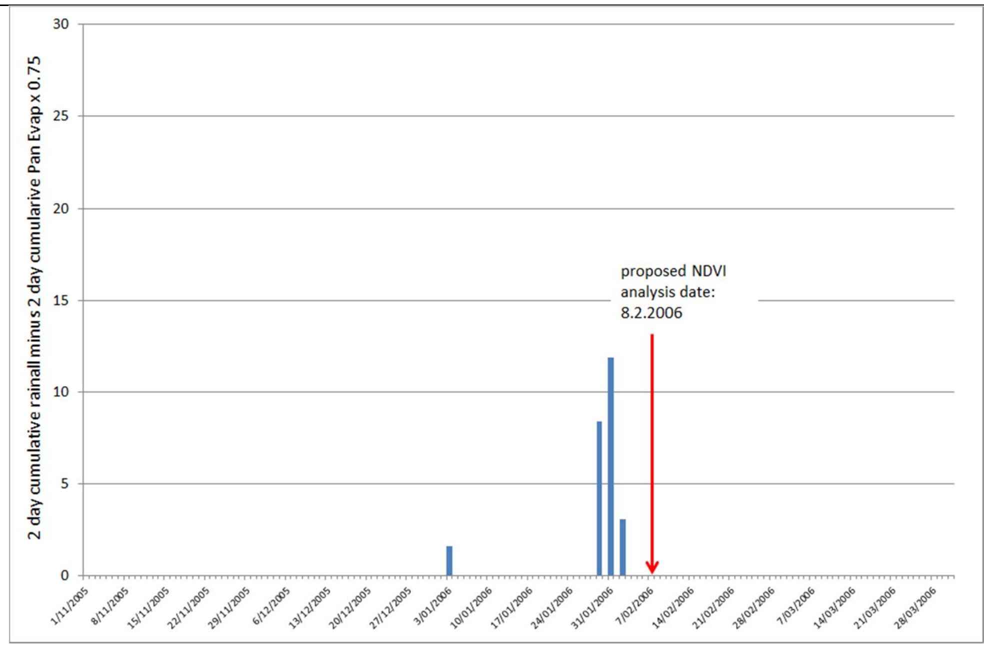


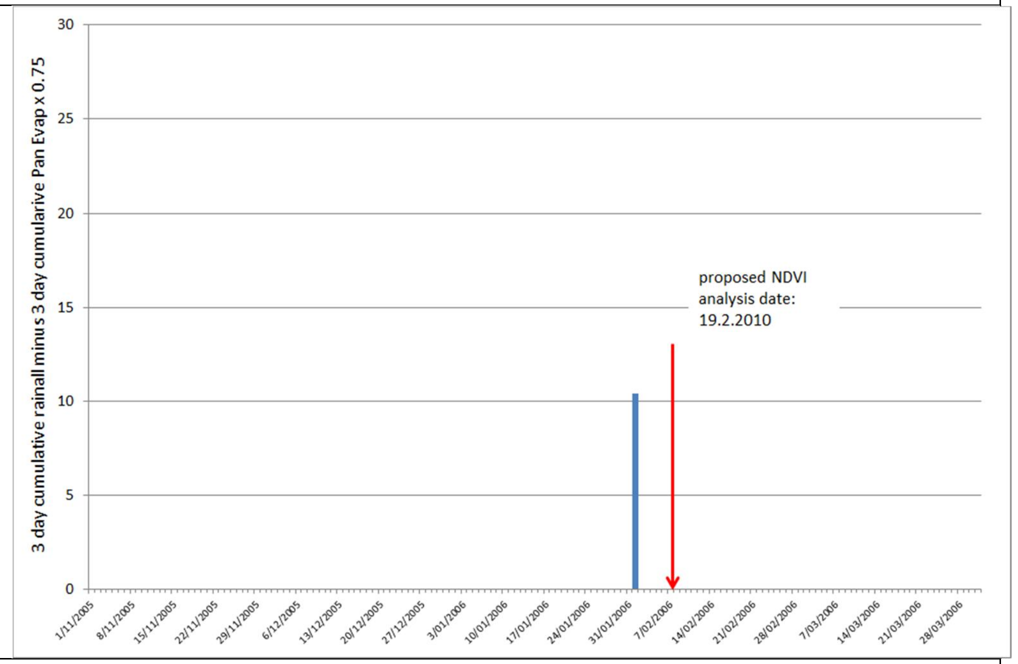




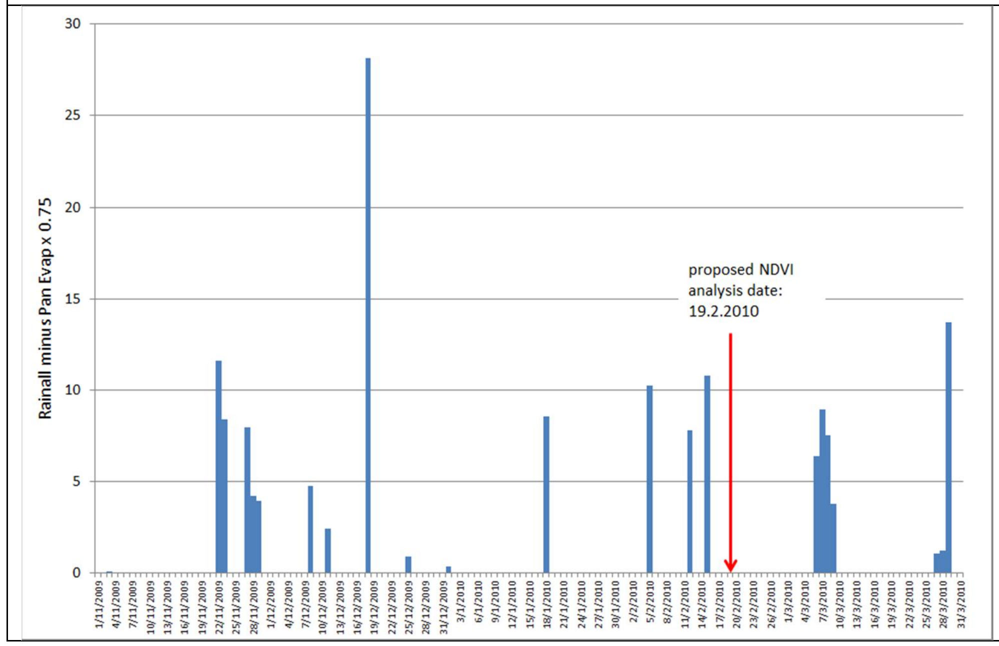
Recovery Date (8 Feb 2006)

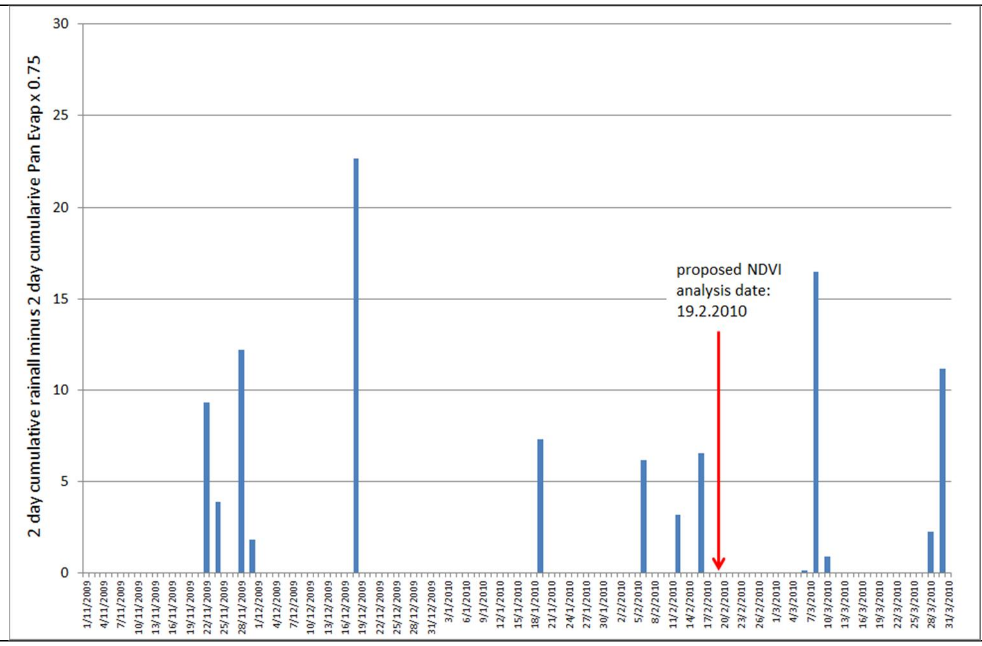


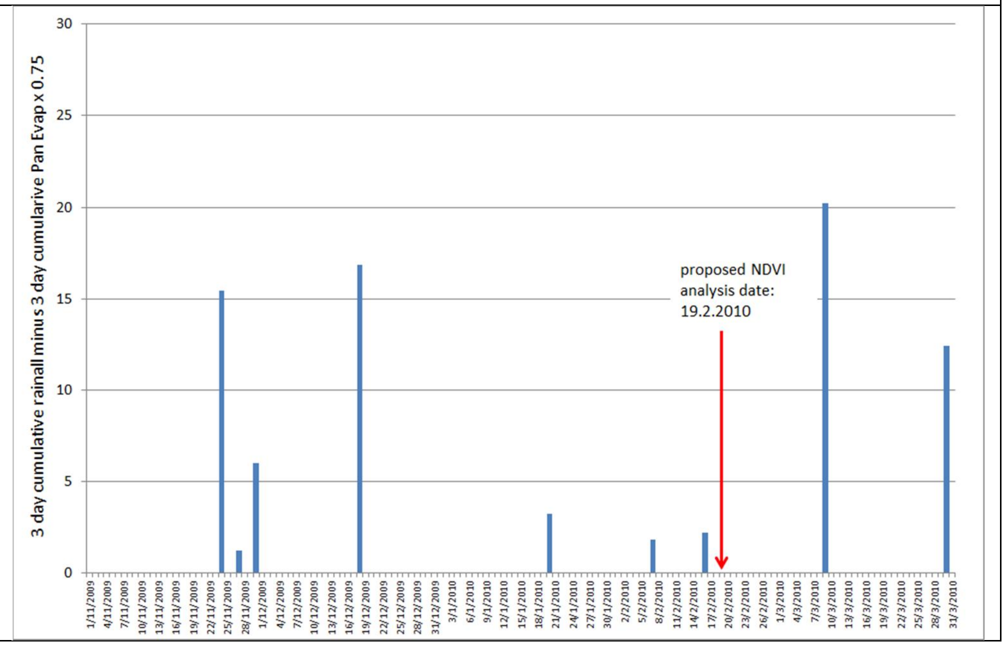




Impact Date 2 – 19 Feb 2010







Appendix C. Soil chemistry and physical properties

Test Report

0439 188 354 | 26 RAILWAY TCE | CUMMINS

www.epanalysis.com.au

Client:

Name	Jacobs Group (Australia) Pty Ltd	Phone 0439 205 600
Address	PO Box 312, Flinders Lane Melbourne VIC 8009	Email Stephen.parsons2@jacobs.com
Attention:	Stephen Parsons	

Sample Log in:

Your Job Reference:	EM1502635 – Jacobs (ISO39500)
EP Analysis Job Reference:	909
Date Received:	26/03/15
No. of Samples:	34
Samples received in appropriate condition for analysis:	yes
Temperature on Receipt:	Ambient
Cooling Method:	None
Turnaround Time requested:	High
Purchase order number/contact:	Stephen Parsons

Results:

Preliminary Report issue date:	NA
Full Report Checked by:	kt
Full Report Issued by:	Kellie Taylor
Full Report issue date:	02/04/15
Via:	email

Quality Control Data:

Quality Control Acceptance Level Definitions can be found in the Report Comments at the end of the report.

Quality Control Results Checked by: kt

Contact Details:

Please direct any queries to Kellie Taylor
ph: 0439 188 354 email: info@epanalysis.com.au

Comments:

Samples will be held for 1 month for water samples and 2 months for Soil Samples from date of receipt of samples.
Perishable samples and dust filters are not retained, unless specifically requested.
Tests not NATA accredited marked with *

Results:

Test	Our Ref:		909-1	909-2	909-3	909-4	909-5
	Your Ref:		011-AA	012-AA	009-AA	010-AA	016-AA
	Matrix:		Soil	Soil	Soil	Soil	Soil
	Depth:		TB1 1.0m	TB1 2.0m	TB2 0.5m	TB2 2.5m	TB4 1.0m
	Unit	Method					
% Sand by Particle Size Determination (pipette method)	%	MTH 2.F	42	73	86	95	66
% Silt by Particle Size Determination (pipette method)	%	MTH 2.F	8	6	10	2	13
% Clay by Particle Size Determination (pipette method)	%	MTH 2.F	50	21	4	3	21

Test	Our Ref:		909-6	909-7	909-8	909-9	909-10
	Your Ref:		017-AA	023-AA	022-AA	004-AA	005-AA
	Matrix:		Soil	Soil	Soil	Soil	Soil
	Depth:		TB4 4.0m	TB5 0.3m	TB5 0.7m	TB6 1.0m	TB6 4.0m
	Unit	Method					
% Sand by Particle Size Determination (pipette method)	%	MTH 2.F	89	76	52	81	97
% Silt by Particle Size Determination (pipette method)	%	MTH 2.F	4	20	12	13	1
% Clay by Particle Size Determination (pipette method)	%	MTH 2.F	7	4	36	6	2

Test	Our Ref:		909-11	909-12	909-13	909-14	909-15
	Your Ref:		006-AA	007-AA	008-AA	018-AA	019-AA
	Matrix:		Soil	Soil	Soil	Soil	Soil
	Depth:		TB7 1.0m	TB7 2.0m	TB7 3.0m	TB8 1.0m	TB8 2.0m
	Unit	Method					
% Sand by Particle Size Determination (pipette method)	%	MTH 2.F	89	59	33	73	65
% Silt by Particle Size Determination (pipette method)	%	MTH 2.F	10	15	15	17	14
% Clay by Particle Size Determination (pipette method)	%	MTH 2.F	1	26	52	10	20

Test	Our Ref:		909-16	909-17	909-18	909-19	909-20
	Your Ref:		020-AA	021-AA	032-AA	033-AA	034-AA
	Matrix:		Soil	Soil	Soil	Soil	Soil
	Depth:		TB8 3.0m	TB8 5.0m	TB9 1.0m	TB9 2.0m	TB9 4.0m
	Unit	Method					
% Sand by Particle Size Determination (pipette method)	%	MTH 2.F	69	38	17	20	58
% Silt by Particle Size Determination (pipette method)	%	MTH 2.F	12	27	46	44	30
% Clay by Particle Size Determination (pipette method)	%	MTH 2.F	18	35	38	36	12

Test	Unit	Method	909-21	909-22	909-23	909-24	909-25
Your Ref:			029-AA	030-AA	031-AA	013-AA	014-AA
Matrix:			Soil	Soil	Soil	Soil	Soil
Depth:			TB10 1.0m	TB10 2.0m	TB10 3.0m	TB11 0.8m	TB11 2.0m
% Sand by Particle Size Determination (pipette method)	%	MTH 2.F	12	52	19	8	6
% Silt by Particle Size Determination (pipette method)	%	MTH 2.F	26	23	34	34	59
% Clay by Particle Size Determination (pipette method)	%	MTH 2.F	62	25	47	58	35

Test	Unit	Method	909-26	909-27	909-28	909-29	909-30
Your Ref:			015-AA	001-AA	002-AA	003-AA	024-AA
Matrix:			Soil	Soil	Soil	Soil	Soil
Depth:			TB11 4.2m	TB12 0.3m	TB12 1.0m	TB12 4.0m	TB13 1.0m
% Sand by Particle Size Determination (pipette method)	%	MTH 2.F	2	77	55	13	21
% Silt by Particle Size Determination (pipette method)	%	MTH 2.F	51	9	33	37	40
% Clay by Particle Size Determination (pipette method)	%	MTH 2.F	47	14	12	50	39

Test	Unit	Method	909-31	909-32	909-33	909-34
Your Ref:			025-AA	026-AA	027-AA	028-AA
Matrix:			Soil	Soil	Soil	Soil
Depth:			TB13 4.0m	TB14 0.3m	TB14 1.6m	TB14 6.0m
% Sand by Particle Size Determination (pipette method)	%	MTH 2.F	1	68	35	63
% Silt by Particle Size Determination (pipette method)	%	MTH 2.F	51	29	30	25
% Clay by Particle Size Determination (pipette method)	%	MTH 2.F	48	3	35	12

Methods:

Method ID	Method Summary
Soils	
In-house 2.F*	Soil Particle Size Analysis (Pipette Method) as per Method 517.02 Organic matter removed from Soil Physical Measurement and Interpretation for Land Evaluation, CSIRO, 2002. Sand Fraction 2mm – 0.063mm, Silt Fraction 0.063mm – 0.002mm, Clay Fraction <0.002mm.

Notes: Tests not NATA accredited marked with *

Quality Control Data:

Assay	Unit	Method	PQL	Duplicate (Base/Dup/%RPD)	Dup. Sample	LCS (%Recovery)
%Sand	%	MTH 2.F	3	59/64/8	909-12	
%Silt	%	MTH 2.F	3	15/12/22	909-12	
%Clay	%	MTH 2.F	3	26/24/8	909-12	103

Assay	Unit	Method	PQL	Duplicate (Base/Dup/%RPD)	Dup. Sample	LCS (%Recovery)
%Sand	%	MTH 2.F	3	19/20/5	909-23	
%Silt	%	MTH 2.F	3	33/32/3	909-23	
%Clay	%	MTH 2.F	3	47/48/2	909-23	102

Sample Collection Data:

Analysis was carried out on samples as received.

Report Comments:

Results:

There are no additional comments.

Quality Control Data:

All Quality Control Data was Acceptable

Glossary of Terms

PQL	Practical Quanititation Limit is 3-5 times the Method Detection Limit.
SPIKE	Addition of the analyte to the sample and reported as percent recovery.
%RPD	Relative Percent Difference between to Duplicate pieces of analysis.
LCS	Laboratory Control Sample – reported as percent recovery.
RM	Reference Material – reported as percent recovery.
Method Blank	In the case of solid samples these are performed on laboratory certified clean sands. In the case of water samples these are performed on de-ionised water.
Surr – Surrogate	The addition of a like compound to the analyte target and reported as percentage recovery.
Duplicate	A second piece of analysis from the same sample and reported in the same units as the result to show comparison.
Batch Duplicate	A second piece of analysis from a sample outside of the clients batch of samples but run within the laboratory batch of analysis.
Batch SPIKE	Spike recovery reported on a sample from outside of the clients batch of samples but run within the laboratory batch of analysis.
COC	Chain of Custody

Quality Control Acceptance Criteria

%RPD Duplicates	Results <10 times the PQL: no limit Results between 10-20 times PQL : RPD must lie between 0-50% Results >20 times the PQL: RPD must lie between 0-30%
LCS Recoveries	Recoveries must lie between 70-130%
CRM Recoveries	Recoveries must lie between 70-130%
Method Blanks	Not to exceed LOR
SPIKE Recoveries	Recoveries must lie between 70-130%
Surrogate Recoveries	Recoveries must lie between 50-150%

Australasian Soil and Plant Analysis Council Inc.

Accredited for compliance with ISO/IEC 17025
NATA Accreditation No: 17220

Full Laboratory Report available upon request
Email: info@epanalysis.com.au

Job No: 909-000 Lab report Date: 02/04/15

Report Authorised by

Kellie Taylor

Managing Director

Final Report – This Report replaces any previously issued Reports.

CERTIFICATE OF ANALYSIS

Work Order	: **EM1502635**	Page	: 1 of 9
Client	: **JACOBS GROUP (AUSTRALIA) PTY LTD**	Laboratory	: Environmental Division Melbourne
Contact	: STEPHEN PARSONS	Contact	: Carol Walsh
Address	: P O BOX 312 FLINDERS LANE MELBOURNE VIC AUSTRALIA 8009	Address	: 4 Westall Rd Springvale VIC Australia 3171
E-mail	: Stephen.Parsons2@jacobs.com	E-mail	: carol.walsh@alsglobal.com
Telephone	: +61 03 8668 3000	Telephone	: +61-3-8549 9608
Facsimile	: +61 03 8668 3001	Facsimile	: +61-3-8549 9601
Project	: IS039500	QC Level	: NEPM 2013 Schedule B(3) and ALS QCS3 requirement
Order number	: ----		
C-O-C number	: ----	Date Samples Received	: 12-MAR-2015
Sampler	: Jacobs	Issue Date	: 19-MAR-2015
Site	: ----		
		No. of samples received	: 34
Quote number	: EN/003/14	No. of samples analysed	: 34

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

NATA Accredited Laboratory 825

Accredited for compliance with ISO/IEC 17025.

WORLD RECOGNISED ACCREDITATION

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Dilani Fernando	Senior Inorganic Chemist	Melbourne Inorganics
Nikki Stepniewski	Senior Inorganic Instrument Chemist	Melbourne Inorganics

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting

- **ED007 and ED008: When Exchangeable Al is reported from these methods, it should be noted that Rayment & Lyons (2011) suggests Exchange Acidity by 1M KCl (Method 15G1) is a more suitable method for the determination of exchange acidity (H+ + Al3+).**
- **ED045G: The presence of thiocyanate can positively contribute to the chloride result, thereby may bias results higher than expected. Results should be scrutinised accordingly.**
- **ED045G:EM1502635_032 has been diluted for Chloride due to sample matrix. LOR has been raised accordingly.**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	TB12 0.3m	TB12 1m	TB12 4m	TB6 1m	TB6 4m
			Client sampling date / time	27-FEB-2015 15:00	27-FEB-2015 15:00	27-FEB-2015 15:00	23-FEB-2015 15:00	23-FEB-2015 15:00
Compound	CAS Number	LOR	Unit	EM1502635-001	EM1502635-002	EM1502635-003	EM1502635-004	EM1502635-005
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	5.9	4.3	3.8	4.4	4.7
EA010: Conductivity								
Electrical Conductivity @ 25°C	----	1	µS/cm	9	12	11	6	4
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	11.4	18.7	39.5	4.2	3.1
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	2.4	0.9	4.5	<0.1	<0.1
Exchangeable Magnesium	----	0.1	meq/100g	2.1	0.5	10.4	0.2	0.2
Exchangeable Potassium	----	0.1	meq/100g	0.1	<0.1	0.2	<0.1	<0.1
Exchangeable Sodium	----	0.1	meq/100g	0.2	0.1	1.1	<0.1	<0.1
Cation Exchange Capacity	----	0.1	meq/100g	4.9	1.7	22.9	0.4	0.4
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	10	mg/kg	<10	10	<10	<10	<10

Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)			*Client sample ID*	TB7 1m	TB7 2m	TB7 3m	TB2 0.5m	TB2 2.5m
			Client sampling date / time	24-FEB-2015 15:00	24-FEB-2015 15:00	24-FEB-2015 15:00	03-MAR-2015 15:00	03-MAR-2015 15:00
Compound	*CAS Number*	*LOR*	*Unit*	**EM1502635-006**	**EM1502635-007**	**EM1502635-008**	**EM1502635-009**	**EM1502635-010**
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	**4.3**	**4.4**	**4.5**	**4.3**	**4.9**
EA010: Conductivity								
Electrical Conductivity @ 25°C	----	1	µS/cm	**2**	**14**	**28**	**37**	**12**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	**3.7**	**17.9**	**24.1**	**2.3**	**8.5**
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	<0.1	<0.1	<0.1	<0.1	<0.1
Exchangeable Magnesium	----	0.1	meq/100g	<0.1	**2.8**	**4.6**	**0.2**	**0.1**
Exchangeable Potassium	----	0.1	meq/100g	<0.1	<0.1	**0.1**	<0.1	<0.1
Exchangeable Sodium	----	0.1	meq/100g	<0.1	**0.3**	**0.6**	**0.2**	**0.1**
Cation Exchange Capacity	----	0.1	meq/100g	<0.1	**3.2**	**5.5**	**0.5**	**0.3**
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	10	mg/kg	<10	<10	**10**	**50**	**10**

Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	TB1 1m	TB1 2m	TB11 0.8m	TB11 2m	TB11 4.2m
Client sampling date / time				26-FEB-2015 15:00	26-FEB-2015 15:00	02-MAR-2015 15:00	02-MAR-2015 15:00	02-MAR-2015 15:00
				EM1502635-011	EM1502635-012	EM1502635-013	EM1502635-014	EM1502635-015
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	5.5	4.1	4.1	4.2	4.2
EA010: Conductivity								
Electrical Conductivity @ 25°C	----	1	µS/cm	232	334	38	24	26
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	15.0	10.6	25.9	23.4	28.9
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	1.3	----	----	1.7	4.2
Exchangeable Magnesium	----	0.1	meq/100g	3.6	----	----	3.1	5.3
Exchangeable Potassium	----	0.1	meq/100g	0.1	----	----	<0.1	0.2
Exchangeable Sodium	----	0.1	meq/100g	2.0	----	----	0.4	0.6
Cation Exchange Capacity	----	0.1	meq/100g	7.2	----	----	5.3	10.3
ED008: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	0.3	1.9	----	----
Exchangeable Magnesium	----	0.1	meq/100g	----	1.0	3.9	----	----
Exchangeable Potassium	----	0.1	meq/100g	----	<0.1	0.2	----	----
Exchangeable Sodium	----	0.1	meq/100g	----	0.1	0.5	----	----
Cation Exchange Capacity	----	0.1	meq/100g	----	1.5	6.8	----	----
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	10	mg/kg	210	410	30	20	30

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)			Client sample ID	TB4 1m	TB4 4m	TB8 1m	TB8 2m	TB8 3m
			Client sampling date / time	26-FEB-2015 15:00	26-FEB-2015 15:00	25-FEB-2015 15:00	25-FEB-2015 15:00	25-FEB-2015 15:00
Compound	CAS Number	LOR	Unit	EM1502635-016	EM1502635-017	EM1502635-018	EM1502635-019	EM1502635-020
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	**4.6**	**4.7**	**4.6**	**4.1**	**3.8**
EA010: Conductivity								
Electrical Conductivity @ 25°C	----	1	µS/cm	**44**	**42**	**22**	**64**	**143**
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	**8.9**	**8.2**	**4.9**	**8.3**	**9.2**
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	<0.1	<0.1	<0.1	**0.2**	<0.1
Exchangeable Magnesium	----	0.1	meq/100g	**3.1**	**0.7**	**0.2**	**1.0**	**1.0**
Exchangeable Potassium	----	0.1	meq/100g	<0.1	<0.1	<0.1	<0.1	<0.1
Exchangeable Sodium	----	0.1	meq/100g	**0.3**	**0.3**	**0.2**	**0.3**	**0.9**
Cation Exchange Capacity	----	0.1	meq/100g	**3.6**	**1.1**	**0.6**	**1.6**	**2.1**
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	10	mg/kg	**60**	**50**	**30**	**80**	**180**

Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)

Compound	CAS Number	LOR	Unit	TB8 5m	TB5 0.7m	TB5 0.3m	TB13 1m	TB13 4m
Client sampling date / time				25-FEB-2015 15:00	02-MAR-2015 15:00	02-MAR-2015 15:00	25-FEB-2015 15:00	25-FEB-2015 15:00
				EM1502635-021	EM1502635-022	EM1502635-023	EM1502635-024	EM1502635-025
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	3.7	4.3	3.8	4.3	8.3
EA010: Conductivity								
Electrical Conductivity @ 25°C	----	1	µS/cm	217	20	8	72	114
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	16.1	10.2	4.4	15.3	26.1
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	1.4	<0.1	<0.1	1.2	13.3
Exchangeable Magnesium	----	0.1	meq/100g	3.2	2.0	0.4	2.9	6.6
Exchangeable Potassium	----	0.1	meq/100g	0.2	<0.1	<0.1	<0.1	0.2
Exchangeable Sodium	----	0.1	meq/100g	1.9	0.3	0.1	0.9	1.5
Cation Exchange Capacity	----	0.1	meq/100g	11.1	2.4	0.7	5.1	21.6
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	10	mg/kg	230	150	20	20	80

Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)

Compound	CAS Number	LOR	Unit	TB14 0.3m	TB14 1.6m	TB14 6m	TB10 1m	TB10 2m
			Client sampling date / time	02-MAR-2015 15:00	02-MAR-2015 15:00	02-MAR-2015 15:00	24-FEB-2015 15:00	24-FEB-2015 15:00
				EM1502635-026	EM1502635-027	EM1502635-028	EM1502635-029	EM1502635-030
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	3.6	4.2	5.2	4.3	4.0
EA010: Conductivity								
Electrical Conductivity @ 25°C	----	1	µS/cm	9	114	41	19	16
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	4.2	13.4	21.3	25.2	17.3
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	0.4	2.2	0.9	<0.1	<0.1
Exchangeable Magnesium	----	0.1	meq/100g	0.4	3.6	0.5	4.7	1.4
Exchangeable Potassium	----	0.1	meq/100g	<0.1	<0.1	<0.1	<0.1	<0.1
Exchangeable Sodium	----	0.1	meq/100g	0.1	1.4	0.2	0.4	0.2
Cation Exchange Capacity	----	0.1	meq/100g	0.9	7.4	1.7	5.2	1.7
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	10	mg/kg	<10	120	60	20	10

Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL)**

Compound	CAS Number	LOR	Unit	TB10 3m	TB9 1m	TB9 2m	TB9 4m	----
			Client sampling date / time	24-FEB-2015 15:00	27-FEB-2015 15:00	27-FEB-2015 15:00	27-FEB-2015 15:00	----
				EM1502635-031	EM1502635-032	EM1502635-033	EM1502635-034	----
EA001: pH in soil using 0.01M CaCl extract								
pH (CaCl2)	----	0.1	pH Unit	3.9	4.0	4.2	5.0	----
EA010: Conductivity								
Electrical Conductivity @ 25°C	----	1	µS/cm	16	37	669	208	----
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	21.0	13.1	21.8	18.9	----
ED007: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	<0.1	0.2	----	1.2	----
Exchangeable Magnesium	----	0.1	meq/100g	3.6	5.6	----	2.3	----
Exchangeable Potassium	----	0.1	meq/100g	<0.1	0.2	----	<0.1	----
Exchangeable Sodium	----	0.1	meq/100g	0.4	0.9	----	1.4	----
Cation Exchange Capacity	----	0.1	meq/100g	5.9	7.3	----	5.0	----
ED008: Exchangeable Cations								
Exchangeable Calcium	----	0.1	meq/100g	----	----	0.4	----	----
Exchangeable Magnesium	----	0.1	meq/100g	----	----	3.1	----	----
Exchangeable Potassium	----	0.1	meq/100g	----	----	<0.1	----	----
Exchangeable Sodium	----	0.1	meq/100g	----	----	1.5	----	----
Cation Exchange Capacity	----	0.1	meq/100g	----	----	5.2	----	----
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	10	mg/kg	<10	<50	1230	300	----

Appendix D. Soil bore logs

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER

SB1

PROJECT NUMBER: **IS039500**
PROJECT NAME: **Barwon Downs Vegetation Investigations**
LOCATION: **Barwon Downs**
DRILLING CO: **Drillmax**
DRILLING METHOD: **Hollow Auger**
BOREHOLE DIAMETER: **125 mm**
DATE STARTED: **26/02/2015** DATE COMPLETED: **26/02/2015**

WELL PERMIT NUMBER: **N/A**
TOTAL DEPTH (m bgl): **3**
REFERENCE POINT: **Ground Surface**
STATIC WATER LEVEL
Date: Depth (mbRP): **3**
PROJECTION: **GDA 1994, Zone 54**
EASTING: **735316** NORTHING: **5743753**

DRILLING INFO.				MATERIAL PROPERTIES		FIELD RECORDS / CONSTRUCTION INFO.						
METHOD	BIT LOG	PENETRATION RATE (m/min)	DEPTH (m)	GRAPHICAL LOG	LITHOLOGY	INTERPRETIVE LOG	WATER CUTS	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	WELL CONSTRUCTION	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
Hollow Augers	125mm Hollow Auger		0.0		Sandy silt: Light brown, soft, loose, poor cohesion.							
					Sandy silt: Light grey/yellow/brown, fine grained, dry minor gravels; up to 20mm, rounded to subrounded, silicic.			-0.81		Roots 1mm diameter to 0.7m		
			1.0		Sandy Clay: Orange/yellow with brown, fine grained, minor mica, minor clay.			-0.62 -1.06	232			42% Sand, 8% Silt, 50% Clay
			2.0		Clayey Sand: Light grey with minor diffuse orange/brown mottling, fine grained becoming courser with depth, firm, friable, low cohesion, minor mica, minor clay.			-1.03 -0.79 -0.83 -1.04	334	damp from 2.5m		73% Sand, 6% Silt, 21% Clay
			3.0		EOH @ 3 metres					Refusal at 3m		
			4.0									
			5.0									
			6.0									

LOGGED: N. Unland DATE: 26/02/2015
CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER: SB2

PROJECT NUMBER: **IS039500**
PROJECT NAME: **Barwon Downs Vegetation Investigations**
LOCATION: **Barwon Downs**
DRILLING CO: **Drillmax**
DRILLING METHOD: **Hollow Auger**
BOREHOLE DIAMETER: **125 mm**
DATE STARTED: **02/03/2015** DATE COMPLETED: **02/03/2015**

WELL PERMIT NUMBER: **N/A**
TOTAL DEPTH (m bgl): **3.2**
REFERENCE POINT: **Ground Surface**
STATIC WATER LEVEL
Date: **02/03/2015** Depth (mbRP): **1.7**
PROJECTION: **GDA 1994, Zone 54**
EASTING: **734639** NORTHING: **5743993**

DRILLING INFO. | MATERIAL PROPERTIES | FIELD RECORDS / CONSTRUCTION INFO.

Method: Hollow Augers (0.0–3.2 m). Bit log: 125mm Hollow Auger (0.0–3.2 m).

DEPTH (m)	LITHOLOGY	WATER CUTS	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
0.0–0.2	Silty sand: Dark brown, fine grained, loose, dry, organic matter.					
0.2–0.8	Sand: Light grey to yellow/brown, medium to fine grained, well sorted, dry.		-0.62	37	Roots up to 3mm in diameter to 0.8m	86% Sand, 10% Silt, 4% Clay
0.8–1.5	Silty Sand: Light grey, fine grained, soft to firm.		-0.09 -0.03		damp from 0.8m	
1.5–3.0	Sand: Light brown to yellow/brown, fine grained, loose.	WC	0 0 0 0	12	Wet after 1.6m	95% Sand, 2% Silt, 3% Clay
3.0–3.2	Sand: Light brown to yellow/brown, iron cemented, fine grained.					
3.2	EOH @ 3.2 metres				Refusal at 3.3m	

LOGGED: N. Unland DATE: 02/03/2015
CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER: SB4

PROJECT NUMBER: **IS039500**
PROJECT NAME: **Barwon Downs Vegetation Investigations**
LOCATION: **Barwon Downs**
DRILLING CO: **Drillmax**
DRILLING METHOD: **Hollow Auger**
BOREHOLE DIAMETER: **125 mm**
DATE STARTED: **26/02/2015** DATE COMPLETED: **26/02/2015**

WELL PERMIT NUMBER: **N/A**
TOTAL DEPTH (m bgl): **6.5**
REFERENCE POINT: **Ground Surface**
STATIC WATER LEVEL
Date: **26/02/2015** Depth (mbRP):
PROJECTION: **GDA 1994, Zone 54**
EASTING: **732955** NORTHING: **57444156**

DRILLING INFO. (METHOD: Hollow Augers; BIT LOG: 125mm Hollow Auger; PENETRATION RATE (m/min); DEPTH (m))

Depth (m)	LITHOLOGY (MATERIAL PROPERTIES)	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
0.0	Sandy silt: Light brown to light grey, fine grained, dry, poor cohesion.				
	Silty sand: Grey/yellow, fine grained, dry.	-0.22			
	Clayey Sand: Yellow/brown to orange, firm to hard.	-0.33			
1.0			44		66% Sand, 13% Silt, 21% Clay
		-0.79			
		-0.65			
2.0	Sandy Silt: Yellow/brown, fine grained, minor quartz clasts.	-0.62		Minor roots ~1mm in diameter above 2m	
		-0.23			
	Sand: Orange/brown, soft, well sorted, damp.	-0.02		Damp from 2.8m	
3.0	Sandy silty clay: Orange with light grey mollting, soft to firm, low plasticity.	0			
	Sandy silty clay: Orange with light grey mollting, soft to firm, low plasticity, interlayered with clay bands.	-0.24			
4.0	Sand: Light grey/brown, fine grained, minor silt, soft, poor cohesion.	-0.01	42		89% Sand, 4% Silt, 7% Clay
	Sand: Light grey/brown with minor orange diffued mottling, fine grained, minor silt, soft with poor cohesion.				
5.0		-0.04			
6.0		-0.02			
6.5	EOH @ 6.5 metres				
7.0					

(Columns GRAPHICAL LOG, INTERPRETIVE LOG, WATER CUTS, WELL CONSTRUCTION: no entries.)

LOGGED: N. Unland DATE: 26/02/2015
CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER: SB5

PROJECT NUMBER:	**IS039500**	WELL PERMIT NUMBER:	**N/A**
PROJECT NAME:	**Barwon Downs Vegetation Investigations**	TOTAL DEPTH (m bgl):	**3.3**
LOCATION:	**Barwon Downs**	REFERENCE POINT:	**Ground Surface**
DRILLING CO:	**Drillmax**	STATIC WATER LEVEL	
DRILLING METHOD:	**Hollow Auger**	Date: **02/03/2015**	Depth (mbRP):
BOREHOLE DIAMETER:	**125 mm**	PROJECTION:	**GDA 1994, Zone 54**
DATE STARTED: **02/03/2015**	DATE COMPLETED: **02/03/2015**	EASTING: **731011**	NORTHING: **5743996**

DRILLING INFO. | MATERIAL PROPERTIES | FIELD RECORDS / CONSTRUCTION INFO.

METHOD	BIT LOG	PENETRATION RATE (m/min)	DEPTH (m)	GRAPHICAL LOG	LITHOLOGY	INTERPRETIVE LOG	WATER CUTS	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	WELL CONSTRUCTION	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
Hollow Augers (0.0–3.3)	125mm Hollow Auger (0.0–3.3)		0.0		Sandy silt: Brown, fine grained, organic matter, soft, dry.							
					Silty sand: Light grey, fine grained, soft, low cohesion.			-0.24	8			76% Sand, 20% Silt, 4% Clay
					Clayey Sand: Orange with red mottling, firm to hard, fine grained.			-0.13	20	Minor roots up to 3 mm in diameter to 0.8m depth		52% Sand, 12% Silt, 36% Clay
			1.0					0		Damp		
					Sandy Clay: Orange with red mottling, firm to hard with depth, fine grained, minor clay, minor iron rich clasts, 20 to 30 mm in size, sub angular.			-0.07				
			2.0					-0.21				
								-0.43				
								-0.34				
			3.0		Sandy Clay: Orange with red, firm to hard with depth, fine grained, damp, minor clay, minor iron rich grains, ~15 mm in size, sub angular.			-0.4				
					EOH @ 3.3 metres					Refusal at 3.3m due to hard sandy material (possibly lithic sandstone)		
			4.0									
			5.0									
			6.0									

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CHECKED: L. Randell — DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

BOREHOLE / WELL NUMBER: SB6

PROJECT NUMBER: **IS039500**
PROJECT NAME: **Barwon Downs Vegetation Investigations**
LOCATION: **Barwon Downs**
DRILLING CO: **Drillmax**
DRILLING METHOD: **Hollow Auger**
BOREHOLE DIAMETER: **125 mm**
DATE STARTED: **23/02/2015** DATE COMPLETED: **23/02/2015**

WELL PERMIT NUMBER: **N/A**
TOTAL DEPTH (m bgl): **4**
REFERENCE POINT: **Ground Surface**
STATIC WATER LEVEL
Date: **23/02/2015** Depth (mbRP):
PROJECTION: **GDA 1994, Zone 54**
EASTING: **729425** NORTHING: **5743269**

METHOD	BIT LOG	PENETRATION RATE (m/min)	DEPTH (m)	GRAPHICAL LOG	LITHOLOGY	INTERPRETIVE LOG	WATER CUTS	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	WELL CONSTRUCTION	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
Hollow Augers (0.0–4.0)	125mm Hollow Auger (0.0–4.0)		0.0–0.3		Sandy silt: Brown, medium to course grained, poor cohesion, minor organic matter.					Minor roots 0 to 0.5m		
			0.3–0.6		Sand: Light grey, medium to course grained, sub rounded, soft, poor cohesion.			-0.19				
			0.6–2.8		Sand: Orange to brown/orange, medium to course grained, sub rounded, soft, poor cohesion.			-0.02				
			1.0						6			81% Sand, 13% Silt, 6% Clay
								-0.07				
			1.5					-0.09		Damp from 1.5m		
			2.0					-0.04				
								-0.07				
			2.8–4.0		Sand: Red/orange with medium brown diffuse mottling, course grained, subrounded.			-0.02				
			3.0					-0.03				
								-0.02				
			4.0		EOH @ 4 metres				4	Refusal at 4m		97% Sand, 1% Silt, 2% Clay

Depth scale: 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0

LOGGED: N. Unland DATE: 23/02/2015
CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

BOREHOLE / WELL NUMBER: SB7

PROJECT NUMBER: **IS039500**
PROJECT NAME: **Barwon Downs Vegetation Investigations**
LOCATION: **Barwon Downs**
DRILLING CO: **Drillmax**
DRILLING METHOD: **Hollow Auger**
BOREHOLE DIAMETER: **125 mm**
DATE STARTED: **24/02/2015** DATE COMPLETED: **24/02/2015**

WELL PERMIT NUMBER: **N/A**
TOTAL DEPTH (m bgl): **3**
REFERENCE POINT: **Ground Surface**
STATIC WATER LEVEL
Date: **24/02/2015** Depth (mbRP):
PROJECTION: **GDA 1994, Zone 54**
EASTING: **727544** NORTHING: **5742302**

DRILLING INFO. | MATERIAL PROPERTIES | FIELD RECORDS / CONSTRUCTION INFO.

Method: Hollow Augers (0.0–3.0 m); Bit log: 125mm Hollow Auger (0.0–3.0 m)

DEPTH (m)	LITHOLOGY	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
0.0	Sand: Orange/brown/grey, medium to course sands, sub rounded, minor silts and clays.				
	Silty Sand: Dark brown/black, medium sub rounded grains.	-0.01		Abundant plant roots 0 to 0.5 m	
	Sand: Light grey, meduim to fine sub rounded grains, well sorted, minor silt.	-0.06		Sample Wet	
1.0	Clayey Sand: Dark brown, medium subrounded grains, silicaoucous.	-0.02	2		89% Sand, 10% Silt, 1% Clay
	Clayey Sand: Light grey with diffuse orange, medium to course grains, rounded.	-0.04			
2.0		-0.12	14		59% Sand, 15% Silt, 26% Clay
	Sandy Clay: Light grey with orange mottling, stiff, high plasticity.	-0.14			
		-0.19			
3.0	EOH @ 3 metres		28		33% Sand, 15% Silt, 52% Clay
4.0					
5.0					
6.0					

LOGGED: N. Unland DATE: 24/02/2015
CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER: SB8

PROJECT NUMBER:	**IS039500**	WELL PERMIT NUMBER:	**N/A**
PROJECT NAME:	**Barwon Downs Vegetation Investigations**	TOTAL DEPTH (m bgl):	**6.5**
LOCATION:	**Barwon Downs**	REFERENCE POINT:	**Ground Surface**
DRILLING CO:	**Drillmax**	STATIC WATER LEVEL	
DRILLING METHOD:	**Hollow Auger**	Date: **25/02/2015**	Depth (mbRP):
BOREHOLE DIAMETER:	**125 mm**	PROJECTION:	**GDA 1994, Zone 54**
DATE STARTED: **25/02/2015**	DATE COMPLETED: **25/02/2015**	EASTING: **734226**	NORTHING: **5741587**

DRILLING INFO. | MATERIAL PROPERTIES | FIELD RECORDS / CONSTRUCTION INFO.

Columns: METHOD | BIT LOG | PENETRATION RATE (m/min) | DEPTH (m) | GRAPHICAL LOG | LITHOLOGY | INTERPRETIVE LOG | WATER CUTS | Soil moisture (MPa) | Soil EC (uS/cm) | COMMENTS | WELL CONSTRUCTION | SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY

Method: Hollow Augers (0.0–6.5 m)

Bit log: 125mm Hollow Auger (0.0–6.5 m)

Depth scale (m): 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0

Lithology (top to bottom):

- Silty sand: Light brown to yellow, medium grained, roots and organic matter, minor clay.
- Sandy Silt: Yellow/brown, minor fine grained sand.
- Silty Sand: Yellow/brown to grey, fine grained.
- Clayey Sand: Yellow /brown with diffuse grey mottling, minor clay, sand; medium to large grains, rounded, poorly sorted.
- Clayey Sand: Light grey, fine grained, firm.
- Gravel: Yellow /brown to light grey, well rounded, pooly sorted alluvial, quatrz, clay matrix; grey, firm cohesive, medium plasticity.
- Silty clay: Light grey with yellow mottling, firm to hard, low to medium plasticity.
- Silty Sandy Clay: Grey with red orange mottling, firm to hard, low to medium plasticity.
- Silty Clay: Soft to firm, low to medium plasticity.

EOH @ 6.5 metres

Soil moisture (MPa), top to bottom: -0.9, -0.23, -0.37, -0.74, -0.42, -0.5, -0.47, -0.5, -0.76, -0.56, -0.37, -0.19

Soil EC (uS/cm), top to bottom: 22, 64, 143, 217

Comments, top to bottom:

- Roots ~1mm diameter.
- Minor roots >1mm in diameter 1.5 to 2.5m
- Hard ground
- Damp, minor roots, 10 to 15 mm 3.5 to 5.7m
- minor roots <1mm 5.7 to 6.5m

Soil texture analysis, top to bottom:

- 73% Sand, 17% Silt, 10% Clay
- 65% Sand, 14% Silt, 20% Clay
- 69% Sand, 12% Silt, 18% Clay
- 38% Sand, 27% Silt, 35% Clay

LOGGED:	N. Unland	DATE:	25/02/2015
CHECKED:	L. Randell	DATE:	20/03/2015

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER: SB9

PROJECT NUMBER:	**IS039500**	WELL PERMIT NUMBER:	**N/A**
PROJECT NAME:	**Barwon Downs Vegetation Investigations**	TOTAL DEPTH (m bgl):	**4**
LOCATION:	**Barwon Downs**	REFERENCE POINT:	**Ground Surface**
DRILLING CO:	**Drillmax**	STATIC WATER LEVEL	
DRILLING METHOD:	**Hollow Auger**	Date: **27/02/2015**	Depth (mbRP):
BOREHOLE DIAMETER:	**125 mm**	PROJECTION:	**GDA 1994, Zone 54**
DATE STARTED: **27/02/2015**	DATE COMPLETED: **27/02/2015**	EASTING: **731968**	NORTHING: **5735446**

DRILLING INFO. | MATERIAL PROPERTIES | FIELD RECORDS / CONSTRUCTION INFO.

METHOD	BIT LOG	PENETRATION RATE (m/min)	DEPTH (m)	GRAPHICAL LOG	LITHOLOGY	INTERPRETIVE LOG	WATER CUTS	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	WELL CONSTRUCTION	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
Hollow Augers	125mm Hollow Auger		0.0		Sandy silt: Light brown, fine grained, soft, poor cohesion.							
					Clayey silt: Light brown/grey, firm to hard, cohesive, low to medium plasticity.			-0.79		Minor roots 0 to 0.2m; Damp		
			1.0		Clayey silt: Light grey with diffuse yellow brown mottles, dry friable, firm to hard.			-0.71; -0.48	37	Abundant roots to 1mm diameter 0.8 to 1.2m		17% Sand, 46% Silt, 38% Clay
			2.0		Silty Sand: Light grey with minor diffuse orange mottling, fine grained, soft, low cohesion, dry.			-0.66; -0.63	669	Minor fine roots with one 8 mm root at 2.1m.		20% Sand, 44% Silt, 36% Clay
			3.0		Silty clay: Dark grey with diffuse yellow mottling, firm to soft, low plasticity, low cohesion, minor fine grained sands increasing with depth.		WC	-0.76; -0.64; -0.76; -0.42		Sample wet from 3m; Minor roots >1mm in diameter 2.2 to 3.7m		
					Sandy clay: Dark grey, soft, low plasticity, minor fine sands.							
			4.0		EOH @ 4 metres			-0.25	208			58% Sand, 30% Silt, 12% Clay
			5.0									
			6.0									

LOGGED: N. Unland DATE: 27/02/2015

CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

BOREHOLE / WELL NUMBER: SB10

JACOBS

PROJECT NUMBER: **IS039500**
PROJECT NAME: **Barwon Downs Vegetation Investigations**
LOCATION: **Barwon Downs**
DRILLING CO: **Drillmax**
DRILLING METHOD: **Hollow Auger**
BOREHOLE DIAMETER: **125 mm**
DATE STARTED: **24/02/2015** DATE COMPLETED: **24/02/2015**

WELL PERMIT NUMBER: **N/A**
TOTAL DEPTH (m bgl): **5**
REFERENCE POINT: **Ground Surface**
STATIC WATER LEVEL
Date: **24/02/2015** Depth (mbRP):
PROJECTION: **GDA 1994, Zone 54**
EASTING: **728385** NORTHING: **5739951**

DRILLING INFO. — METHOD: Hollow Augers (0.0–5.0 m); BIT LOG: 125mm Hollow Auger (0.0–5.0 m)

DEPTH (m)	LITHOLOGY	WATER CUTS	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
0.0–0.3	Silt: Dark brown with yellow brown mottling, minor sands, fine grained, dry, poor cohesion.					
0.3–0.5	Clayey silt: Yellow/brown to brown grey, minor fine sands, poor cohesion, soft.		-0.05		Slightly damp minor roots <1mm diameter	
0.5–1.5	Clay: Light grey with orange mottling, heavy, high plasticity, firm to hard.		-0.18 -0.14	19		12% Sand, 26% Silt, 62% Clay
1.5–1.8	Clay: Light grey, heavy, hard, minor silts and fine sands.		-0.11		Slightly damp minor roots <6mm diameter	
1.8–2.0	Sand: Orange/brown, fine to medium grained.					
2.0–2.5	Clayey Silt: Light grey, minor sands, fine grained, poor cohesion.		-0.02 -0.06	16		52% Sand, 23% Silt, 25% Clay
2.5–3.0	Clayey Silt: Orange, minor fine sands, poor cohesion.		-0.31			
3.0–3.3	Silty Clay: Light grey with diffuse orange mottling, medium plasticity, minor sands; light grey, fine grained.		-0.03	16		19% Sand, 34% Silt, 47% Clay
3.3–4.0	Silty clay: Light grey, moderate plasticity,minor sands increasing with depth.		-0.02 -0.09			
4.0–5.0	Clay: Brown to orange, firm to soft, high plasticity, traces of mica.	WC			Sample wet following 4.5m	
5.0	EOH @ 5 metres		-0.01			

LOGGED: N. Unland DATE: 24/02/2015
CHECKED: L. Randell DATE: 20/03/2015

JACOBS

FIELD BOREHOLE / WELL LOG

BOREHOLE / WELL NUMBER: SB11

PROJECT NUMBER:	**IS039500**	WELL PERMIT NUMBER:	**N/A**
PROJECT NAME:	**Barwon Downs Vegetation Investigations**	TOTAL DEPTH (m bgl):	**5**
LOCATION:	**Barwon Downs**	REFERENCE POINT:	**Ground Surface**
DRILLING CO:	**Drillmax**	STATIC WATER LEVEL	
DRILLING METHOD:	**Hollow Auger**	Date: **02/03/2015**	Depth (mbRP):
BOREHOLE DIAMETER:	**125 mm**	PROJECTION:	**GDA 1994, Zone 54**
DATE STARTED: **02/03/2015**	DATE COMPLETED: **02/03/2015**	EASTING: **730561**	NORTHING: **5736699**

DRILLING INFO. — METHOD | BIT LOG | PENETRATION RATE (m/min) | DEPTH (m)

MATERIAL PROPERTIES — GRAPHICAL LOG | LITHOLOGY | INTERPRETIVE LOG

FIELD RECORDS / CONSTRUCTION INFO. — WATER CUTS | Soil moisture (MPa) | Soil EC (uS/cm) | COMMENTS | WELL CONSTRUCTION | SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY

METHOD: Hollow Augers (0.0–5.0 m)

BIT LOG: 125mm Hollow Auger (0.0–5.0 m)

Depth (m)	Lithology
0.0–0.4	Sandy silt: Yellow/brown to grey/brown, firm, minor sands.
0.4–1.5	Silty clay: Orange/brown/white with light grey mottling, moderate plasticity, friable.
1.5–2.5	Silty Clay: Light grey with diffuse yellow brown mottling, heavy, high plasticity, highly coheasive, firm to hard, minor mica.
2.5–3.0	Clay: Light grey with diffuse red mottling, heavy, high plasticity, highly coheasive, firm, minor mica.
3.0–5.0	Silty Clay: Light grey with diffuse red mottling, heavy, high plasticity, highly coheasive, soft to firm, getting harder with depth, minor mica.
5.0	EOH @ 5 metres

Soil moisture (MPa)	Soil EC (uS/cm)	Comments	Soil texture analysis
-0.22		Abundant roots 1 to 2mm in diameter	
-0.07	38		8% Sand, 34% Silt, 58% Clay
-0.01		Damp from 0.5m onwards	
-0.01			
-0.05	24		6% Sand, 59% Silt, 35% Clay
-0.04			
-0.15			
-0.01			
-0.02			
-0.06			
	26		2% Sand, 51% Silt, 47% Clay
0			

LOGGED: N. Unland DATE: 02/03/2015

CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER: SB12

PROJECT NUMBER:	**IS039500**	WELL PERMIT NUMBER:	**N/A**
PROJECT NAME:	**Barwon Downs Vegetation Investigations**	TOTAL DEPTH (m bgl):	**4**
LOCATION:	**Barwon Downs**	REFERENCE POINT:	**Ground Surface**
DRILLING CO:	**Drillmax**	STATIC WATER LEVEL	
DRILLING METHOD:	**Hollow Auger**	Date: **27/02/2015**	Depth (mbRP):
BOREHOLE DIAMETER:	**125 mm**	PROJECTION:	**GDA 1994, Zone 54**
DATE STARTED: **27/02/2015**	DATE COMPLETED: **27/02/2015**	EASTING: **731130**	NORTHING: **5740159**

DRILLING INFO. | MATERIAL PROPERTIES | FIELD RECORDS / CONSTRUCTION INFO.

METHOD	BIT LOG	PENETRATION RATE (m/min)	DEPTH (m)	GRAPHICAL LOG	LITHOLOGY	INTERPRETIVE LOG	WATER CUTS	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	WELL CONSTRUCTION	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
Hollow Augers (0.0–4.0)	125mm Hollow Auger (0.0–4.0)		0.0		Sandy silt: Brown, minor gravels; well rounded quartz, to 15mm, organic matter, moderate cohesion.					Abundant roots 0 to 0.5m		
					Silty sand: Orange brown, medium to fine grained, soft, poor cohesion, minor clay, damp to very damp, minor course sands; silicic, rounded grains.			-0.11	9	Very damp to wet from 0.6m		77% Sand, 9% Silt, 14% Clay
			1.0		Silty Sand: Grey, soft, cohesive, low plasticity.			0	12	Abundant roots, red staining surrounding roots possibly iron hydroxide related to potential acid sulphate soil.		55% Sand, 33% Silt, 12% Clay
					Clay: Grey, moderate to high plasticity, soft to firm, coheasive.			-0.01				
								-0.02				
			2.0		Sandy clay: Light grey with horizontal orange mottled layers ~1mm thick, moderate to high plasticity, minor fine sands.			0		Minor roots 1mm one 3mm root at ~2.5m		
			3.0									
					Silty Clay: Light grey, with orange horizontal mottling, firm, minor mica.							
			4.0		EOH @ 4 metres				11			13% Sand, 37% Silt, 50% Clay
			5.0									
			6.0									

LOGGED: N. Unland DATE: 27/02/2015

CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER: SB13

PROJECT NUMBER:	**IS039500**	WELL PERMIT NUMBER:	**N/A**
PROJECT NAME:	**Barwon Downs Vegetation Investigations**	TOTAL DEPTH (m bgl):	**5.5**
LOCATION:	**Barwon Downs**	REFERENCE POINT:	**Ground Surface**
DRILLING CO:	**Drillmax**	STATIC WATER LEVEL	
DRILLING METHOD:	**Hollow Auger**	Date: **25/02/2015**	Depth (mbRP):
BOREHOLE DIAMETER:	**125 mm**	PROJECTION:	**GDA 1994, Zone 54**
DATE STARTED: **25/02/2015**	DATE COMPLETED: **25/02/2015**	EASTING: **729600**	NORTHING: **5738929**

DRILLING INFO. (METHOD: Hollow Augers, 0.0–4.0 m; BIT LOG: 125mm Hollow Auger, 0.0–4.0 m)

DEPTH (m)	LITHOLOGY	WATER CUTS	Soil moisture (MPa)	Soil EC (uS/cm)	COMMENTS	SOIL TEXTURE ANALYSIS % SAND, % SILT, % CLAY
0.0–0.3	Silt: Brown, dry, poor cohesion.					
0.3–0.6	Silt: Light brown/yellow, firm friable, dry.		-0.08		Roots up to 8mm in diameter.	
0.6–1.5	Silty Clay: Yellow/brown with light grey mottling, firm friable, poor to moderate cohesion.		-0.18		Roots ~1mm diameter	
				72	Slightly damp	21% Sand, 40% Silt, 39% Clay
			-0.08			
1.5–2.0	Clay: Light grey with yellow/brown diffuse mottling, firm, moderate plasticity.		-0.21			
2.0–3.0	Clayey silt: Light grey with yellow/brown diffuse mottling, friable, firm, minor sands; fine grained.		-0.67			
			-0.47			
			-0.43			
3.0–4.0	Silty clay: Yellow/brown, firm, low plasticity.		-0.16			
			-0.12			
4.0–5.5	Silty clay: Yellow/brown with light grey mottling, firm, low plasticity.		-0.26	114	Minor roots (5 to 10mm) at 4m	1% Sand, 51% Silt, 48% Clay
		WC			Sample wet below 4.8m	
			-0.02			
5.5	EOH @ 5.5 metres					

LOGGED: N. Unland DATE: 25/02/2015

CHECKED: L. Randell DATE: 20/03/2015

FIELD BOREHOLE / WELL LOG

JACOBS

BOREHOLE / WELL NUMBER: SB14

PROJECT NUMBER: **IS039500**
PROJECT NAME: **Barwon Downs Vegetation Investigations**
LOCATION: **Barwon Downs**
DRILLING CO: **Drillmax**
DRILLING METHOD: **Hollow Auger**
BOREHOLE DIAMETER: **125 mm**
DATE STARTED: **28/02/2015** DATE COMPLETED: **28/02/2015**

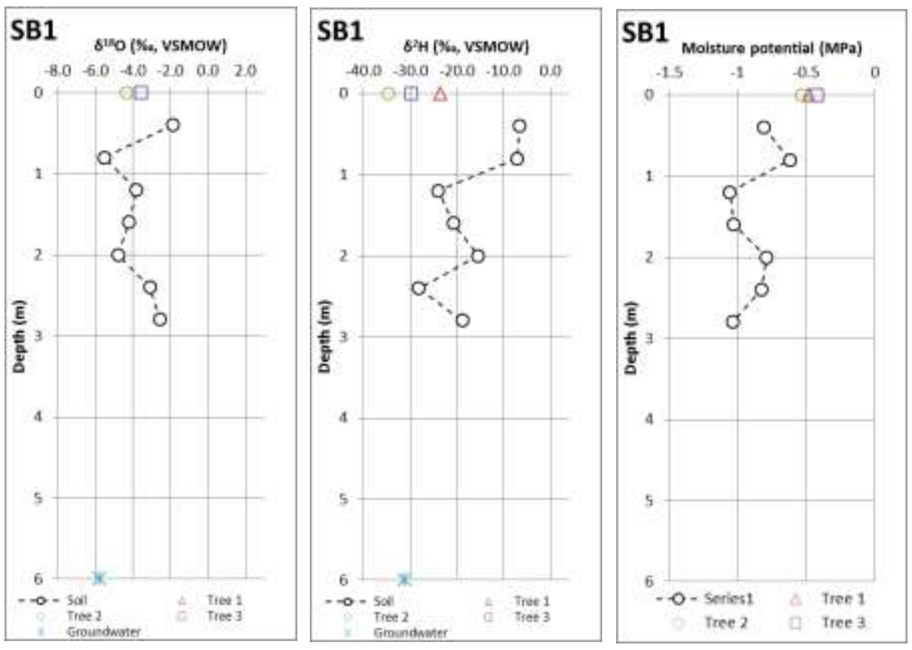
WELL PERMIT NUMBER: **N/A**
TOTAL DEPTH (m bgl): **6**
REFERENCE POINT: **Ground Surface**
STATIC WATER LEVEL
Date: **28/02/2015** Depth (mbRP):
PROJECTION: **GDA 1994, Zone 54**
EASTING: **726683** NORTHING: **5740005**

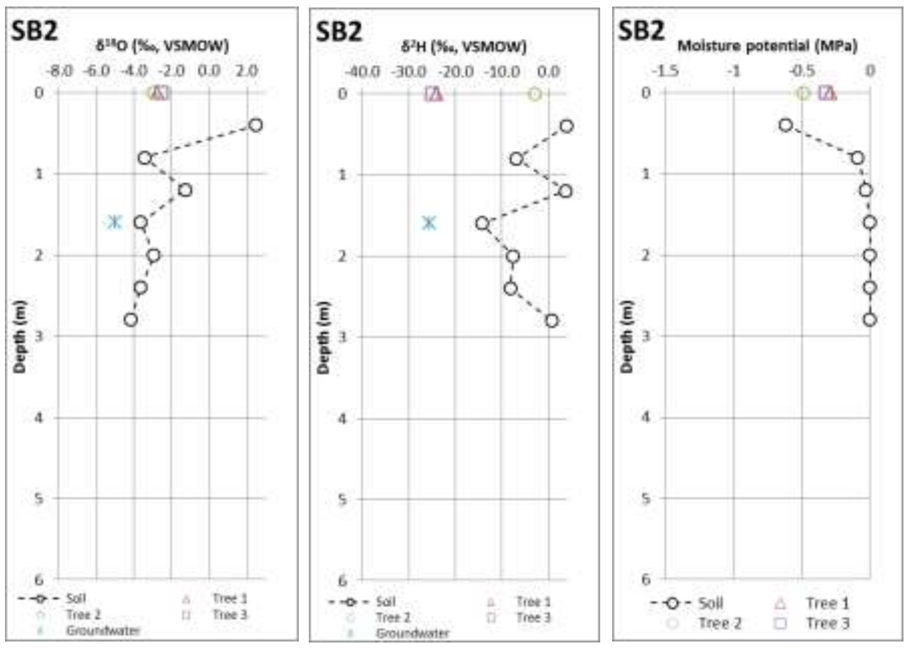
DRILLING INFO. — Method: Hollow Augers (0.0–6.0 m); Bit log: 125mm Hollow Auger (0.0–6.0 m)

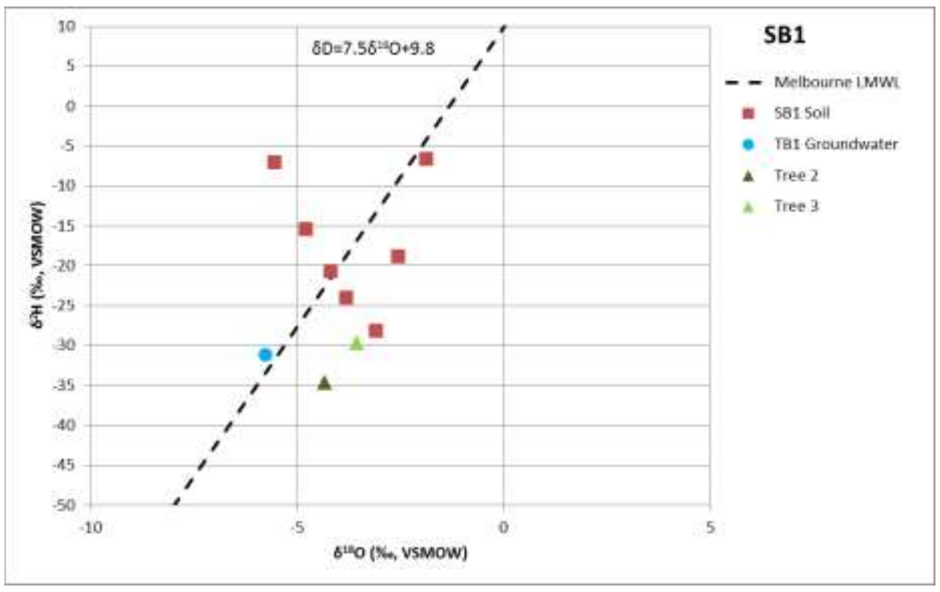
Depth (m)	Lithology	Water cuts	Soil moisture (MPa)	Soil EC (uS/cm)	Comments	Soil texture analysis (% Sand, % Silt, % Clay)
0.0–0.3	Silt: Black, fine grained, loose, organic matter.					
0.3–0.7	Silty Sand: Light grey, fine grained, loose, organic matter.		-0.08	9	Abundant roots 0 to 0.7m	68% Sand, 29% Silt, 3% Clay
0.7–1.5	Clay: Orange with grey mottling, low plasticity.		-0.18 -0.08			
1.5–2.0	Silty Sand: Dark brown, low plasticity.		-0.21	114		35% Sand, 30% Silt, 35% Clay
2.0–4.5	Silty Sand: Grey with orange mottling, low plasticity.		-0.67 -0.47 -0.43 -0.16 -0.12 -0.26		Sample damp from 3.8m	
4.5–5.7	Silty Sand: Light grey, fine grained.	WC	-0.02		Sample saturated from 4.5m	
5.7–6.0	Silty Sandy: Black, fine grained.					63% Sand, 25% Silt, 12% Clay
6.0	EOH @ 6 metres					

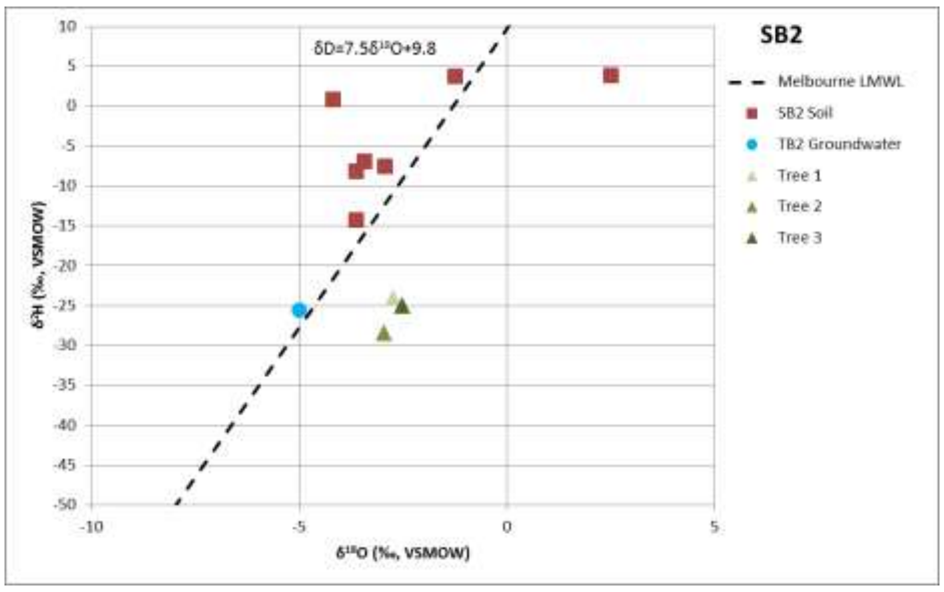
LOGGED: L.Randell DATE: 28/02/2015
CHECKED: L. Randell DATE: 20/03/2015

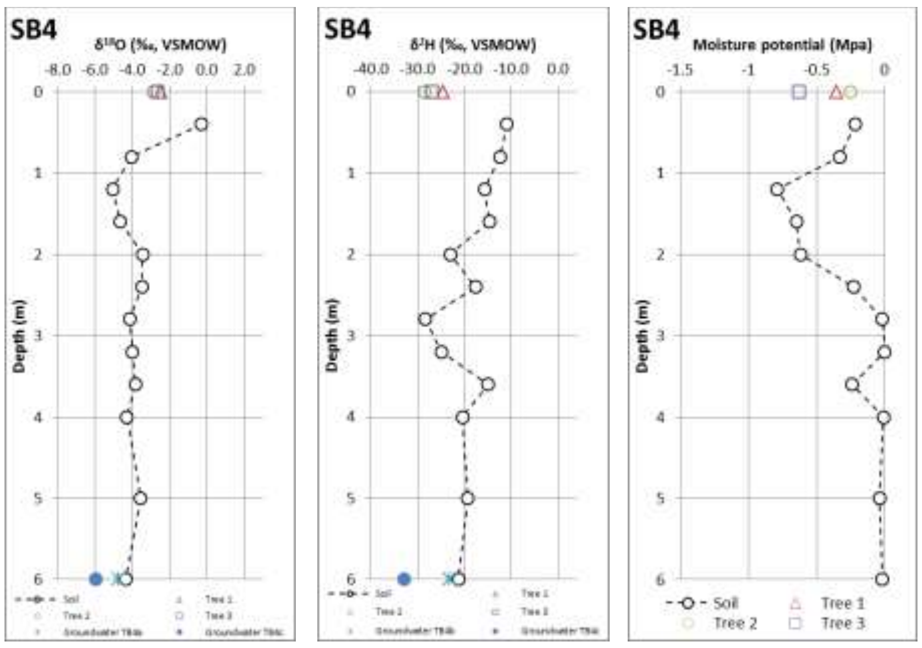
Appendix E. Stable isotope plots

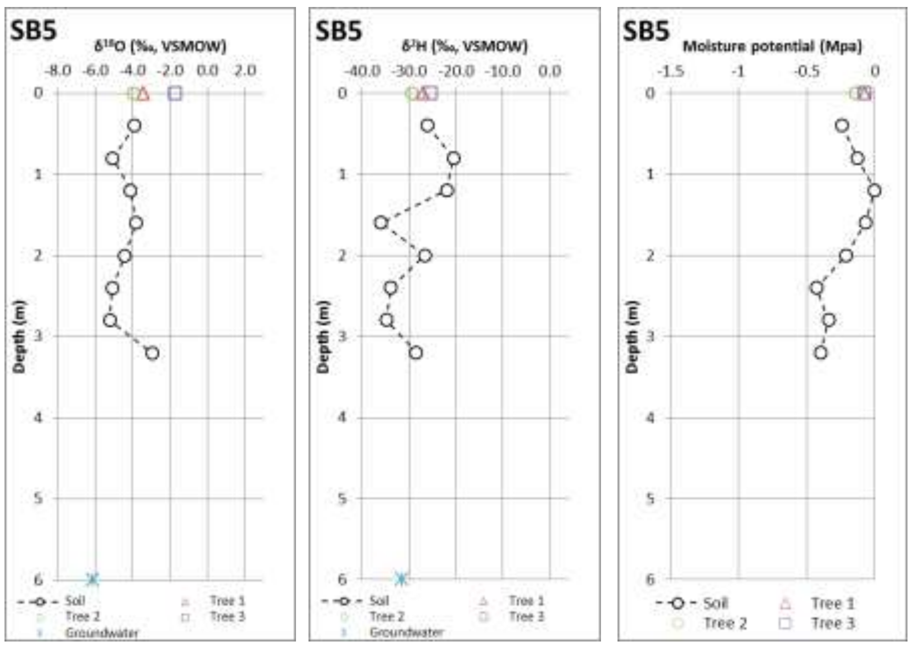


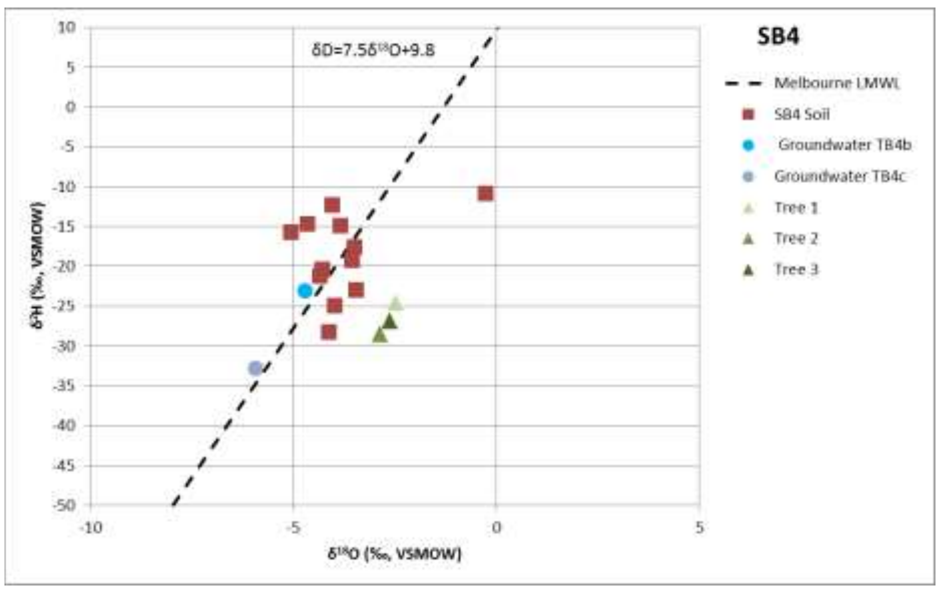


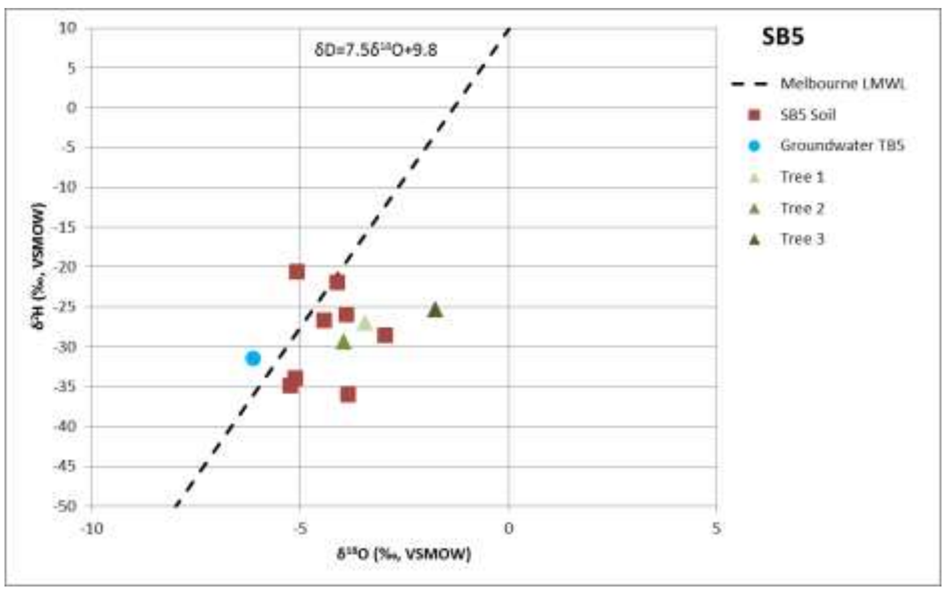


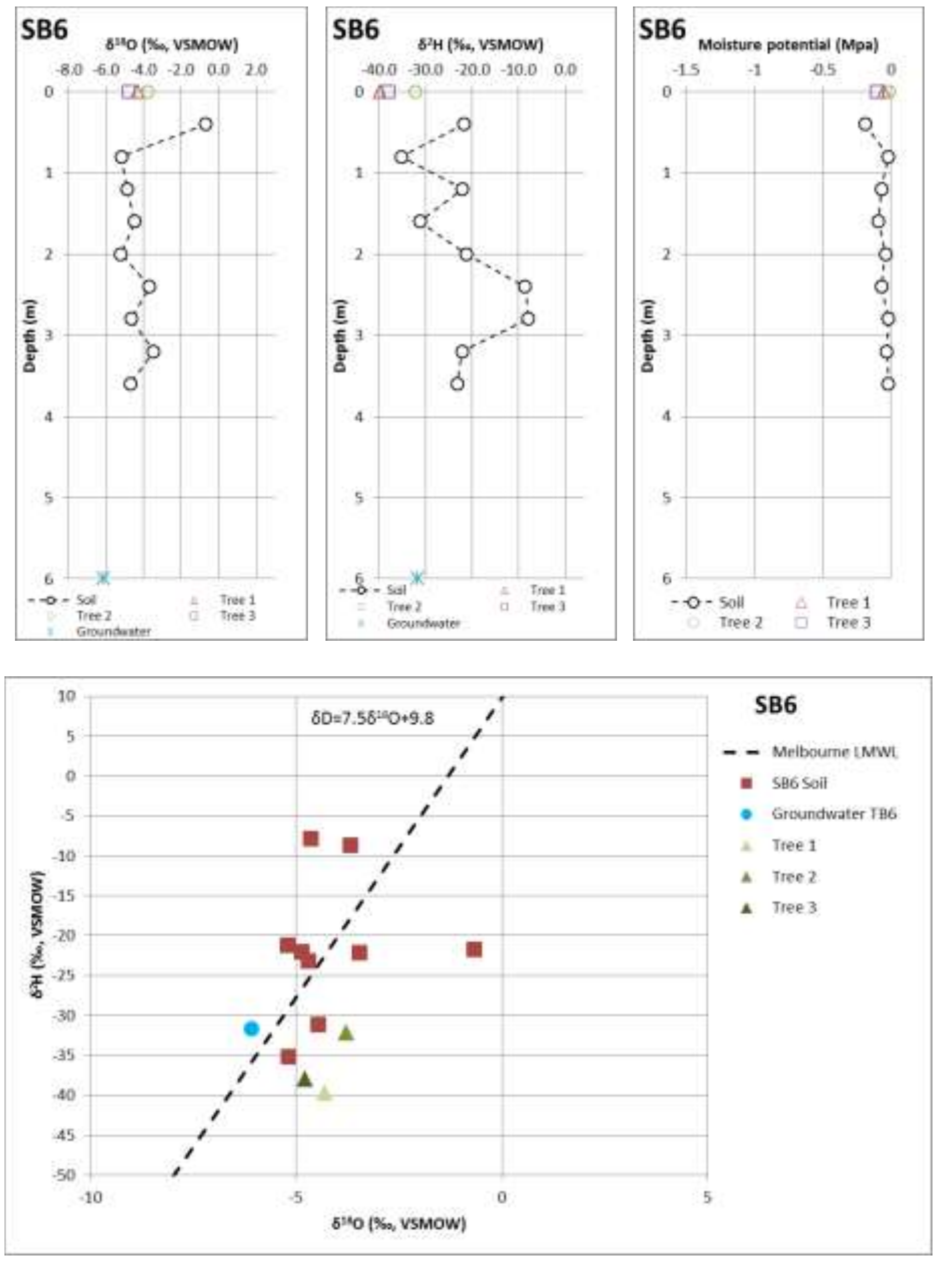


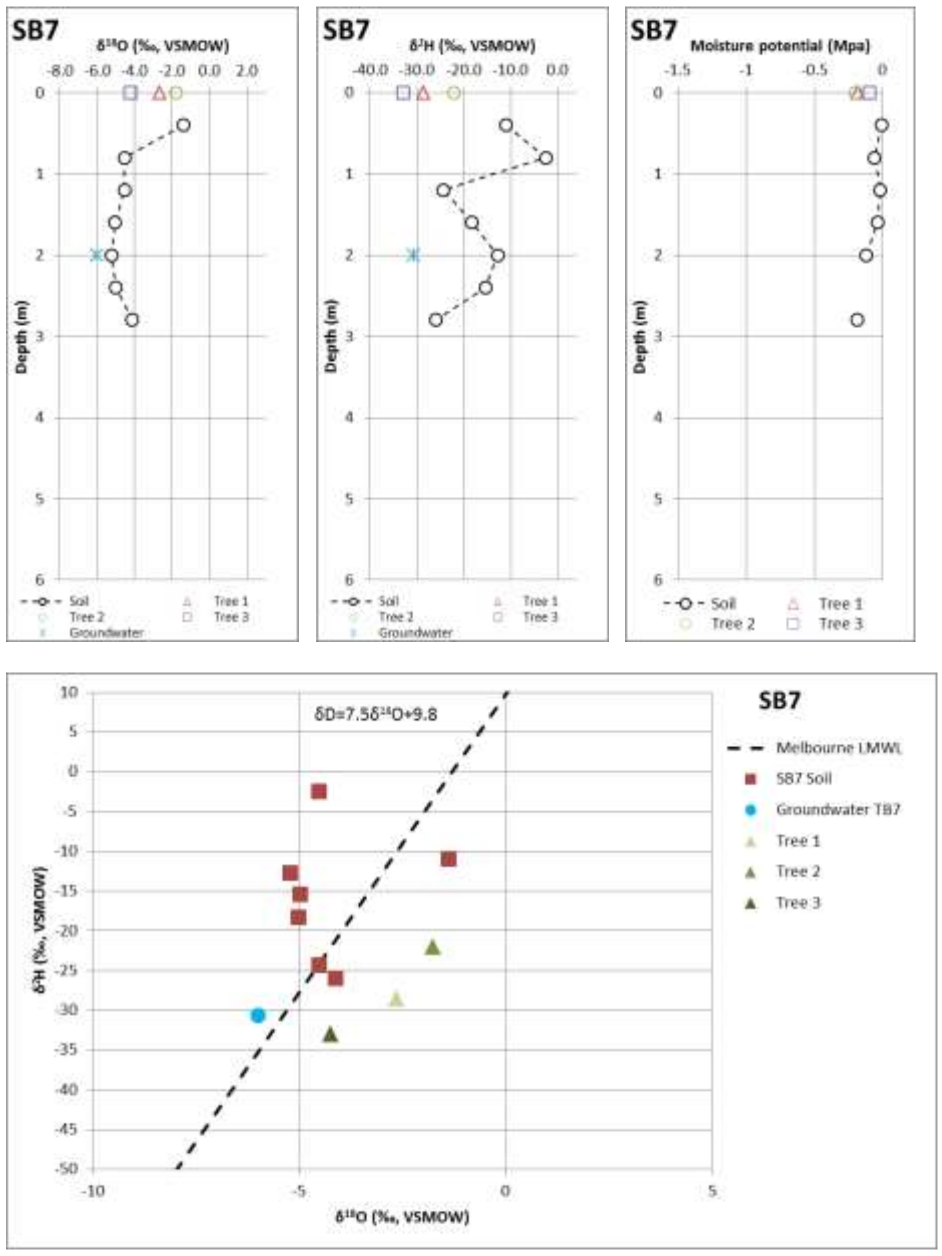


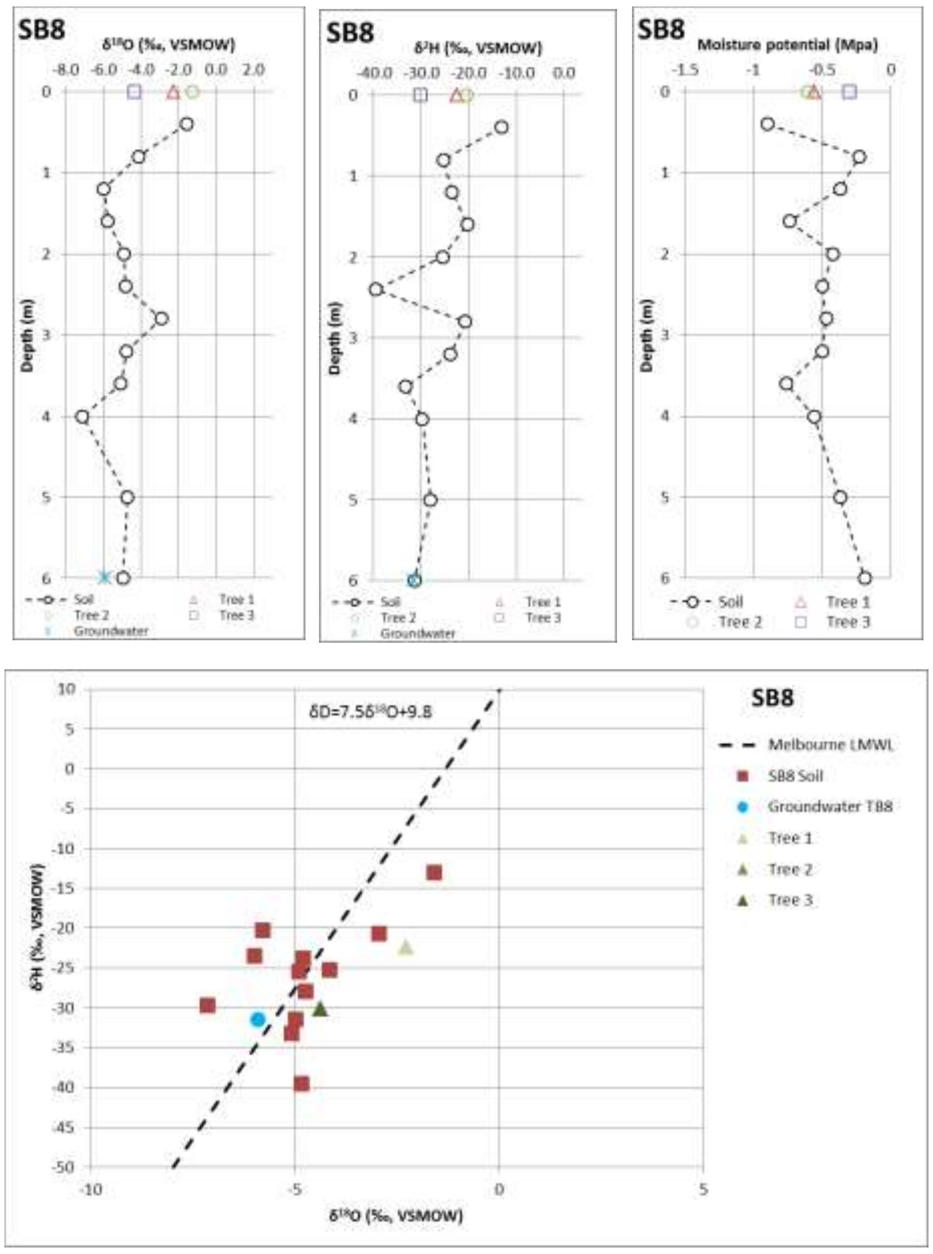


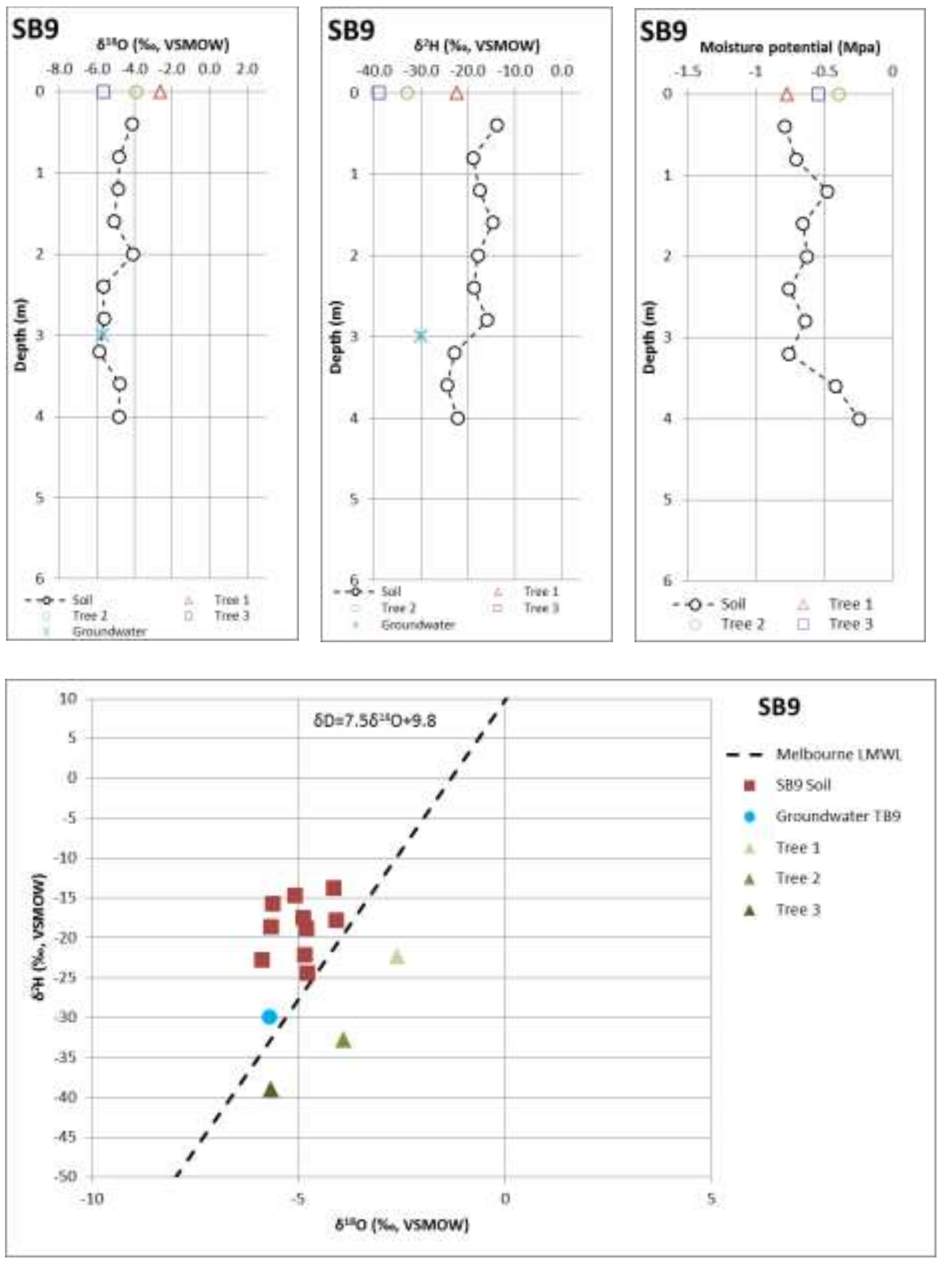


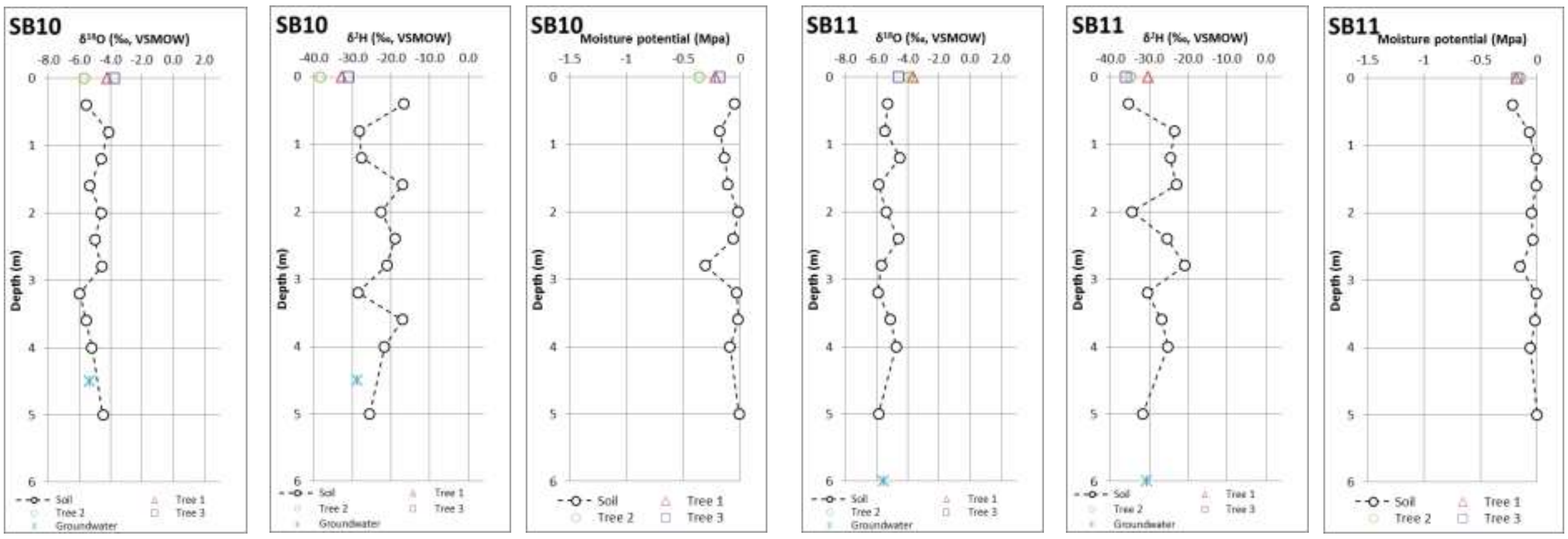


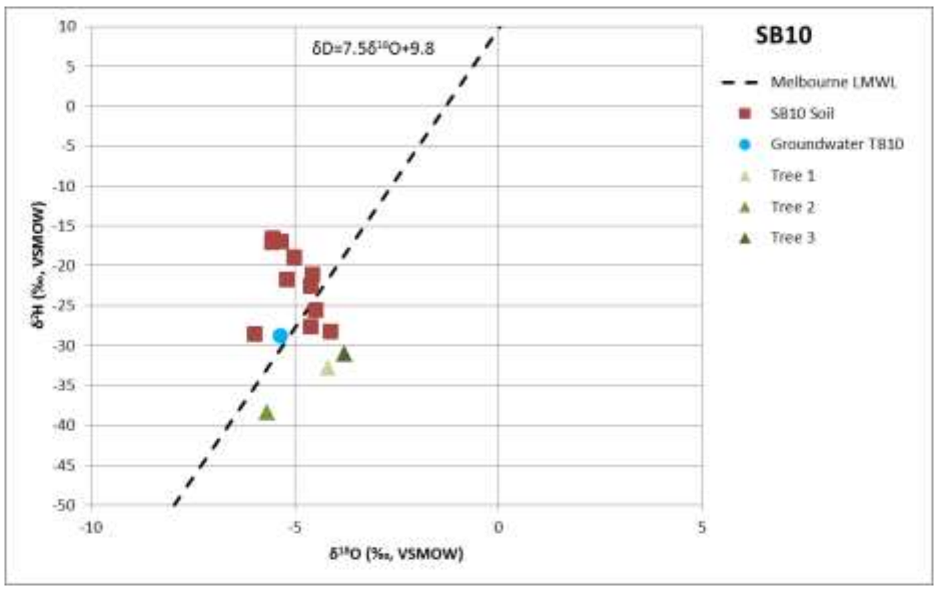

SB6
δ18O (‰, VSMOW)
δ2H (‰, VSMOW)
Moisture potential (Mpa)
Depth (m)
δD=7.5δ18O+9.8
Melbourne LMWL
SB6 Soil
Groundwater TB6
Tree 1
Tree 2
Tree 3
δ2H (‰, VSMOW)
δ18O (‰, VSMOW)

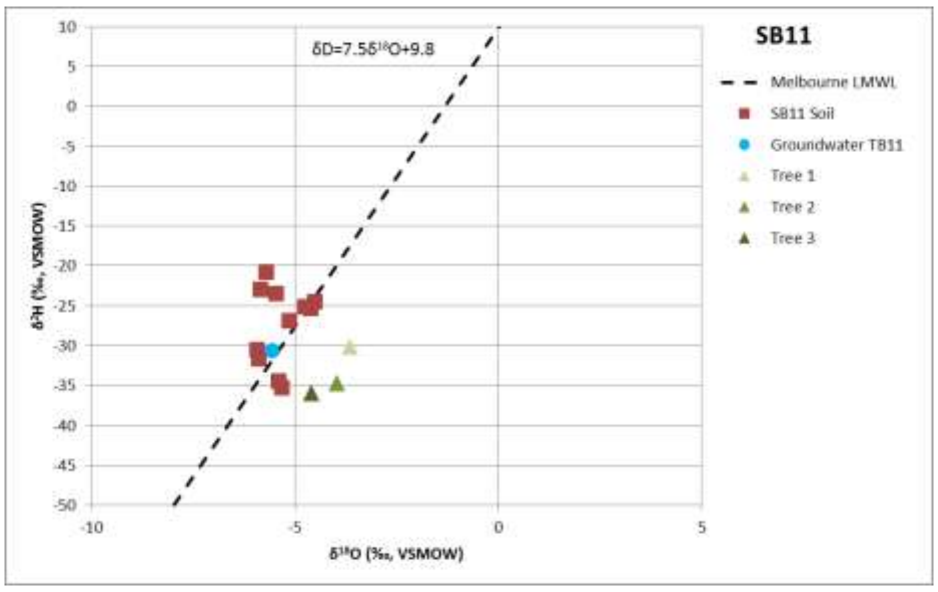

SB7
δ18O (‰, VSMOW)
δ2H (‰, VSMOW)
Moisture potential (Mpa)
Depth (m)
δD=7.5δ18O+9.8
Melbourne LMWL
SB7 Soil
Groundwater TB7
Tree 1
Tree 2
Tree 3
δ2H (‰, VSMOW)
δ18O (‰, VSMOW)

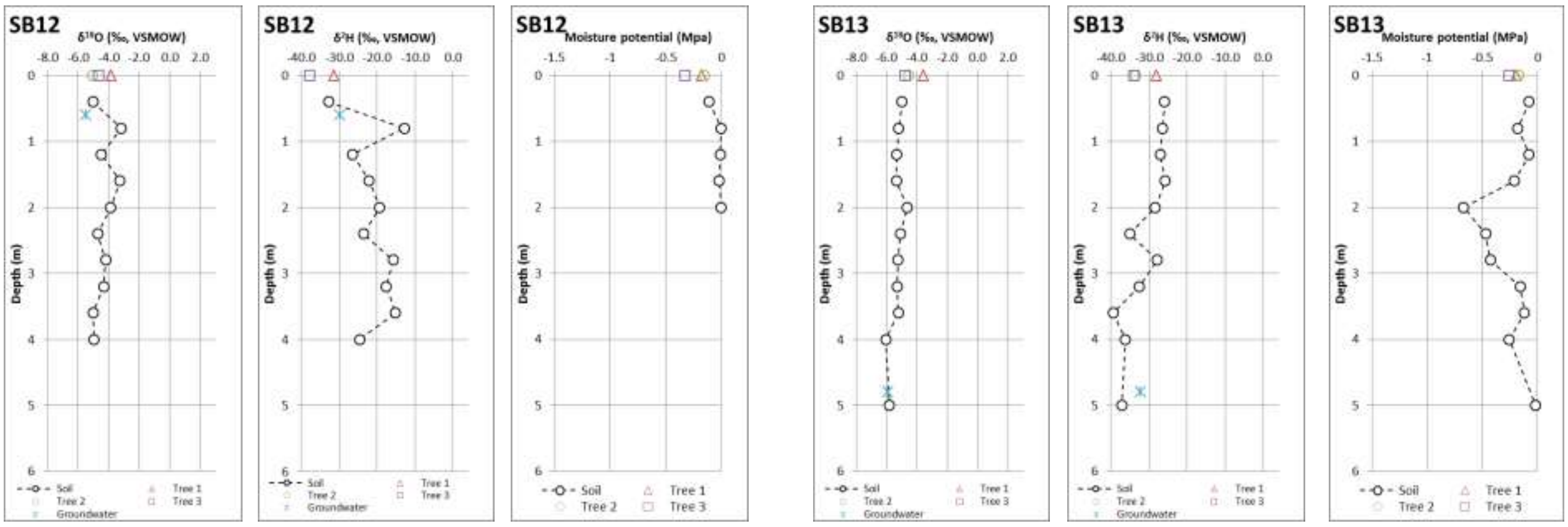

SB8
δ18O (‰, VSMOW)
δ2H (‰, VSMOW)
Moisture potential (Mpa)
Depth (m)
δD=7.5δ18O+9.8
Melbourne LMWL
SB8 Soil
Groundwater TB8
Tree 1
Tree 2
Tree 3
δ2H (‰, VSMOW)
δ18O (‰, VSMOW)

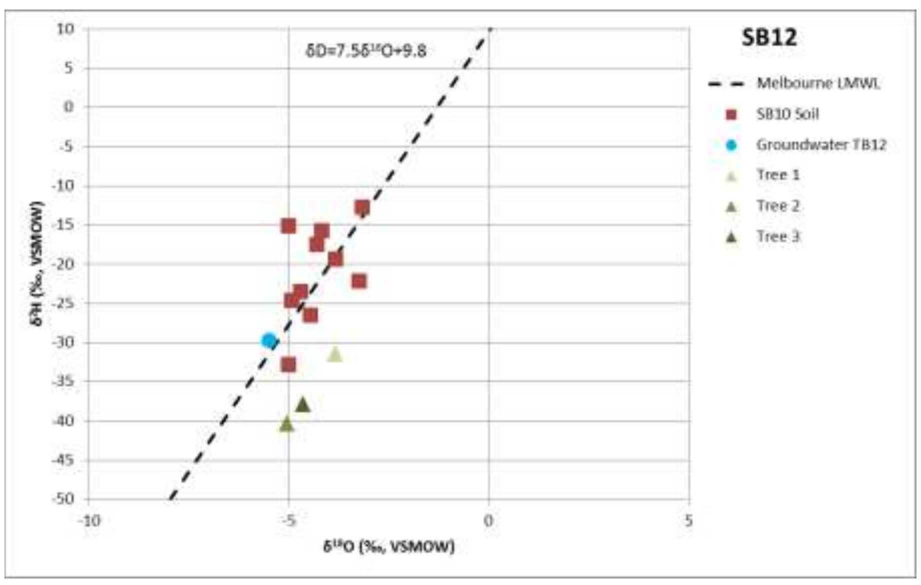

SB9
δ18O (‰, VSMOW)
δ2H (‰, VSMOW)
Moisture potential (Mpa)
Depth (m)
δD=7.5δ18O+9.8
Melbourne LMWL
SB9 Soil
Groundwater TB9
Tree 1
Tree 2
Tree 3
δ2H (‰, VSMOW)
δ18O (‰, VSMOW)

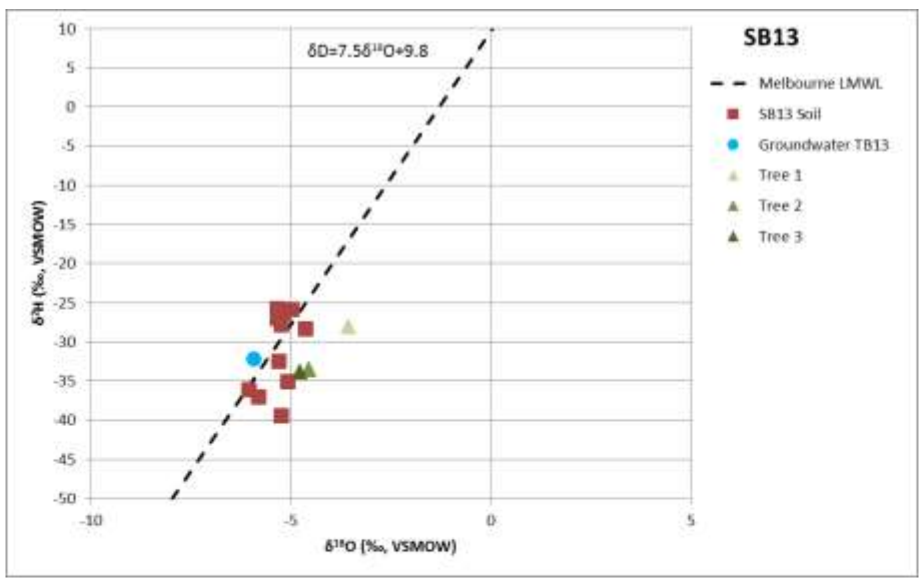

SB10
δ¹⁸O (‰, VSMOW)
Depth (m)
SB10
δ²H (‰, VSMOW)
SB10
Moisture potential (Mpa)
SB11
δ¹⁸O (‰, VSMOW)
SB11
δ²H (‰, VSMOW)
SB11
Moisture potential (Mpa)
Soil
Tree 1
Tree 2
Tree 3
Groundwater

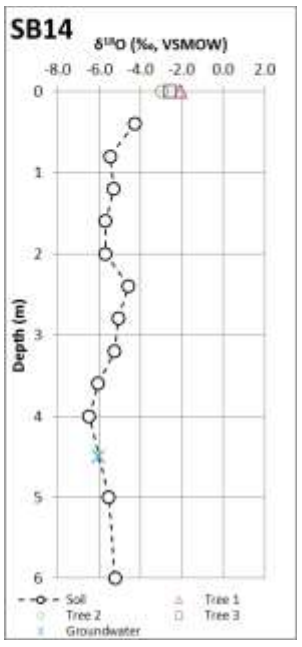

SB10
δD=7.5δ¹⁸O+9.8
Melbourne LMWL
SB10 Soil
Groundwater TB10
Tree 1
Tree 2
Tree 3
δ²H (‰, VSMOW)
δ¹⁸O (‰, VSMOW)

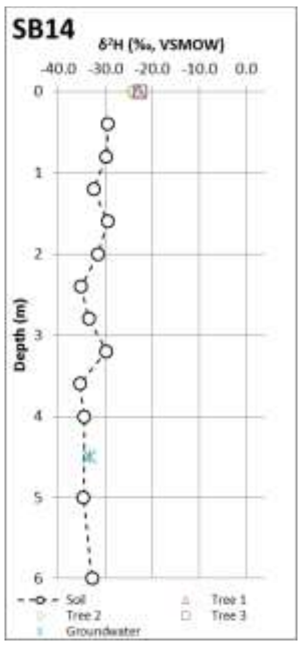

SB11
δD=7.5δ¹⁸O+9.8
Melbourne LMWL
SB11 Soil
Groundwater TB11
Tree 1
Tree 2
Tree 3
δ²H (‰, VSMOW)
δ¹⁸O (‰, VSMOW)

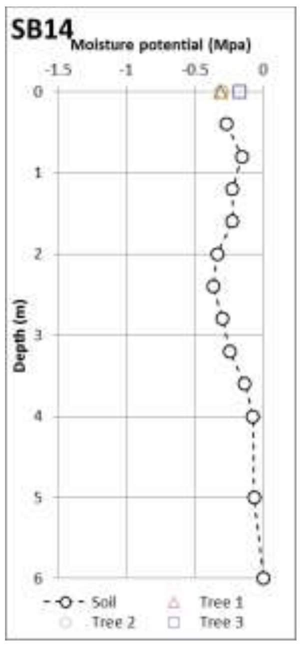

SB12
δ¹⁸O (‰, VSMOW)
Depth (m)
SB12
δ²H (‰, VSMOW)
SB12
Moisture potential (Mpa)
SB13
δ¹⁸O (‰, VSMOW)
SB13
δ²H (‰, VSMOW)
SB13
Moisture potential (MPa)
Soil
Tree 1
Tree 2
Tree 3
Groundwater

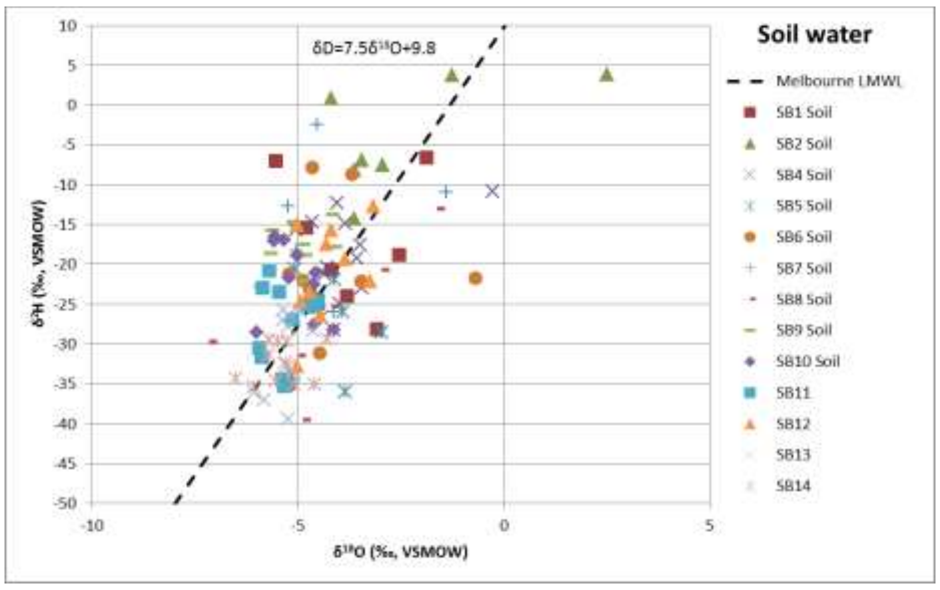

SB12
δD=7.5δ¹⁸O+9.8
Melbourne LMWL
SB10 Soil
Groundwater TB12
Tree 1
Tree 2
Tree 3
δ²H (‰, VSMOW)
δ¹⁸O (‰, VSMOW)

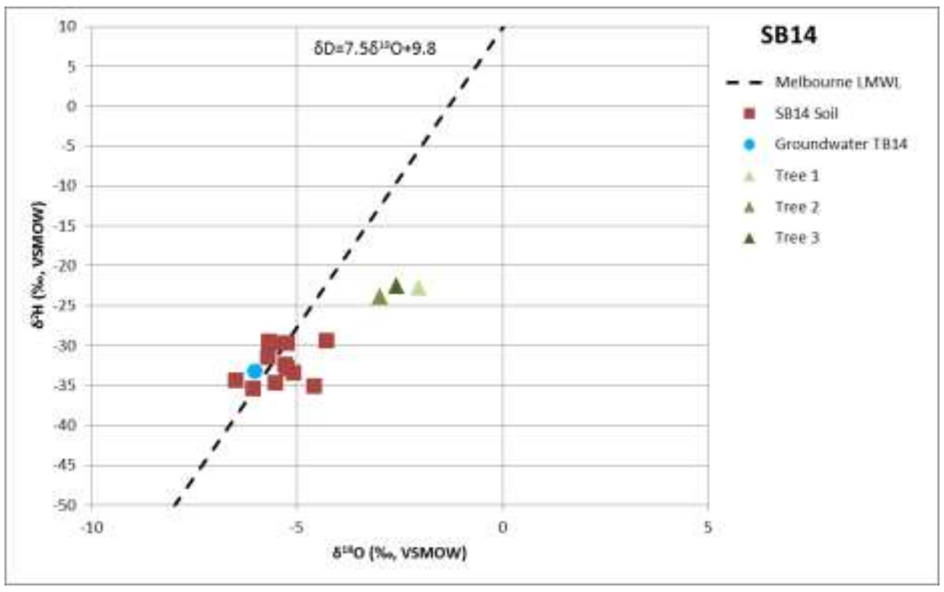

SB13
δD=7.5δ¹⁸O+9.8
Melbourne LMWL
SB13 Soil
Groundwater TB13
Tree 1
Tree 2
Tree 3
δ²H (‰, VSMOW)
δ¹⁸O (‰, VSMOW)

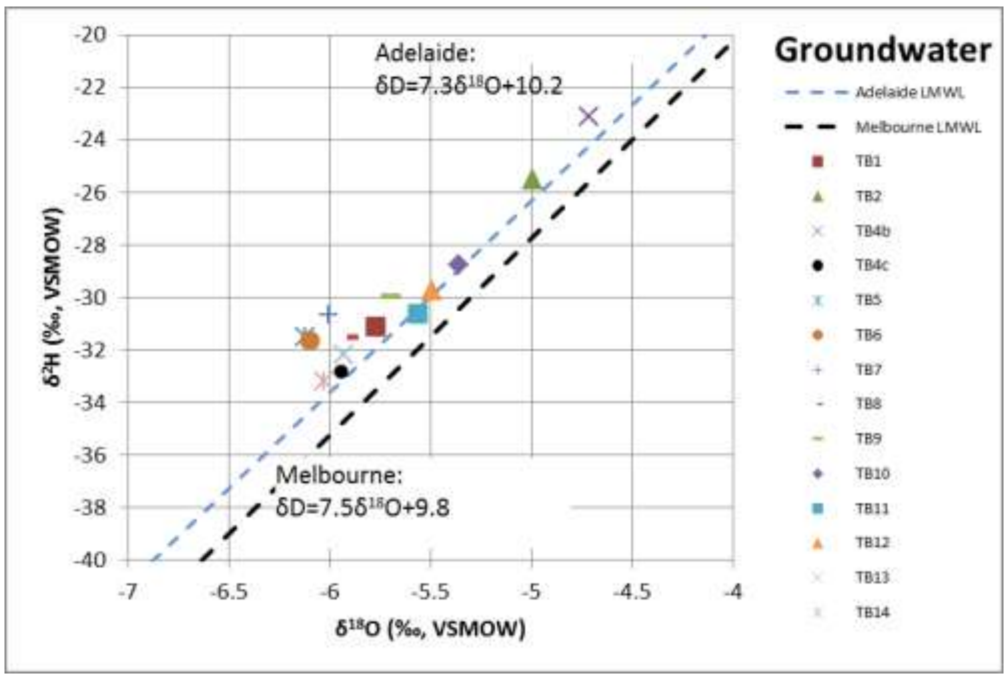

SB14
δ18O (‰, VSMOW)
-8.0 -6.0 -4.0 -2.0 0.0 2.0
Depth (m)
Soil
Tree 1
Tree 2
Tree 3
Groundwater


SB14
δ2H (‰, VSMOW)
-40.0 -30.0 -20.0 -10.0 0.0
Depth (m)
Soil
Tree 1
Tree 2
Tree 3
Groundwater


SB14
Moisture potential (Mpa)
-1.5 -1 -0.5 0
Depth (m)
Soil
Tree 1
Tree 2
Tree 3


Soil water
δD=7.5δ18O+9.8
δ2H (‰, VSMOW)
δ18O (‰, VSMOW)
Melbourne LMWL
SB1 Soil
SB2 Soil
SB4 Soil
SB5 Soil
SB6 Soil
SB7 Soil
SB8 Soil
SB9 Soil
SB10 Soil
SB11
SB12
SB13
SB14


SB14
δD=7.5δ18O+9.8
δ2H (‰, VSMOW)
δ18O (‰, VSMOW)
Melbourne LMWL
SB14 Soil
Groundwater TB14
Tree 1
Tree 2
Tree 3


Groundwater
Adelaide:
δD=7.3δ18O+10.2
Melbourne:
δD=7.5δ18O+9.8
δ2H (‰, VSMOW)
δ18O (‰, VSMOW)
Adelaide LMWL
Melbourne LMWL
TB1
TB2
TB4b
TB4c
TB5
TB6
TB7
TB8
TB9
TB10
TB11
TB12
TB13
TB14

Appendix F. Stable isotope results

SB1 Soil		
Depth (m)	δ18O	δ2H
0.4	-1.9	-6.6
0.8	-5.5	-7.0
1.2	-3.8	-24.0
1.6	-4.2	-20.7
2	-4.8	-15.4
2.4	-3.1	-28.1
2.8	-2.5	-18.8
Vegetation		
Tree/twig	δ18O	δ2H
1/1	Sample damaged	
1/2	Sample Damaged	
Average		-23.53
2/1	-4.33	-34.82
2/2	-4.35	-34.41
Average	-4.34	-34.62
3/1	-3.52	-29.33
3/2	-3.59	-30.01
Average	-3.56	-29.67
Groundwater		
Well	δ18O	δ2H
TB1	-5.77	-31.13

SB2 Soil		
Depth (m)	δ18O	δ2H
0.4	2.5	3.8
0.8	-3.4	-6.9
1.2	-1.3	3.8
1.6	-3.6	-14.3
2	-2.9	-7.5
2.4	-3.6	-8.2
2.8	-4.2	0.8
Vegetation		
Tree/twig	δ18O	δ2H
1/1	-2.71	-24.70
1/2	-2.75	-23.42
Average	-2.73	-24.06
2/1	-2.65	-28.26
2/2	-3.28	-28.56
Average	-2.97	-28.41
3/1	-2.26	-24.29
3/2	-2.78	-25.68
Average	-2.52	-24.98
Groundwater		
Well	δ18O	δ2H
TB2	-5.00	-25.50

SB4 Soil		
Depth (m)	δ18O	δ2H
0.4	-0.3	-10.9
0.8	-4.1	-12.3
1.2	-5.1	-15.7
1.6	-4.6	-14.6
2	-3.5	-23.0
2.4	-3.5	-17.5
2.8	-4.1	-28.3
3.2	-4.0	-24.9
3.6	-3.8	-14.9
4	-4.3	-20.4
5	-3.6	-19.2
6	-4.4	-21.3
Vegetation		
Tree/twig	δ18O	δ2H
1/1	-2.35	-24.07
1/2	-2.61	-25.11
Average	-2.48	-24.59
2/1	-2.69	-27.15
2/2	-3.07	-29.87
Average	-2.88	-28.51
3/1	-2.64	-25.27
3/2	-2.61	-28.54
Average	-2.63	-26.91
Groundwater		
Well	δ18O	δ2H
TB4b	-4.72	-23.11
TB4c	-5.94	-32.83

SB5 Soil		
Depth (m)	δ18O	δ2H
0.4	-3.9	-26.0
0.8	-5.1	-20.5
1.2	-4.1	-21.9
1.6	-3.8	-36.0
2	-4.4	-26.7
2.4	-5.1	-33.9
2.8	-5.2	-34.8
3.2	-3.0	-28.5
Vegetation		
Tree/twig	δ18O	δ2H
1/1	-3.74	-27.75
1/2	-3.12	-26.29
Average	-3.43	-27.02
2/1	-3.92	-28.62
2/2	-3.99	-30.14
Average	-3.96	-29.38
3/1	-1.82	-24.31
3/2	-1.68	-26.48
Average	-1.75	-25.40
Groundwater		
Well	δ18O	δ2H
TB5	-6.12	-31.49

SB6 Soil		
Depth (m)	δ18O	δ2H
0.4	-0.7	-21.7
0.8	-5.2	-35.2
1.2	-4.9	-22.1
1.6	-4.5	-31.2
2	-5.2	-21.2
2.4	-3.7	-8.6
2.8	-4.7	-7.9
3.2	-3.5	-22.1
3.6	-4.7	-23.2
Vegetation		
Tree/twig	δ18O	δ2H
1/1	-4.16	-39.33
1/2	-4.44	-40.16
Average	-4.30	-39.75
2/1	-3.76	-32.82
2/2	-3.81	-31.57
Average	-3.78	-32.19
3/1	-4.13	-35.93
3/2	-5.45	-40.00
Average	-4.79	-37.97
Groundwater		
Well	δ18O	δ2H
TB6	-6.10	-31.62

SB7 Soil

Depth (m)	$\delta^{18}O$	$\delta^{2}H$
0.4	-1.4	-10.9
0.8	-4.5	-2.5
1.2	-4.5	-24.3
1.6	-5.0	-18.3
2	-5.2	-12.7
2.4	-5.0	-15.4
2.8	-4.1	-26.0

Vegetation Tree/twig	$\delta^{18}O$	$\delta^{2}H$
1/1	-2.58	-28.93
1/2	-2.70	-28.11
Average	-2.64	-28.52
2/1	-1.73	-21.37
2/2	-1.80	-22.71
Average	-1.76	-22.04
3/1	-3.63	-30.49
3/2	-4.84	-35.43
Average	-4.23	-32.96

Groundwater Well	$\delta^{18}O$	$\delta^{2}H$
TB7	-6.01	-30.68

SB8 Soil

Depth (m)	$\delta^{18}O$	$\delta^{2}H$
0.4	-1.6	-13.1
0.8	-4.1	-25.3
1.2	-6.0	-23.5
1.6	-5.8	-20.2
2	-4.9	-25.5
2.4	-4.8	-39.5
2.8	-2.9	-20.7
3.2	-4.8	-23.8
3.6	-5.1	-33.2
4	-7.1	-29.7
5	-4.7	-28.0
6	-5.0	-31.4

Vegetation Tree/twig	$\delta^{18}O$	$\delta^{2}H$
1/1	-2.31	-22.32
1/2	-2.24	-22.43
Average	-2.27	-22.37
2/1	Sample Damaged	
2/2	Sample Damaged	
Average		
3/1	-3.89	-28.34
3/2	-4.86	-31.78
Average	-4.37	-30.06

Groundwater Well	$\delta^{18}O$	$\delta^{2}H$
TB8	-5.91	-31.50

SB9 Soil

Depth (m)	$\delta^{18}O$	$\delta^{2}H$
0.4	-4.1	-13.8
0.8	-4.8	-18.9
1.2	-4.9	-17.5
1.6	-5.1	-14.7
2	-4.1	-17.8
2.4	-5.7	-18.6
2.8	-5.6	-15.8
3.2	-5.9	-22.8
3.6	-4.8	-24.4
4	-4.8	-22.2

Vegetation Tree/twig	$\delta^{18}O$	$\delta^{2}H$
1/1	-2.52	-21.65
1/2	-2.70	-23.02
Average	-2.61	-22.33
2/1	-3.98	-32.69
2/2	-3.81	-32.99
Average	-3.89	-32.84
3/1	-6.01	-39.20
3/2	-5.30	-38.73
Average	-5.66	-38.97

Groundwater Well	$\delta^{18}O$	$\delta^{2}H$
TB9	-5.70	-29.94

SB10 Soil

Depth (m)	$\delta^{18}O$	$\delta^{2}H$
0.4	-5.5	-16.6
0.8	-4.1	-28.2
1.2	-4.6	-27.6
1.6	-5.3	-17.0
2	-4.6	-22.5
2.4	-5.0	-19.0
2.8	-4.6	-21.1
3.2	-6.0	-28.5
3.6	-5.6	-17.0
4	-5.2	-21.7
5	-4.5	-25.5

Vegetation Tree/twig	$\delta^{18}O$	$\delta^{2}H$
1/1	-4.06	-31.90
1/2	-4.33	-33.65
Average	-4.19	-32.78
2/1	-6.75	-43.30
2/2	-4.61	-33.41
Average	-5.68	-38.36
3/1	-3.57	-29.90
3/2	-4.01	-32.14
Average	-3.79	-31.02

Groundwater Well	$\delta^{18}O$	$\delta^{2}H$
TB10	-5.36	-28.77

SB11 Soil

Depth (m)	$\delta^{18}O$	$\delta^{2}H$
0.4	-5.3	-35.2
0.8	-5.5	-23.4
1.2	-4.5	-24.6
1.6	-5.9	-23.0
2	-5.4	-34.4
2.4	-4.6	-25.3
2.8	-5.7	-20.8
3.2	-5.9	-30.5
3.6	-5.1	-26.9
4	-4.7	-25.2
5	-5.9	-31.7

Vegetation Tree/twig	$\delta^{18}O$	$\delta^{2}H$
1/1	-3.66	-30.61
1/2	-3.62	-29.84
Average	-3.64	-30.22
2/1	-4.23	-34.93
2/2	-3.69	-34.57
Average	-3.96	-34.75
3/1	-4.35	-37.82
3/2	Sample damaged	
Average	-4.59516	-36.0252

Groundwater Well	$\delta^{18}O$	$\delta^{2}H$
TB11	-5.57	-30.63

SB12 Soil

Depth (m)	δ18O	δ2H
0.4	-5.0	-32.8
0.8	-3.2	-12.7
1.2	-4.5	-26.4
1.6	-3.2	-22.1
2	-3.8	-19.3
2.4	-4.7	-23.5
2.8	-4.2	-15.7
3.2	-4.3	-17.5
3.6	-5.0	-15.1
4	-4.9	-24.6

Vegetation

Tree/twig	δ18O	δ2H
1/1	-4.00	-32.86
1/2	-3.69	-29.94
Average	-3.84	-31.40
2/1	-4.83	-40.47
2/2	-5.29	-40.20
Average	-5.06	-40.33
3/1	-4.36	-37.46
3/2	-4.92	-38.26
Average	-4.64318	-37.8559

Groundwater

Well	δ18O	δ2H
TB12	-5.50	-29.74

SB13 Soil

Depth (m)	δ18O	δ2H
0.4	-5.0	-25.8
0.8	-5.2	-26.4
1.2	-5.3	-27.0
1.6	-5.4	-25.7
2	-4.6	-28.3
2.4	-5.1	-35.1
2.8	-5.2	-27.8
3.2	-5.3	-32.5
3.6	-5.2	-39.4
4	-6.1	-36.1
5	-5.8	-37.1

Vegetation

Tree/twig	δ18O	δ2H
1/1	-3.75	-27.76
1/2	-3.36	-28.22
Average	-3.56	-27.99
2/1	-5.23	-34.91
2/2	-3.89	-32.12
Average	-4.56	-33.51
3/1	-5.48	-36.70
3/2	-4.07	-31.06
Average	-4.78	-33.88

Groundwater

Well	δ18O	δ2H
TB13	-5.93	-32.18

SB14 Soil

Depth (m)	δ18O	δ2H
0.4	-4.3	-29.3
0.8	-5.5	-29.7
1.2	-5.3	-32.4
1.6	-5.7	-29.5
2	-5.7	-31.5
2.4	-4.6	-35.1
2.8	-5.1	-33.4
3.2	-5.3	-29.7
3.6	-6.1	-35.4
4	-6.5	-34.4
5	-5.5	-34.6
6	-5.2	-32.8

Vegetation

Tree/twig	δ18O	δ2H
1/1	-2.03	-23.15
1/2	-2.06	-22.47
Average	-2.05	-22.81
2/1	-2.78	-23.55
2/2	-3.19	-24.17
Average	-2.98	-23.86
3/1	-2.44	-21.80
3/2	-2.71	-23.21
Average	-2.57	-22.51

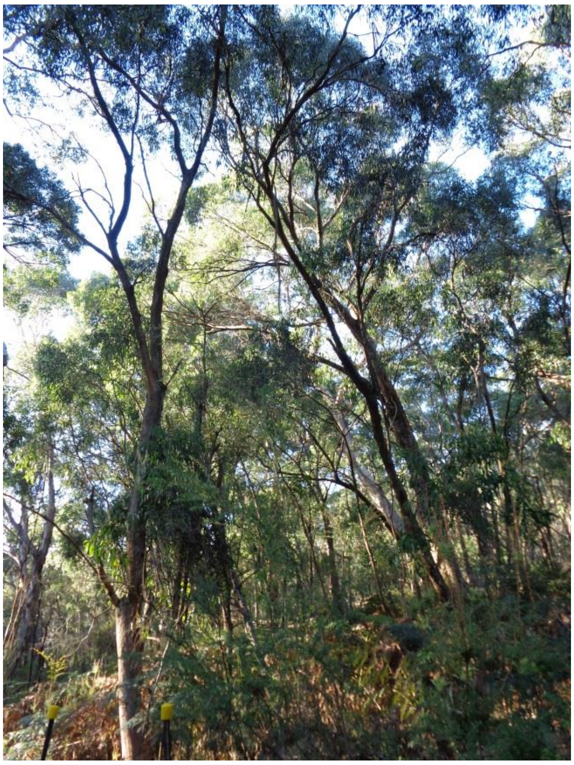
Groundwater

Well	δ18O	δ2H
TB14	-6.03	-33.20

Appendix G. Site images

Site: TB1

Site: TB2



Site: TB4

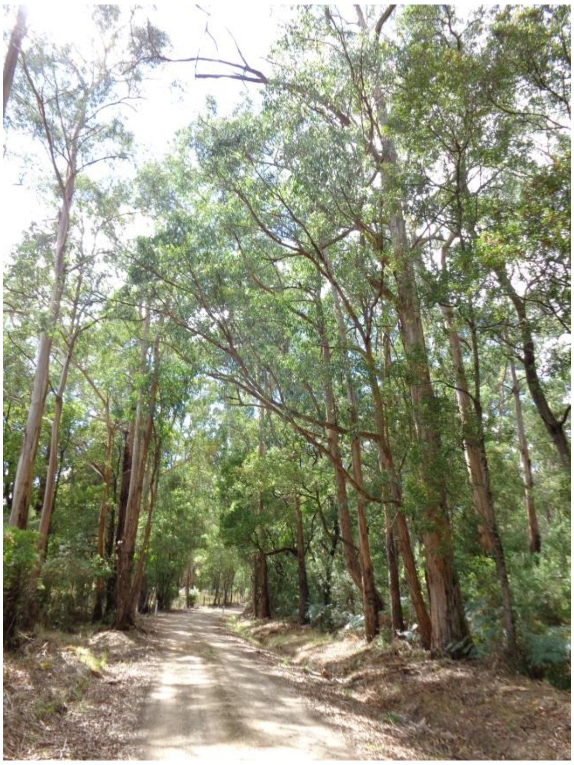
Site: TB5

Site: TB6

Site: TB7

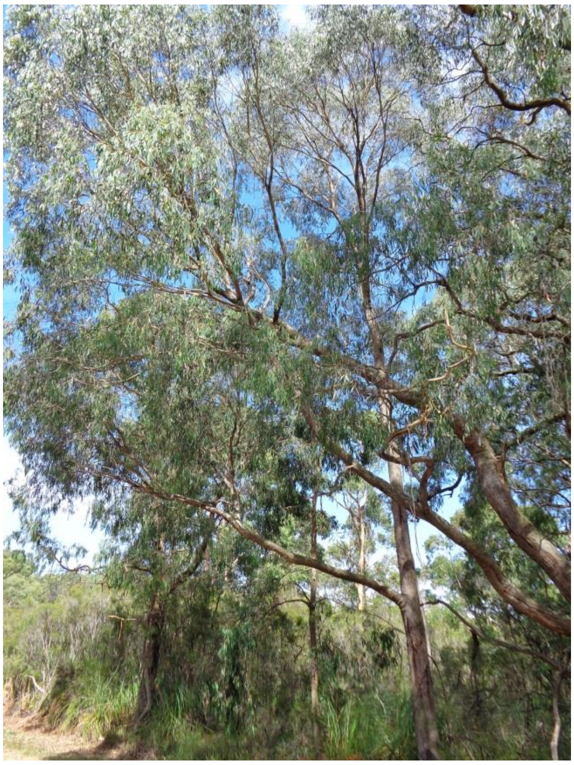
Site: TB8

Site: TB9



Site: TB10

Site: TB11



Site: TB12

Site: TB13

Site: TB14	
	

Appendix H. Water potential data

Soil

SB1

Depth (m)	Moisture Potential (MPa)
0.4	-0.81
0.8	-0.62
1.2	-1.06
1.6	-1.03
2	-0.79
2.4	-0.83
2.8	-1.04

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.53	0.91
1/2	0.55	0.88
1/3	0.49	0.86
Corrected average	-0.48	-0.84
2/1	0.52	1.20
2/2	0.53	1.41
2/3	0.61	1.67
Corrected average	-0.53	-1.41
3/1	0.45	1.30
3/2	0.47	1.02
3/3	0.43	1.38
Corrected average	-0.42	-1.20

Tree	Sample Height (m)	Correction Factor
1	4	0.04
2	2	0.02
3	3	0.03

Soil

SB2

Depth (m)	Moisture Potential (MPa)
0.4	-0.62
0.8	-0.09
1.2	-0.03
1.6	0
2	0
2.4	0
2.8	0

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.25	1.66
1/2	0.38	1.78
1/3	0.36	1.45
Corrected average	-0.29	-1.59
2/1	0.35	2.14
2/2	0.60	2.16
2/3	0.60	1.75
Corrected average	-0.49	-1.99
3/1	0.52	1.05
3/2	0.31	1.51
3/3	0.23	1.43
Corrected average	-0.32	-1.30

Tree	Sample Height (m)	Correction Factor
1	4	0.04
2	3	0.03
3	3	0.03

Soil

SB4

Depth (m)	Moisture Potential (MPa)
0.4	-0.22
0.8	-0.33
1.2	-0.79
1.6	-0.65
2	-0.62
2.4	-0.23
2.8	-0.02
3.2	0
3.6	-0.24
4	-0.01
5	-0.04
6	-0.02

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.35	1.61
1/2	0.45	1.79
1/3	0.34	1.78
Corrected average	-0.36	-1.71
2/1	0.27	1.84
2/2	0.25	1.63
2/3	0.30	1.85
Corrected average	-0.25	-1.75
3/1	0.45	1.59
3/2	0.69	1.45
3/3	0.81	1.54
Corrected average	-0.63	-1.51

Tree	Sample Height (m)	Correction Factor
1	2	0.02
2	2	0.02
3	2	0.02

Soil

SB5

Depth (m)	Moisture Potential (MPa)
0.4	-0.24
0.8	-0.13
1.2	0
1.6	-0.07
2	-0.21
2.4	-0.43
2.8	-0.34
3.2	-0.4

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.12	1.52
1/2	0.15	1.80
1/3	0.07	2.05
Corrected average	-0.07	-1.75
2/1	0.27	0.75
2/2	0.18	1.12
2/3	0.13	1.42
Corrected average	-0.14	-1.05
3/1	0.16	0.82
3/2	0.13	1.31
3/3	0.08	1.01
Corrected average	-0.07	-1.00

Tree	Sample Height (m)	Correction Factor
1	4	0.04
2	5	0.05
3	5	0.05

Soil

SB6

Depth (m)	Moisture Potential (MPa)
0.4	-0.19
0.8	-0.02
1.2	-0.07
1.6	-0.09
2	-0.04
2.4	-0.07
2.8	-0.02
3.2	-0.03
3.6	-0.02

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.13	1.70
1/2	0.12	1.56
1/3	0.15	1.81
Corrected average	-0.05	-1.61
2/1	0.11	1.51
2/2	0.06	1.72
2/3	0.05	1.60
Corrected average	-0.01	-1.55
3/1	0.16	1.48
3/2	0.08	1.48
3/3	0.17	1.48
Corrected average	-0.11	-1.45

Tree	Sample Height (m)	Correction Factor
1	8	0.08
2	6	0.06
3	3	0.03

Soil

SB7

Depth (m)	Moisture Potential (MPa)
0.4	-0.01
0.8	-0.06
1.2	-0.02
1.6	-0.04
2	-0.12
2.4	
2.8	-0.19

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.13	1.00
1/2	0.23	1.12
1/3	0.27	1.08
Corrected average	-0.18	-1.04
2/1	0.21	1.03
2/2	0.22	1.28
2/3	0.23	1.25
Corrected average	-0.20	-1.17
3/1	0.12	0.92
3/2	0.20	1.15
3/3	0.16	1.20
Corrected average	-0.10	-1.03

Tree	Sample Height (m)	Correction Factor
1	3	0.03
2	2	0.02
3	6	0.06

Soil

SB8

Depth (m)	Moisture Potential (MPa)
0.4	-0.9
0.8	-0.23
1.2	-0.37
1.6	-0.74
2	-0.42
2.4	-0.5
2.8	-0.47
3.2	-0.5
3.6	-0.76
4	-0.56
5	-0.37
6	-0.19

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.50	1.30
1/2	0.65	1.31
1/3	0.64	1.41
Corrected average	-0.56	-1.31
2/1	0.75	1.25
2/2	0.58	1.31
2/3	0.76	1.32
Corrected average	-0.61	-1.20
3/1	0.35	1.03
3/2	0.22	1.27
3/3	0.38	1.18
Corrected average	-0.30	-1.15

Tree	Sample Height (m)	Correction Factor
1	3.5	0.035
2	9	0.09
3	1.5	0.015

Soil

SB9

Depth (m)	Moisture Potential (MPa)
0.4	-0.79
0.8	-0.71
1.2	-0.48
1.6	-0.66
2	-0.63
2.4	-0.76
2.8	-0.64
3.2	-0.76
3.6	-0.42
4	-0.25

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.81	1.71
1/2	0.82	1.65
1/3	0.85	1.58
Corrected average	-0.78	-1.60
2/1	0.40	1.11
2/2	0.53	1.18
2/3	0.38	1.19
Corrected average	-0.40	-1.12
3/1	0.49	1.20
3/2	0.65	1.45
3/3	0.63	1.80
Corrected average	-0.55	-1.44

Tree	Sample Height (m)	Correction Factor
1	5	0.05
2	4	0.04
3	4	0.04

Soil

SB10

Depth (m)	Moisture Potential (MPa)
0.4	-0.05
0.8	-0.18
1.2	-0.14
1.6	-0.11
2	-0.02
2.4	-0.06
2.8	-0.31
3.2	-0.03
3.6	-0.02
4	-0.09
5	-0.01

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.28	0.41
1/2	0.21	0.50
1/3	0.28	0.42
Corrected average	-0.22	-0.40
2/1	0.50	0.45
2/2	0.37	0.41
2/3	0.30	0.44
Corrected average	-0.36	-0.40
3/1	0.20	0.38
3/2	0.19	0.40
3/3	0.28	0.40
Corrected average	-0.18	-0.35

Tree	Sample Height (m)	Correction Factor
1	4	0.04
2	3	0.03
3	4	0.04

Soil

SB11

Depth (m)	Moisture Potential (MPa)
0.4	-0.22
0.8	-0.07
1.2	-0.01
1.6	-0.01
2	-0.05
2.4	-0.04
2.8	-0.15
3.2	-0.01
3.6	-0.02
4	-0.06
5	0

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.26	1.45
1/2	0.21	1.42
1/3	0.24	1.37
Corrected average	-0.19	-1.36
2/1	0.20	1.84
2/2	0.21	1.92
2/3	0.18	1.75
Corrected average	-0.15	-1.79
3/1	0.20	2.15
3/2	0.21	2.00
3/3	0.23	1.95
Corrected average	-0.17	-1.99

Tree	Sample Height (m)	Correction Factor
1	5	0.05
2	5	0.05
3	4	0.04

Soil

SB12

Depth (m)	Moisture Potential (MPa)
0.4	-0.11
0.8	0
1.2	-0.01
1.6	-0.02
2	0
2.4	
2.8	
3.2	
3.6	
4	

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.25	1.53
1/2	0.21	1.47
1/3	0.18	1.49
Corrected average	-0.18	-1.46
2/1	0.18	1.64
2/2	0.13	1.60
2/3	0.21	1.40
Corrected average	-0.15	-1.53
3/1	0.28	1.20
3/2	0.37	1.29
3/3	0.38	1.38
Corrected average	-0.32	-1.27

Tree	Sample Height (m)	Correction Factor
1	3.5	0.035
2	2	0.02
3	2	0.02

Soil

SB13

Depth (m)	Moisture Potential (MPa)
0.4	-0.08
0.8	-0.18
1.2	-0.08
1.6	-0.21
2	-0.67
2.4	-0.47
2.8	-0.43
3.2	-0.16
3.6	-0.12
4	-0.26
5	-0.02

Vegetation

Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.25	0.53
1/2	0.21	0.47
1/3	0.18	0.47
Corrected average	-0.19	-0.47
2/1	0.14	1.00
2/2	0.13	1.00
2/3	0.29	1.07
Corrected average	-0.17	-1.00
3/1	0.30	0.50
3/2	0.31	0.55
3/3	0.27	0.65
Corrected average	-0.26	-0.54

Tree	Sample Height (m)	Correction Factor
1	2	0.02
2	2	0.02
3	3	0.03

Soil

SB14

Depth (m)	Moisture Potential (MPa)
0.4	-0.27
0.8	-0.16
1.2	-0.23
1.6	-0.23
2	-0.34
2.4	-0.37
2.8	-0.3
3.2	-0.25
3.6	-0.14
4	-0.08
5	-0.07
6	0

Vegetation

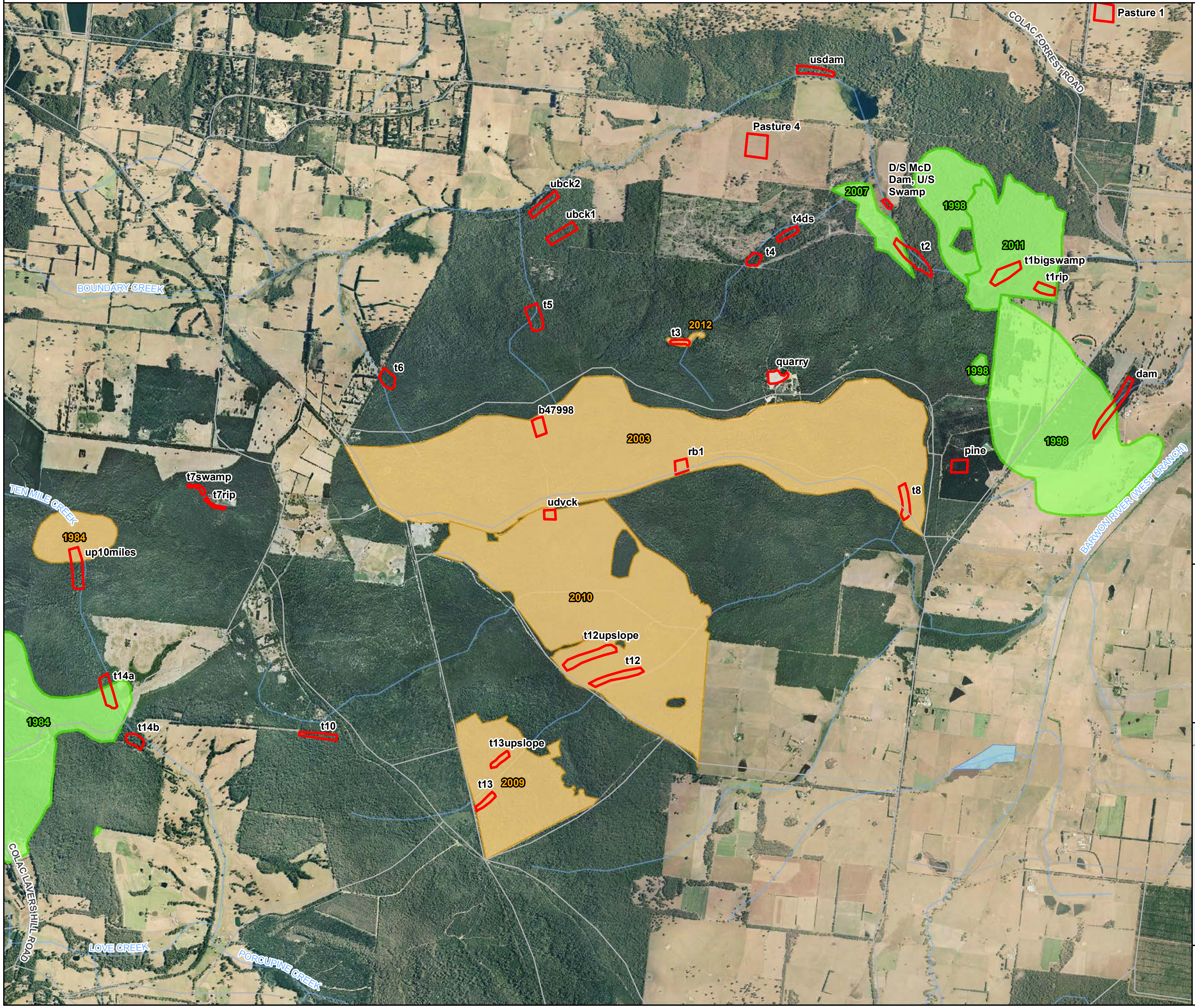
Tree/sample	Pre-dawn (Mpa)	Mid-day (Mpa)
1/1	0.38	1.52
1/2	0.36	1.80
1/3	0.36	2.05
Corrected average	-0.32	-1.74
2/1	0.32	0.75
2/2	0.34	1.12
2/3	0.38	1.42
Corrected average	-0.31	-1.06
3/1	0.25	0.82
3/2	0.28	1.31
3/3	0.23	1.01
Corrected average	-0.17	-0.97

Tree	Sample Height (m)	Correction Factor
1	5	0.05
2	4	0.04
3	8	0.08

Appendix I. Fire History Around NDVI Sites

Fire History around NDVI Sites

Groundwater Dependent Terrestrial Vegetation Investigation



Legend

- NDVI Analysis Site

Fire History by Season

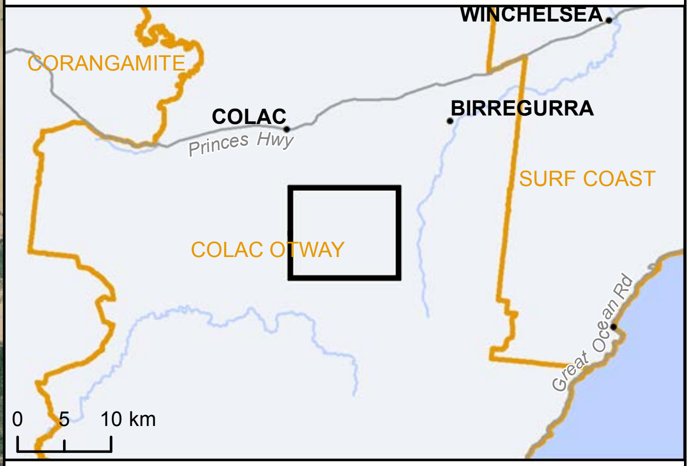
- Planned Burn
- Bushfire
- Minor Road
- Watercourse
- Lake

N

IS039500
GDA 1994 MGA Zone 55

0 1 2
kilometres

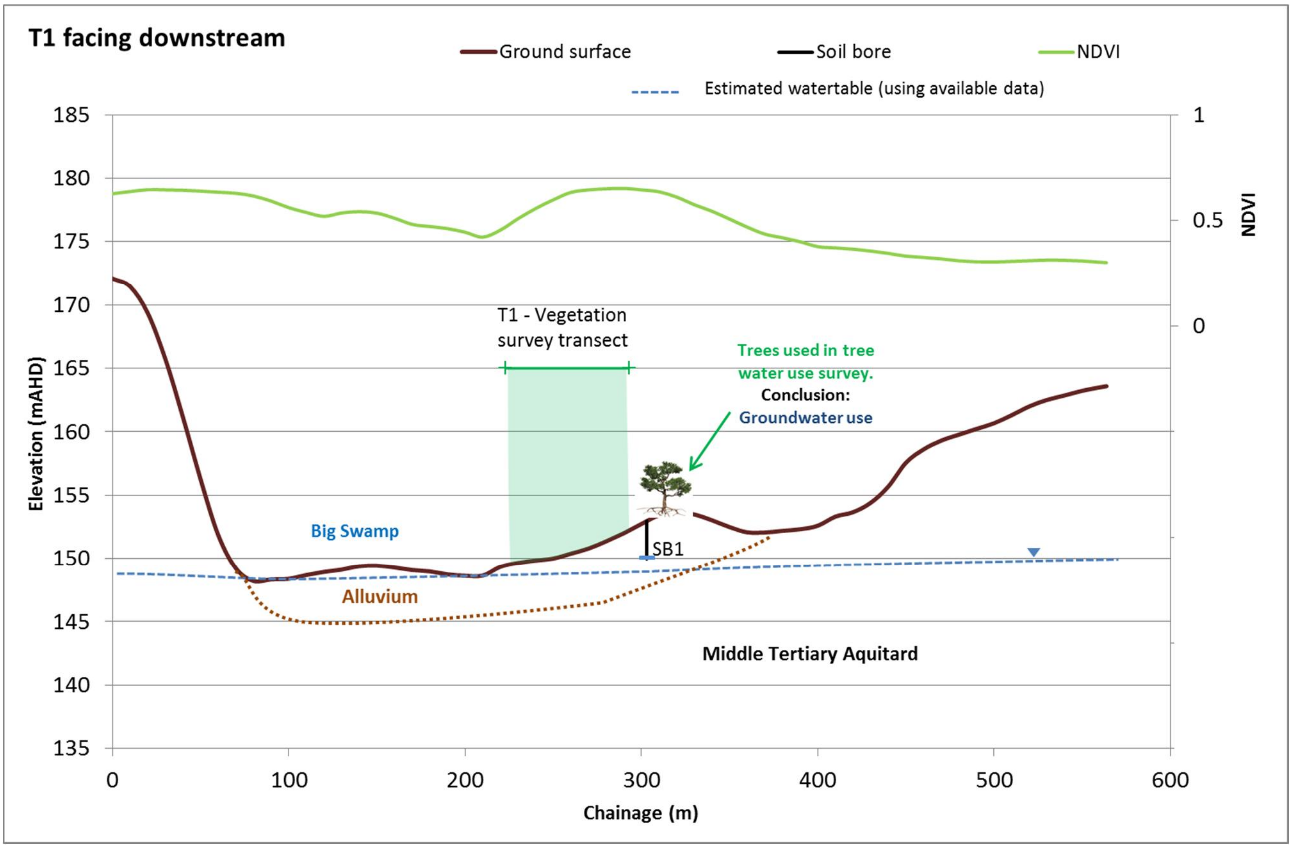
DATA SOURCES
© Commonwealth of Australia (Geoscience Australia) 2006 Geodata Topo 250k Series 3; Vicmap Data © State of Victoria 2015; Jacobs 2015; Fire History: © The State of Victoria, Department of Environment, Land, Water & Planning 2015. Imagery: Barwon Region Water Corporation, Barwon Water Monitoring Program 2008.



BarwonWater JACOBS

Appendix J. Cross sections

Transect 1



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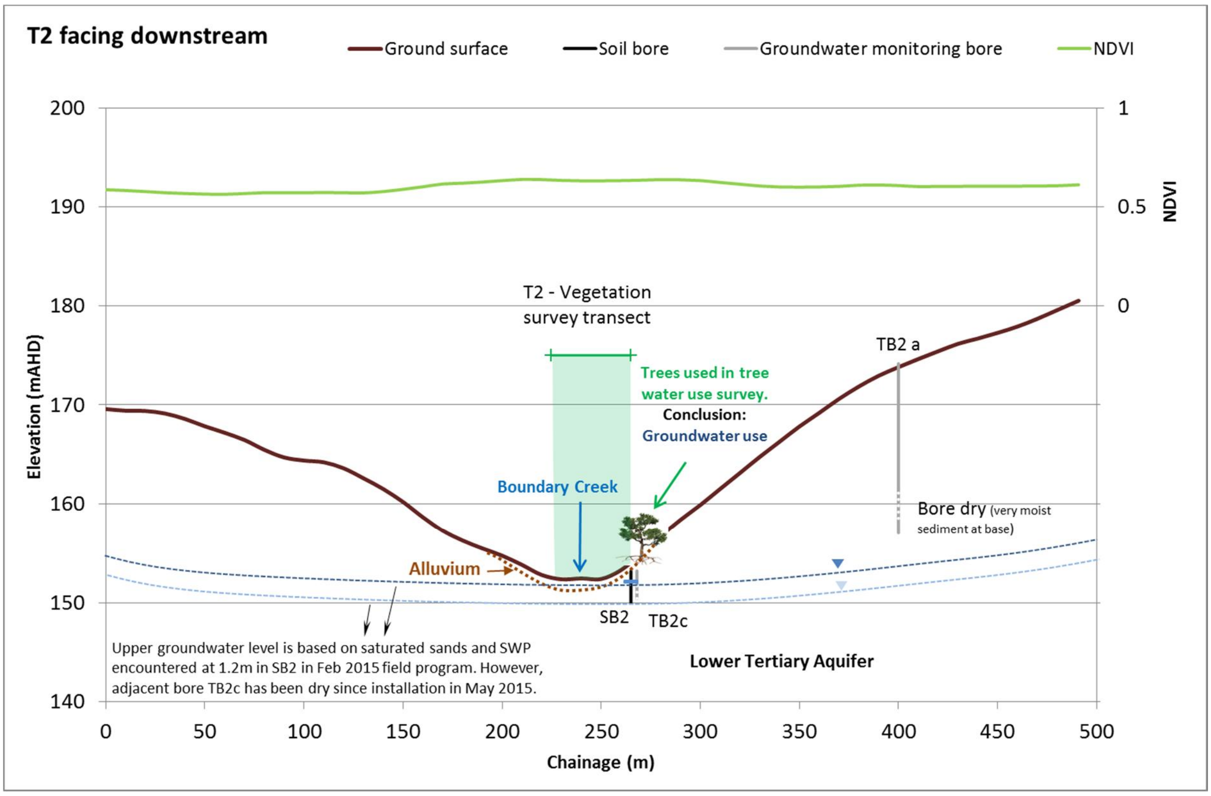

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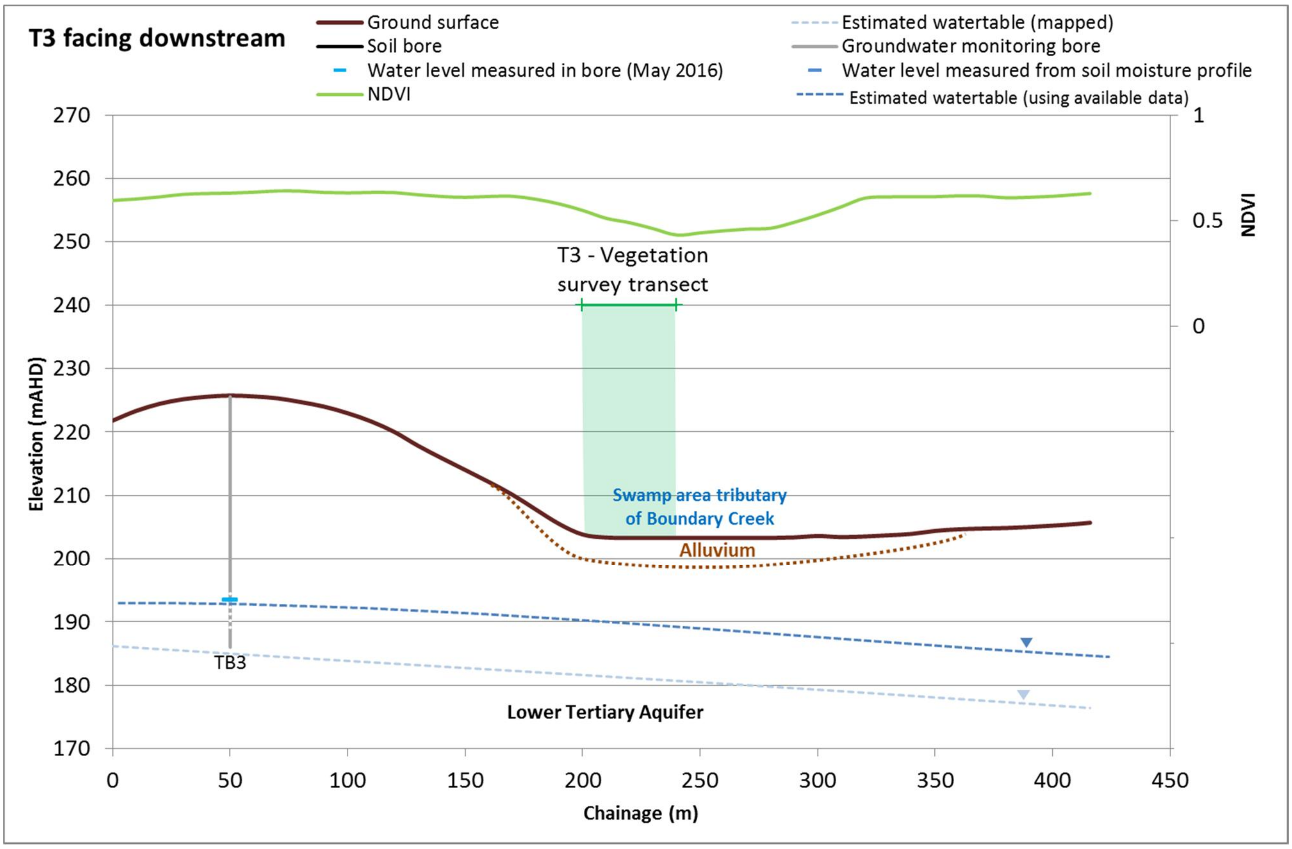

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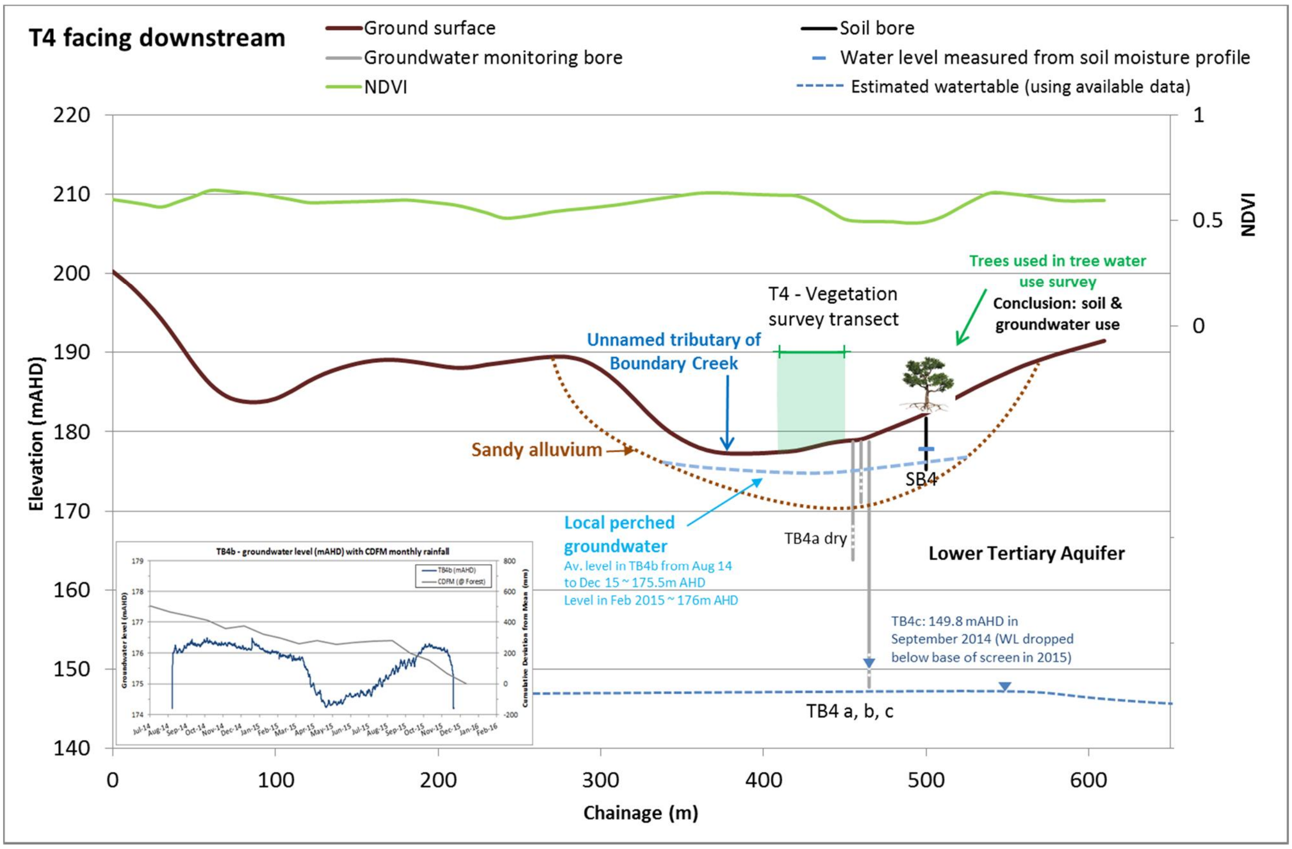

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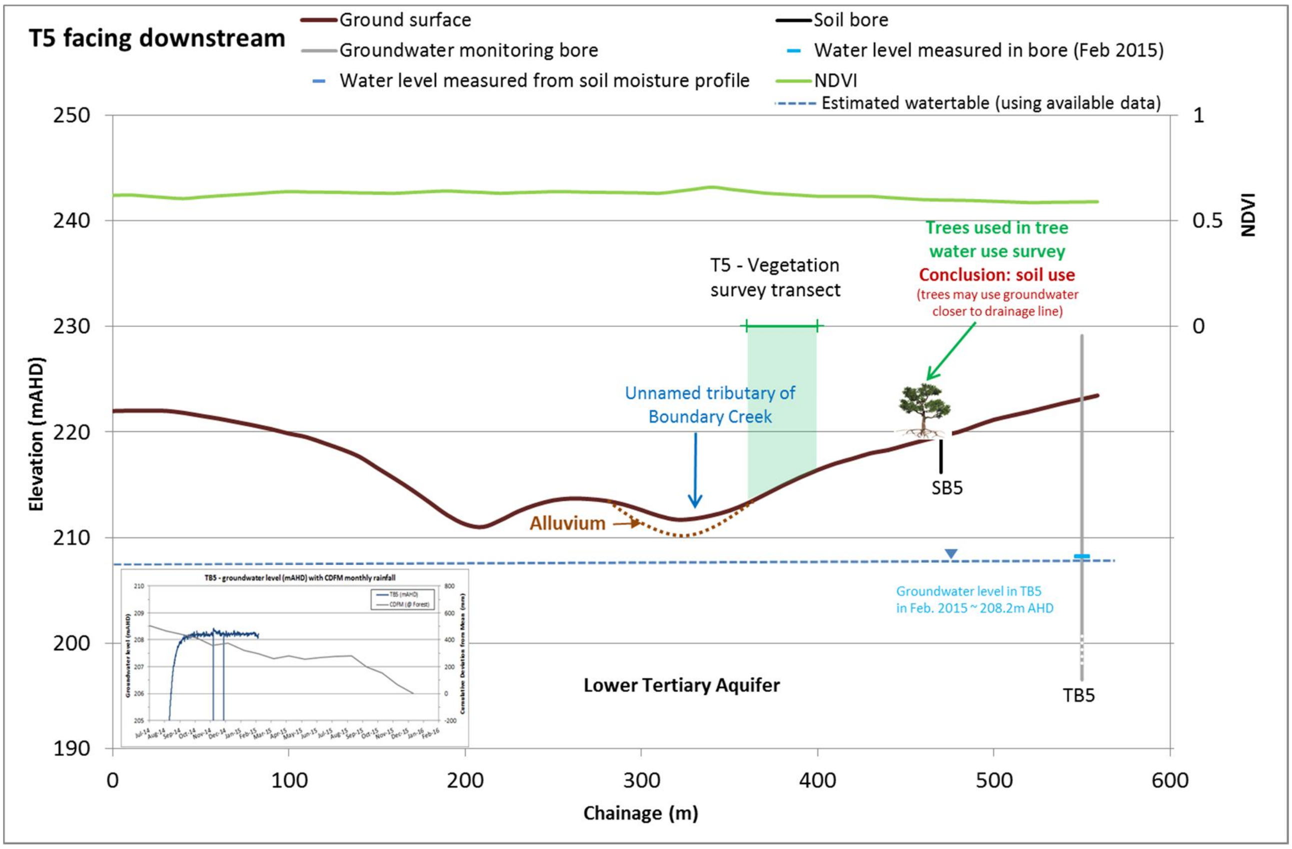

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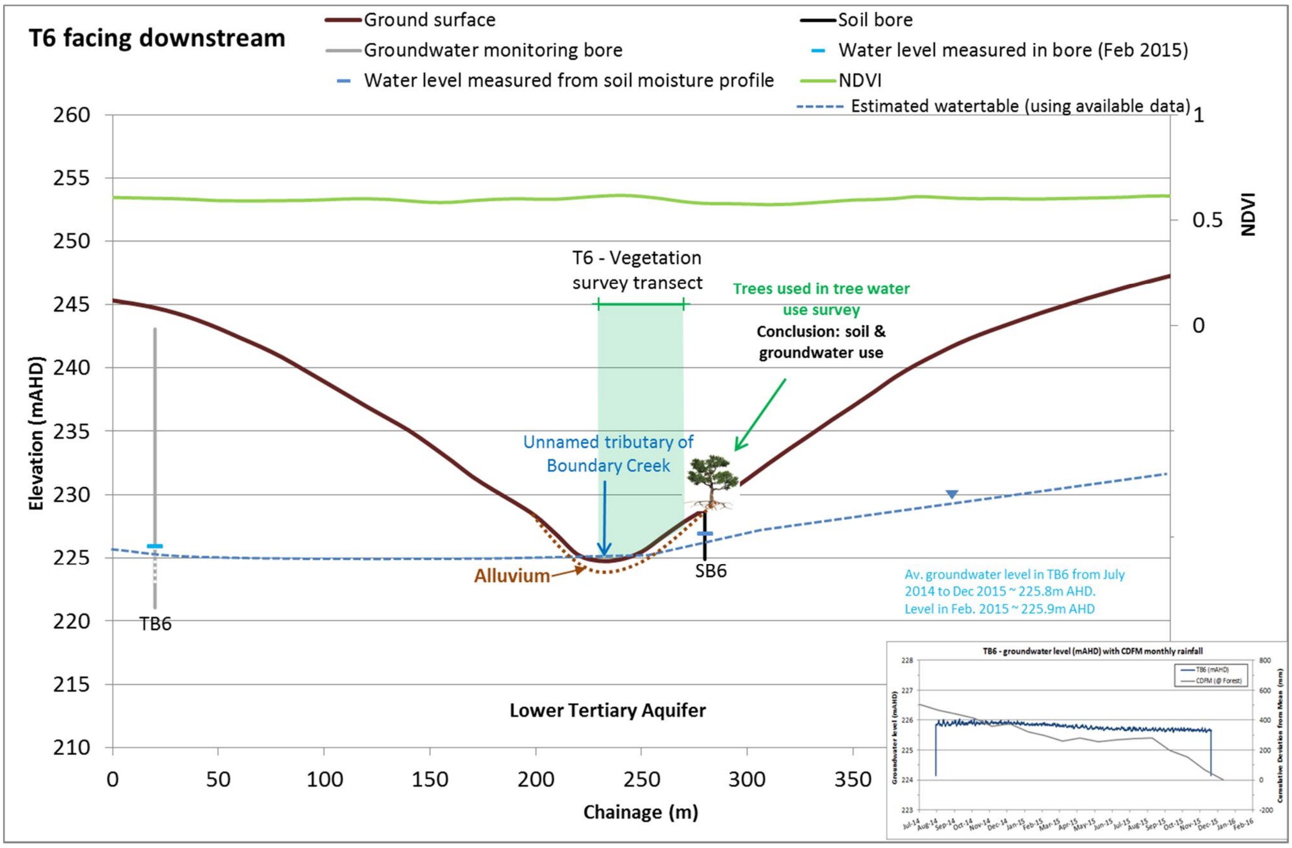

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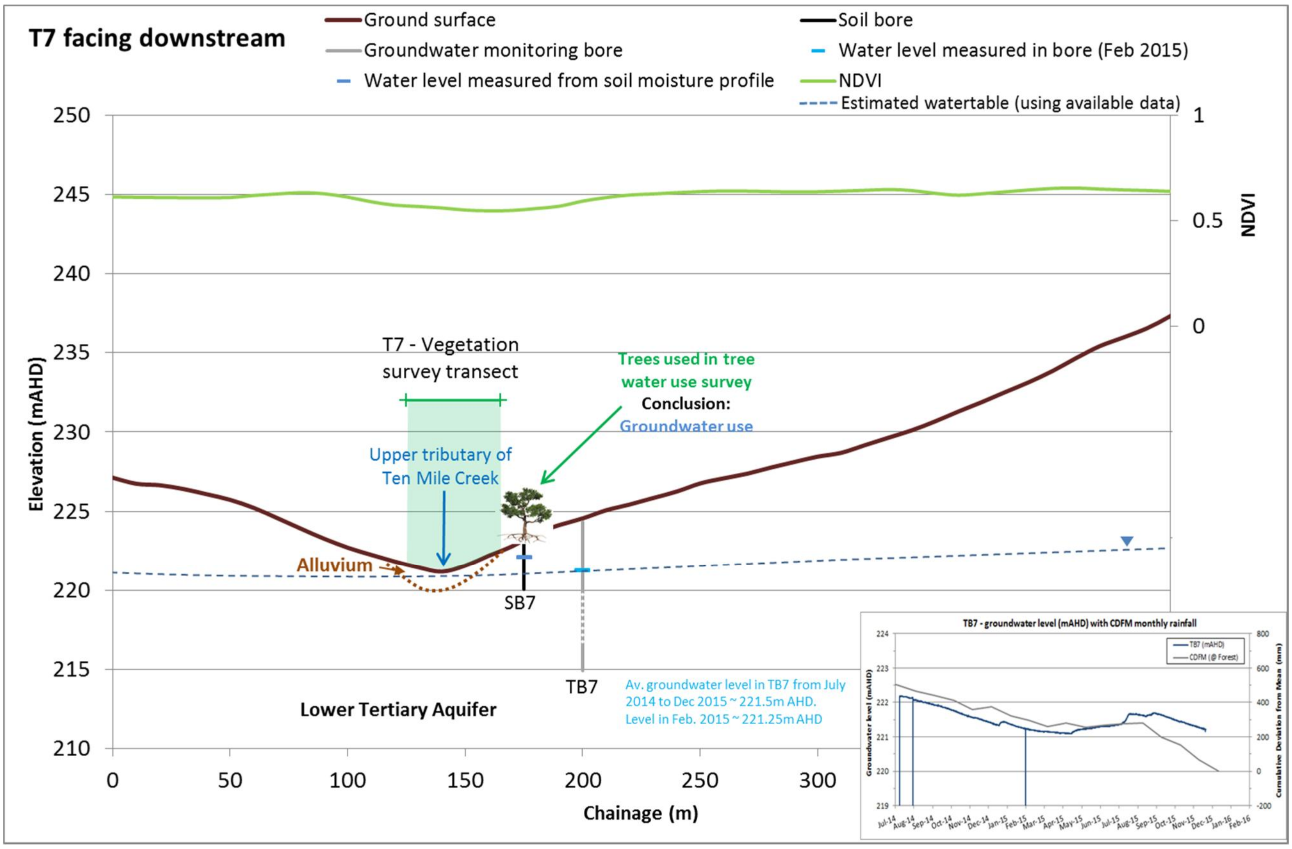

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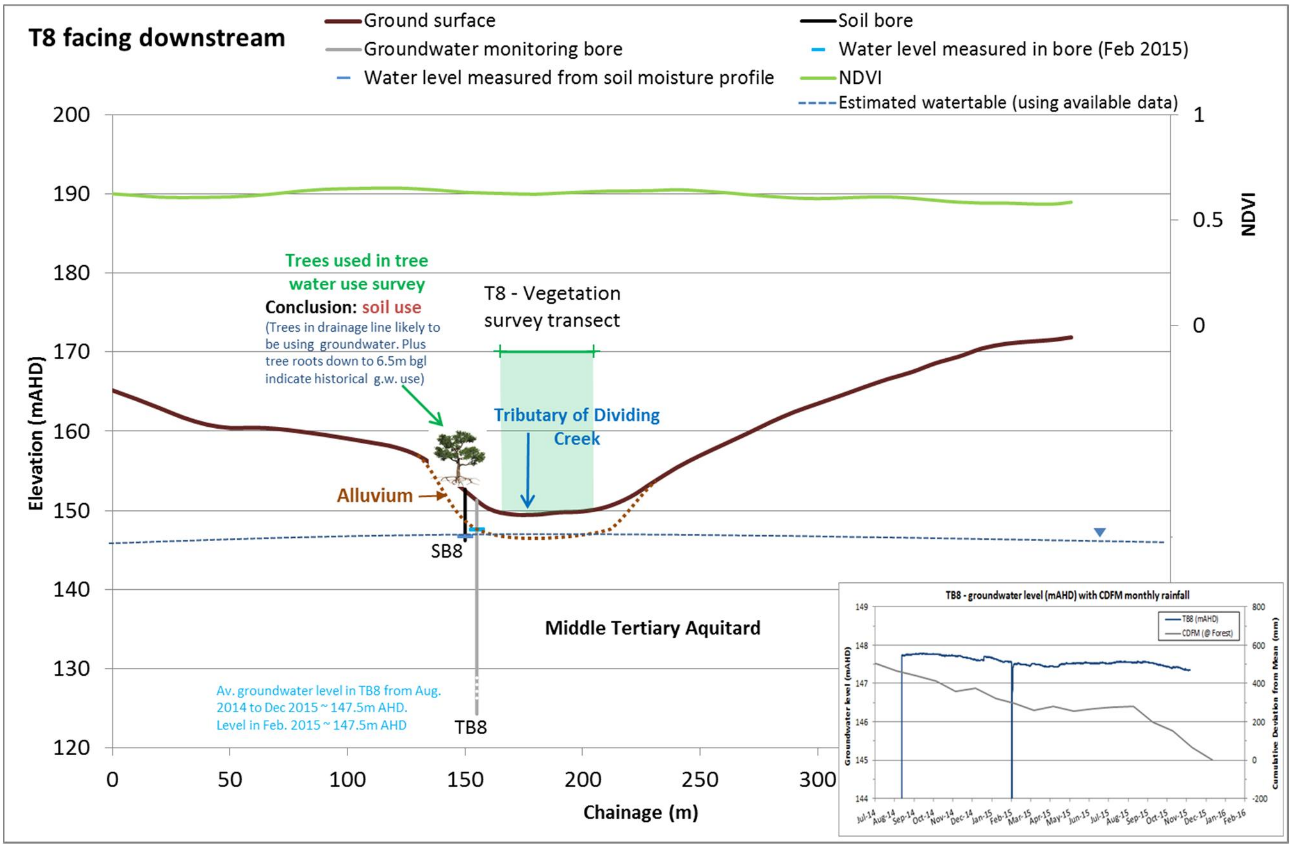
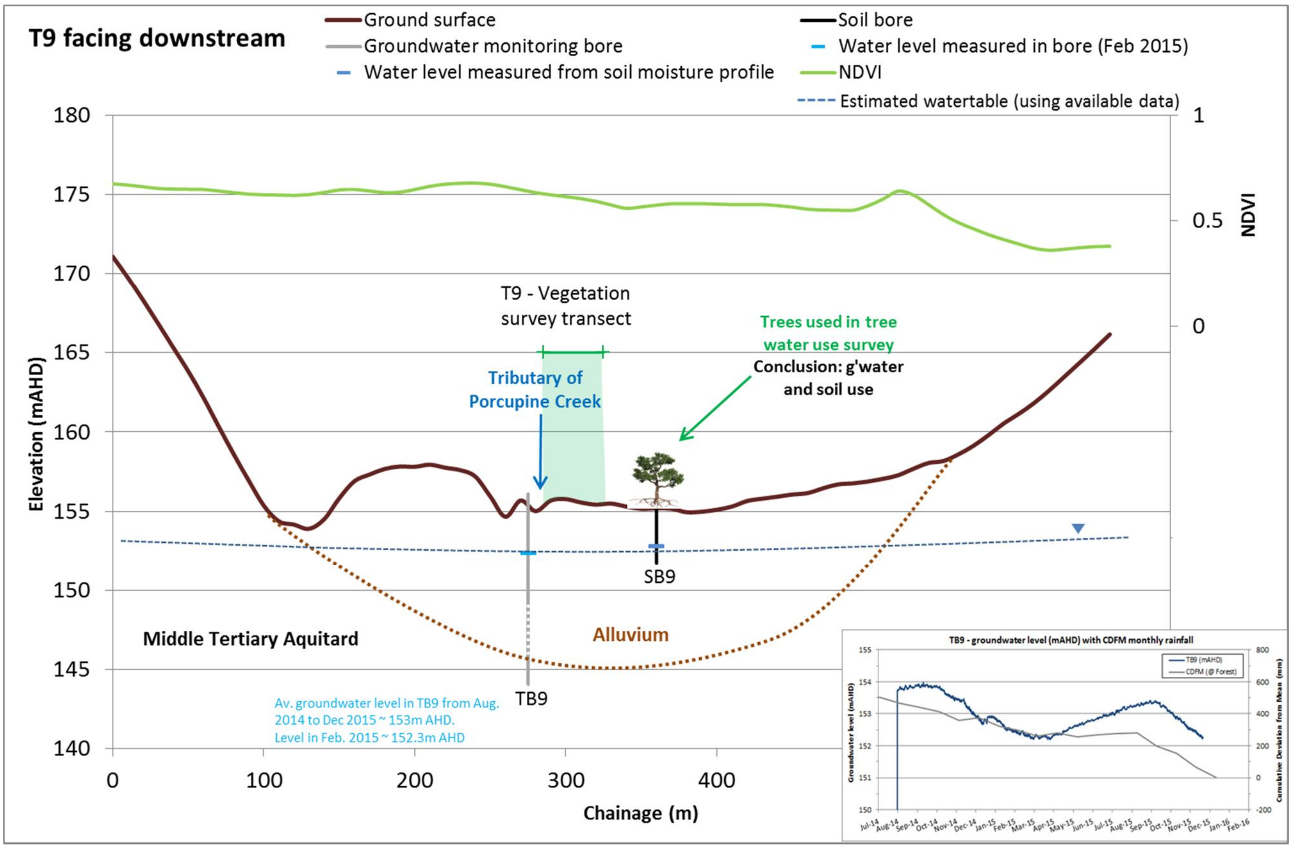
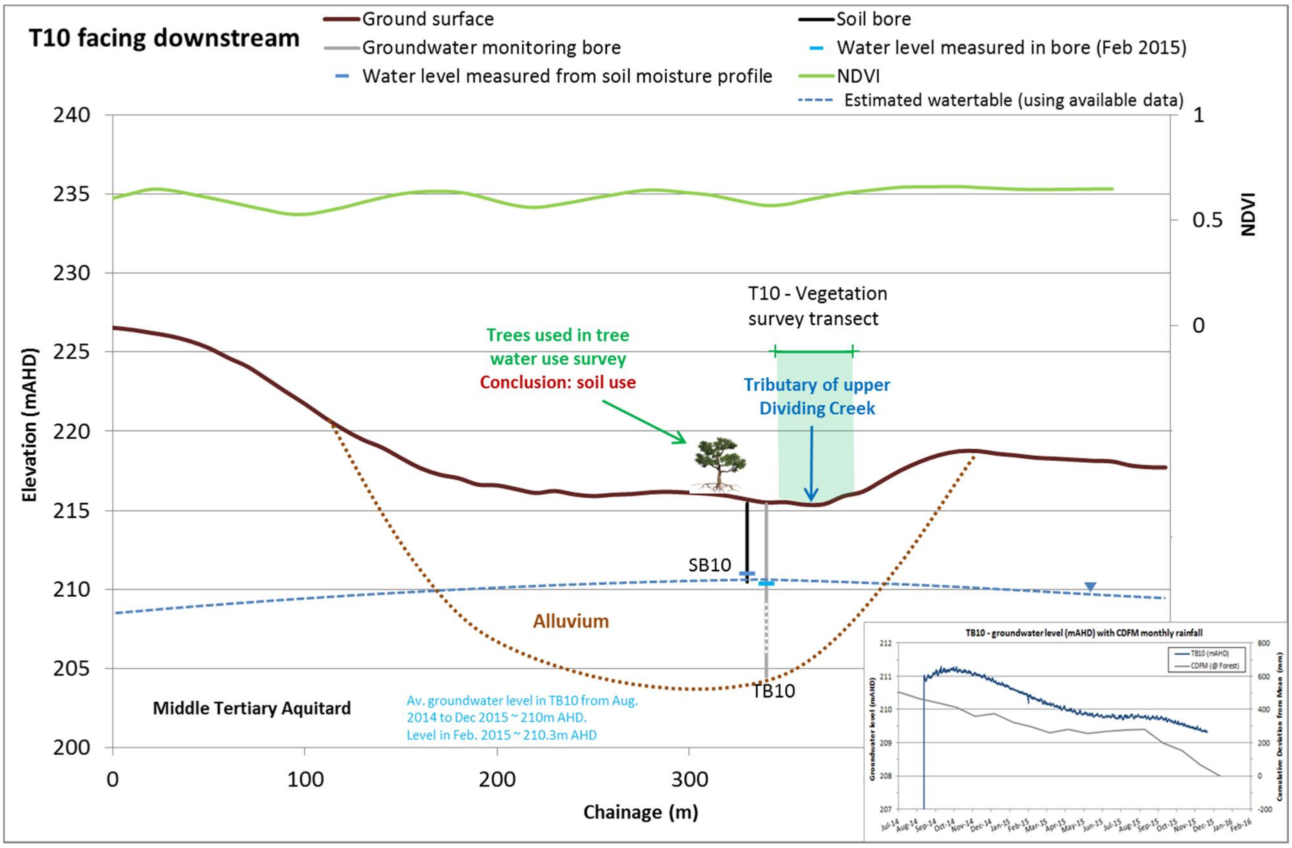


Transect 9



Transect 10



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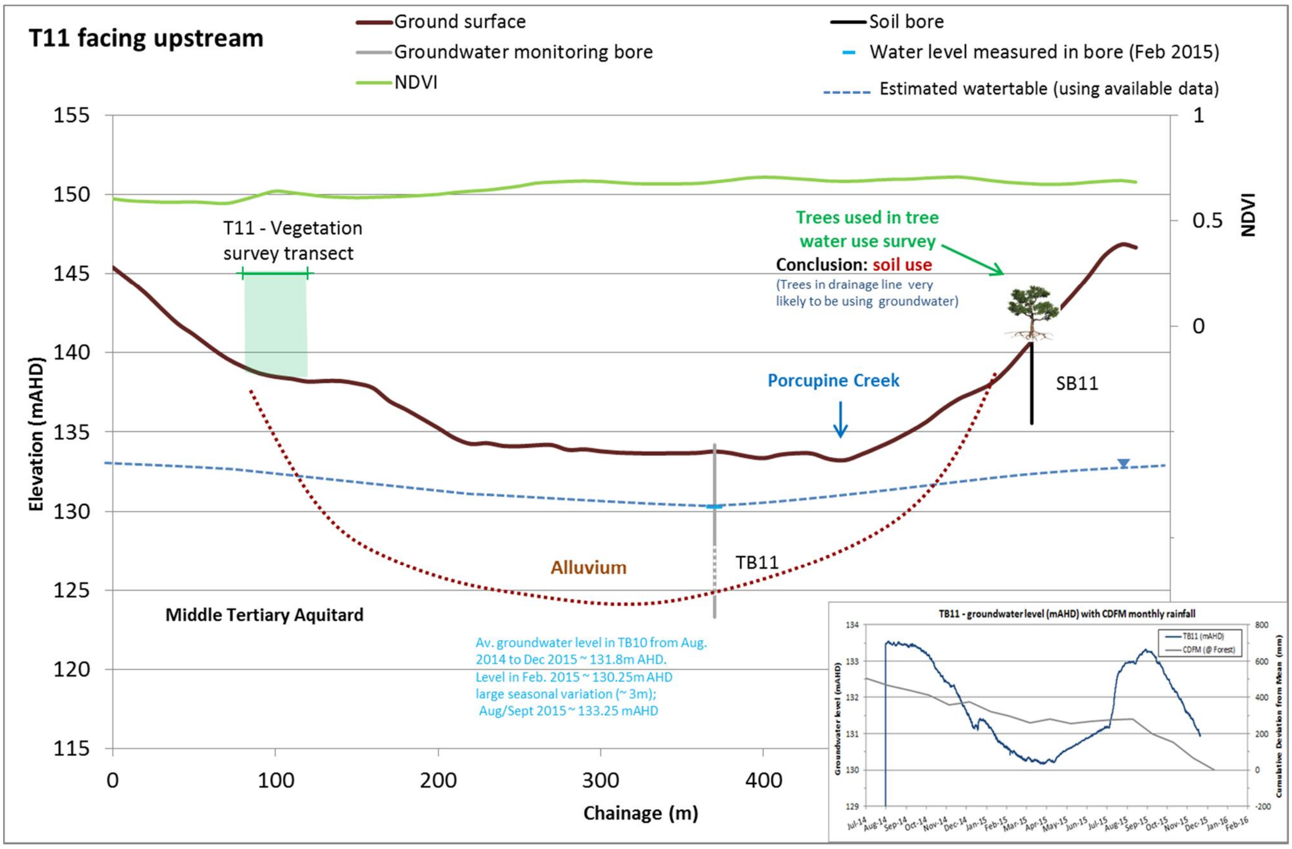
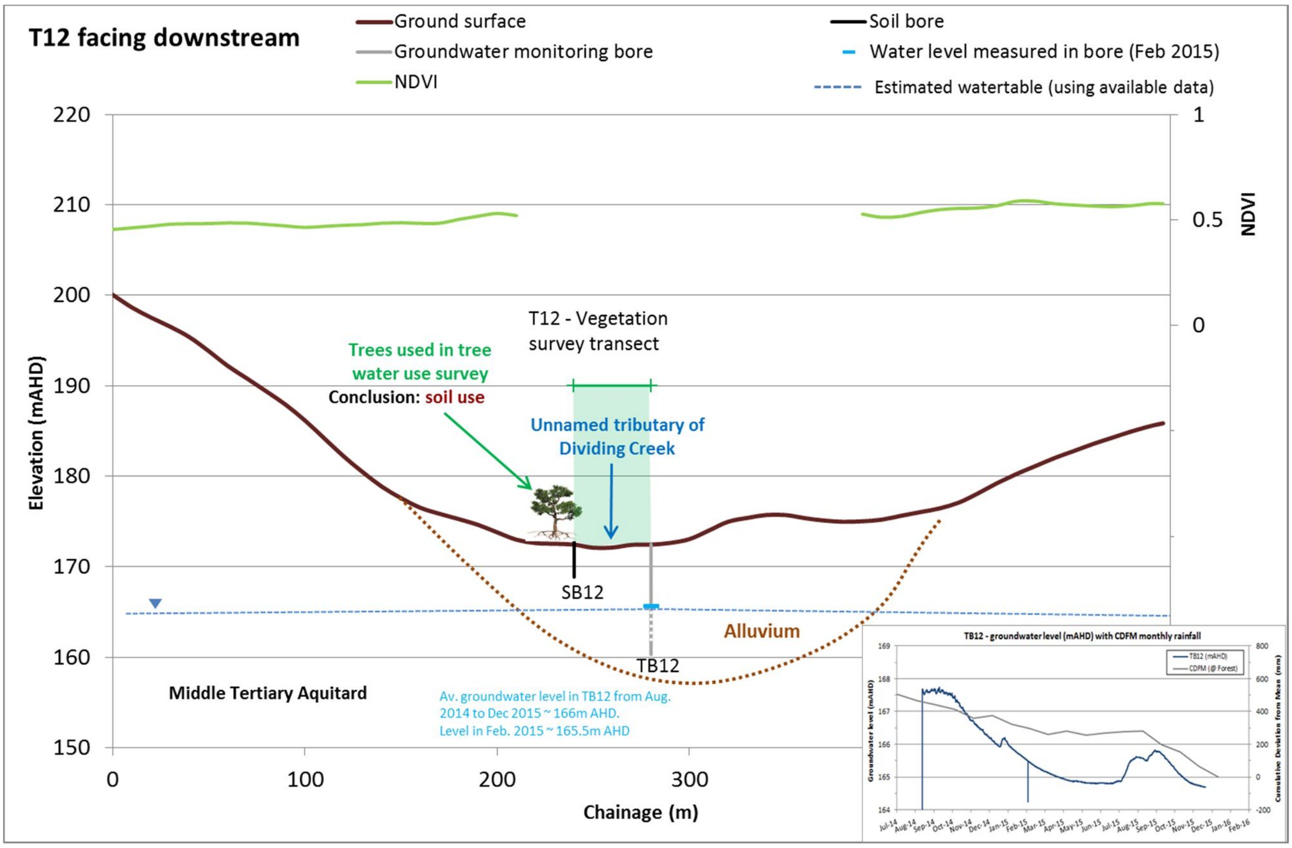


Transect 12



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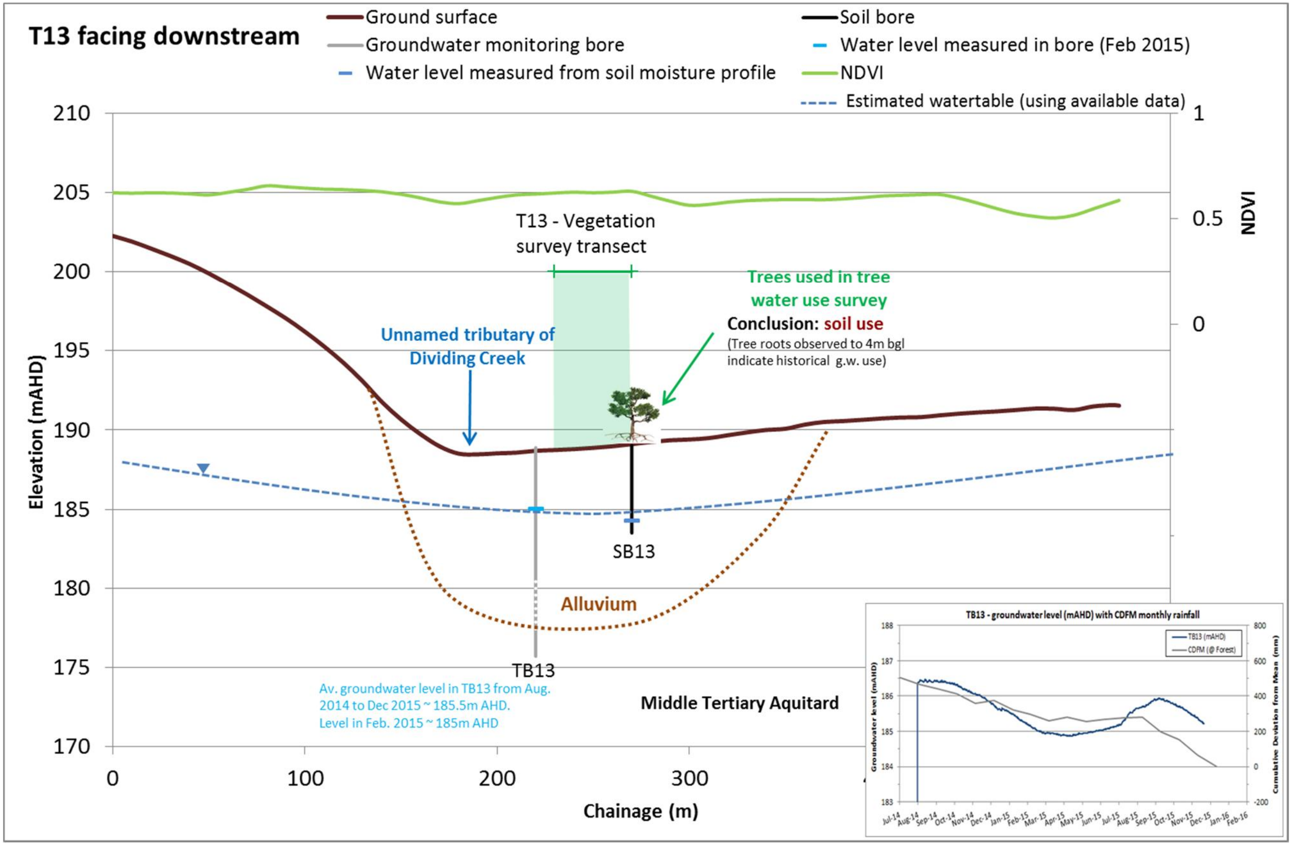

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