Accounting for the hydrological impacts of the regional plantation forest estate in the Lower South East of South Australia

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
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Acknowledgements

This project is funded by the South East Natural Resources Management Board. This report, and the technical work behind it, is the first part of a project that aims to better understand the hydrological impact of commercial plantation forests in the Lower Limestone Coast region's landscape. Learnings from this part of the project will assist in a review of the Wattle Range 2010 (WR2010) groundwater numerical model, and a review of the resource conditions and management approach required by the Water Allocation Plan for the Lower Limestone Coast Prescribed Wells Area, with respect to accounting for plantation forest hydrological impacts in the region.

The author would like to acknowledge the cooperation received from the forest industry, through the auspices of the Green Triangle Regional Plantation Committee. Similarly, a number of staff members from the Water Science and Monitoring Branch of DEWNR have provided advice in respect to the collection and management of data used in this report, its collation, presentation and review. The interest and advice from an independent external reviewer of this report is also acknowledged.

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Introduction

The aim of this investigation is to assess whether the forest water accounting model that underpins the forest water accounting system in the *Water Allocation Plan for the Lower Limestone Coast Prescribed Wells Area* (LLC WAP) adequately reflects the impacts of plantation forests on groundwater resources in the region for groundwater management purposes. Such analysis is necessary for stakeholder confidence in any related groundwater technical assessments and management responses, and the forest water licensing system which involves a valued water property right. For these reasons, it is important that the forest water accounting model is considered to be suitably accurate and 'fit for purpose'.

The investigation has concluded that the forest water accounting model can be considered to be sufficiently accurate for the intended purpose of quantifying the hydrological impacts of hardwood and softwood plantations at a management area scale. There are however, some constraints which include:

- the depth of the watertable at which plantation extraction is deemed to occur
- significant divergence of plantation forest management from the characterised management for the regional 'average' forest that is incorporated in the adopted forest water model.

Softwood plantation forests

The study indicates the model is robust for reasonable variability in softwood plantation management about the characterised average plantation. This applies to the length of plantation life and the number of thinning operations during that life. It is considered that some minor upward adjustment in the deemed groundwater extraction by softwood plantations may better reflect reality at the sites studied. Similarly, an increase in the deemed plantation forest recharge for the period prior to canopy closure may provide a more accurate assessment of in-field recharge impacts at the studied sites.

A significant factor is groundwater extraction by softwood plantations is occurring at depths greater than the adopted policy position, which assumes that plantation forests only extract groundwater where the watertable is no more than six metres below ground level. For administrative purposes, the current 6 m depth to the watertable is referenced at June 2004 for the existing plantation forest estate, and any proposed expansion of the estate.

Hardwood plantation forests

Several issues have been identified in respect to hardwood plantation hydrological accounting. The main factor is the management of these plantations has resulted in an almost doubling of the period of plantation groundwater extraction. While there is also a reduced aggregate recharge due to a low level of plantation renewal, it is the aggregated groundwater extraction factor that significantly pushes the water account into a negative position. This results in a greater annual net reduction in groundwater in storage than previously modelled by the WR2010 numerical groundwater model. While the extended period of continuous extraction is the main issue, it is considered that the actual annual extraction value per hectare may be marginally lower than that estimated by the hardwood extraction model.

Implications for technical assessments, modelling and policy

Adjusting any of the parameters applied in the adopted forest water model will require careful consideration as a change may have unintended implications for the recently granted plantation forest water property rights.

Whether or not there are changes to the forest water management policy and the associated forest water accounting model, it is suggested that numerical groundwater modelling considers the observations and findings from this study to achieve greater confidence in the output from modelling various management scenarios.

1 Aims and objectives

1.1 Aims

The main aim of this investigation is to assess whether the forest water accounting model that underpins the forest water accounting system adopted by the *Water Allocation Plan for the Lower Limestone Coast Water Prescribed Wells Area* (LLC WAP) adequately quantifies the hydrological impacts of plantation forests on groundwater resources in the Lower Limestone Coast Prescribed Wells Area (LLC PWA).

A secondary aim is to inform the review of the Wattle Range 2010 (WR2010) numerical groundwater model, which was established to consider the consequences of various management scenarios related to the extensive land use change from farming and grazing to plantation forests in the Wattle Range area (west of Penola).

The process involves testing the predictive accuracy of the forest water accounting model against actual observed changes in groundwater levels (and hence storage) for a study period in the order of 30 to 40 years at seven 5000 ha sites in the LLC PWA where plantation forests are a significant land use. This is undertaken by developing a net annual water-mass-balance account for each site, using the annual components from the adopted forest water accounting model and other relevant parameters embodied in the LLC WAP, and comparing the accounting outcomes with the net annual changes in groundwater in storage at the seven sites.

1.2 Background

The forest water accounting model is applied separately to the hardwood and softwood forest categories. For each forest category where the plantations overlay a shallow watertable, the model accounts for the impact of plantation forests on groundwater recharge and extraction. In this report, the 2006 model components (Harvey 2009) are applied to address softwood recharge, softwood extraction, hardwood recharge and hardwood extraction.

While the forest water accounting model expresses the hydrological impacts of a characterised 'average' plantation forests in an annualised form, the model is built on annual hydrological increments for recharge and extraction impacts over the full rotation life of the relevant plantation forest. The annualised value is an aggregate of all the annual hydrological impacts of a plantation forest, from planting to site clean-up following its clear felling, divided by the total number of years in the characterised 'average' forest rotation. The annualised values can be considered to be a mean annual impact value of the complete forest life cycle. The deemed annualised impact values, whilst technically inaccurate for any specific stage in the life of any forest compartment, are considered to be sufficiently representative of the aggregate impact of the plantation forest estate on the groundwater resource, at a sub-regional area scale, if the forest management aligns with the characterised 'average' forest.

The annualised format was supported by industry stakeholders when the initial 2001 forest water recharge model was revised in 2006 and the forest groundwater extraction by plantation forests was incorporated. An underlying premise at that time was the softwood industry considered itself to be a 'mature' industry where the softwood forest estate was comprised of mixed aged plantings, with the aggregate of each age-class being of a similar area. The industry considered this to be an essential commercial characteristic to maintain a steady and predictable flow of logs to the value adding sectors of the industry. The softwood plantation forest industry considered 35 years from planting to clear felling to be an 'average' industry rotation length and the softwood forest water accounting was based on this management characterisation.

The first commercial plantings of hardwood forests began in the late 1990s and rapid expansion continued into the early 2000s. At the time of the forest water model review in 2006, there was a proposal to develop a paper pulp mill in the region to add value to the regional hardwood plantation forest production. This new enterprise would also require a managed constant flow of plantation forest feedstock for its operation, and consequently, there was a need to transition the new regional hardwood forest estate to a 'mature' industry status where the estate would have relatively uniform areas across the different forest age classes.

The hardwood industry advised it would rapidly transition to a regional plantation forest estate where hardwood plantations would have an average rotation period of approximately 10 years (Harvey 2009).

It was therefore considered that annualised forest water accounting would be sufficiently accurate and appropriate for groundwater accounting and management if the plantation forest estate was structured and managed as a 'mature 'industry with constant cycles of plantation renewal, as proposed by both the hardwood and softwood industry sectors. The annualised accounting approach is intended to minimise reporting, administration and compliance burdens for both the forest managers and the agency responsible for managing the state's water resources, whilst providing a relatively accurate summary of the aggregate volumes of groundwater associated with plantation forest recharge and discharge, where plantation forests are a significant land use, at a groundwater management area scale[1].

In revising the forest water accounting model and incorporating forest groundwater extraction in 2006, the forest management calendar advice and plantation management observations by the plantation forest industry were taken into account when applying the biophysical principles on which the models are based. Outcomes of research undertaken by Benyon and Doody (2004) on groundwater extraction by plantation forests overlying shallow watertables was also applied in the construction of the extraction component of the forest water accounting model. Model detail and development are described by Harvey (2009) and a brief summary of each component for recharge and extraction for hardwood and softwood is available in Appendices A, B, C and D.

Recent data provided by the plantation forest industry indicates that the combined regional softwood and hardwood industrial plantation estate at the end of 2014 totalled 149 010 ha. This comprised 108 046 ha of softwood plantations, where the main species is *Pinus radiata* (pine) and 40 964 ha of hardwood where *Eucalyptus globulus* (Tasmanian Blue Gum) is the main species. These areas exclude the relatively small areas of farm forests, as defined by the LLC WAP.

Under the LLC WAP, the commercial forest estate now has licensed water allocations totalling approximately 308 GL, which represents about 30 per cent of all licensed water allocations in the region (LLC WAP 2013); these being granted on the basis of the annualised output values of the 2006-version forest water accounting model.

Various names are applied to the main forest types in the LLC PWA, but this report will use the identifiers of softwood for the pine or long rotation forests and hardwood for the blue gum or short rotation forests. All forest observations and commentary relates only to commercial (or industrial scale) plantation forests.

A map displaying the distribution of the regional plantation forest estate is presented in Figure 1.1.

Until now, there has been no attempt to test the accuracy and suitability of the forest water accounting model for groundwater accounting and management purposes. This current investigation has been commissioned by the South East Natural Resources Management Board and collaboratively scoped with representatives of the regional hardwood and softwood plantation forest industries, through the auspices of the Green Triangle Regional Plantation Committee.

1.3 Review of forest water accounting models

For confidence in groundwater technical assessments and appropriate groundwater management responses, it is important that the efficacy of the forest water accounting system is analysed and if appropriate, declare that it is fit for the intended purpose. Similarly, for stakeholder confidence in regard to their water property rights, it is

[1] There are 61 groundwater management areas in the LLC PWA which range in area from 3775 ha to 55 600 ha, with an average area of about 24 000 ha.

desirable to demonstrate that the adopted forest water accounting system suitably reflects the actual hydrological impacts of plantation forests at a management area scale. It is envisaged that if any technical gaps, or weakness in the forest water accounting model become evident, this study will help inform discussions related to any possible corrective measures to be considered.

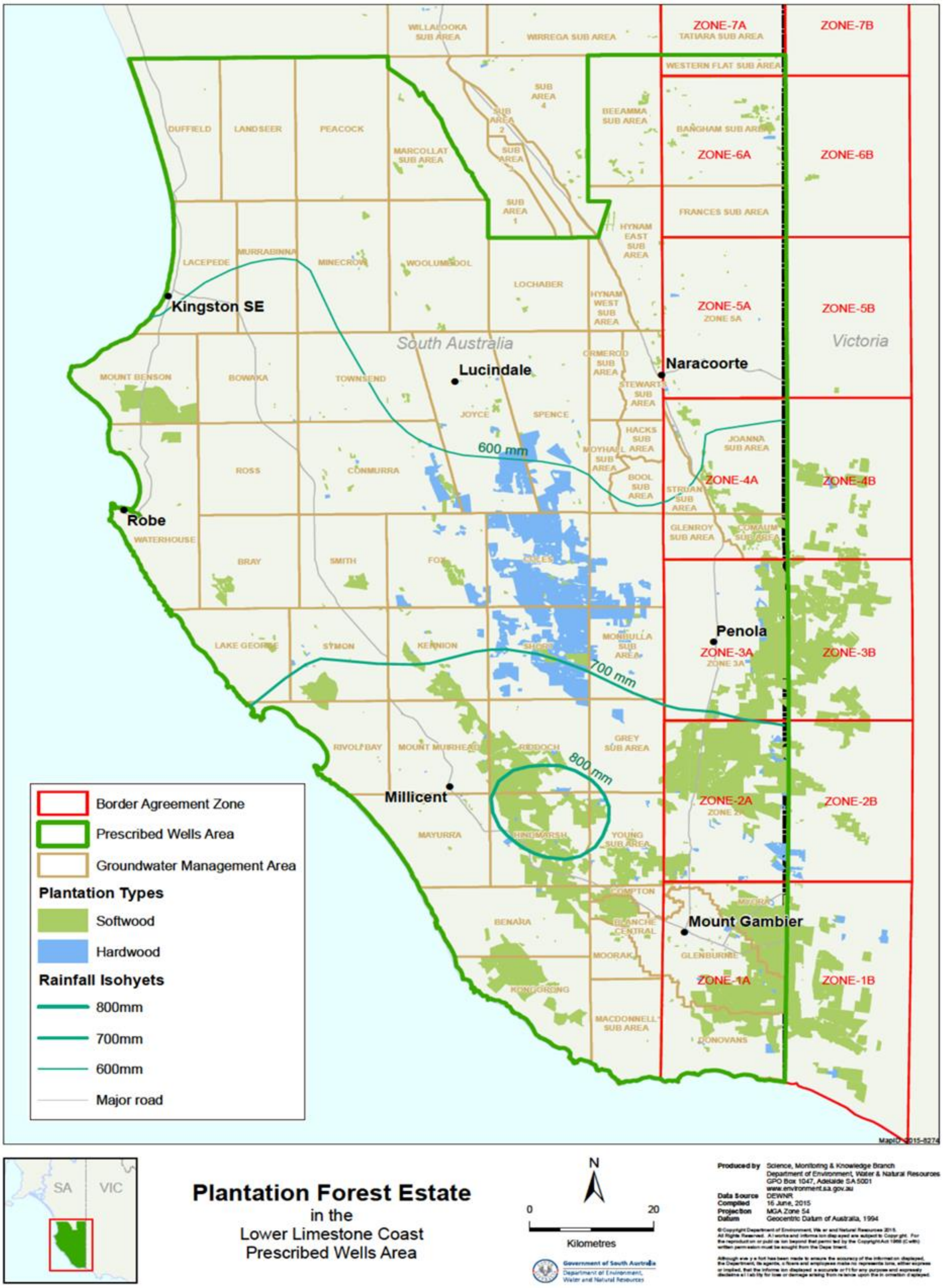

Figure 1.1: Lower Limestone Coast Prescribed Wells Area plantation forest estate distribution

1.4 Numerical modelling

The WR2010 model is a 3D numerical groundwater model, developed by Aquaterra (2010) using the finite difference code MODFLOW (Harbaugh, 2005). The model simulates groundwater flow within a 3440 km^2 portion of the LLC PWA centred on the main areas of hardwood plantation (refer to Figure 1.2). The model has one layer representing the regional unconfined Tertiary Limestone Aquifer. Inflow processes in the model are regional inflow from the east and diffuse rainfall recharge. Key outflow processes in the WR2010 model are regional groundwater outflow, groundwater extraction for irrigation, potential outflow through drains, and groundwater extraction by plantation forests.

Simulated rates of forest extraction and recharge interception are based on the values described by Harvey (2009) and adopted by the LLC WAP (2013). The WR2010 model tested 18 scenarios, exploring different groundwater management arrangements in the South East, including changes in land use and plantation forest areas. Scenarios were also run to assess model sensitivity to changes in groundwater recharge. The model results were used to guide the development of groundwater management policies for the Wattle Range area through the LLC WAP (2013).

Detail of the current WR2010 model and the various scenario outputs developed in 2010 are presented in the report *Modelling forestry effects on groundwater resources in the southeast of South Australia* (Aquaterra 2010).

The knowledge gained from testing the 2006 forest water model and analysing plantation forest estate data in this report, has assisted in a review of WR2010 numerical groundwater model. This revision of the WR2010 model will help inform discussions on groundwater management options for the Wattle Range area in the LLC PWA. The model revision, scenarios and outcomes are described in the DEWNR Technical Report 2017/14, Lower Limestone Coast forest water accounting groundwater model.

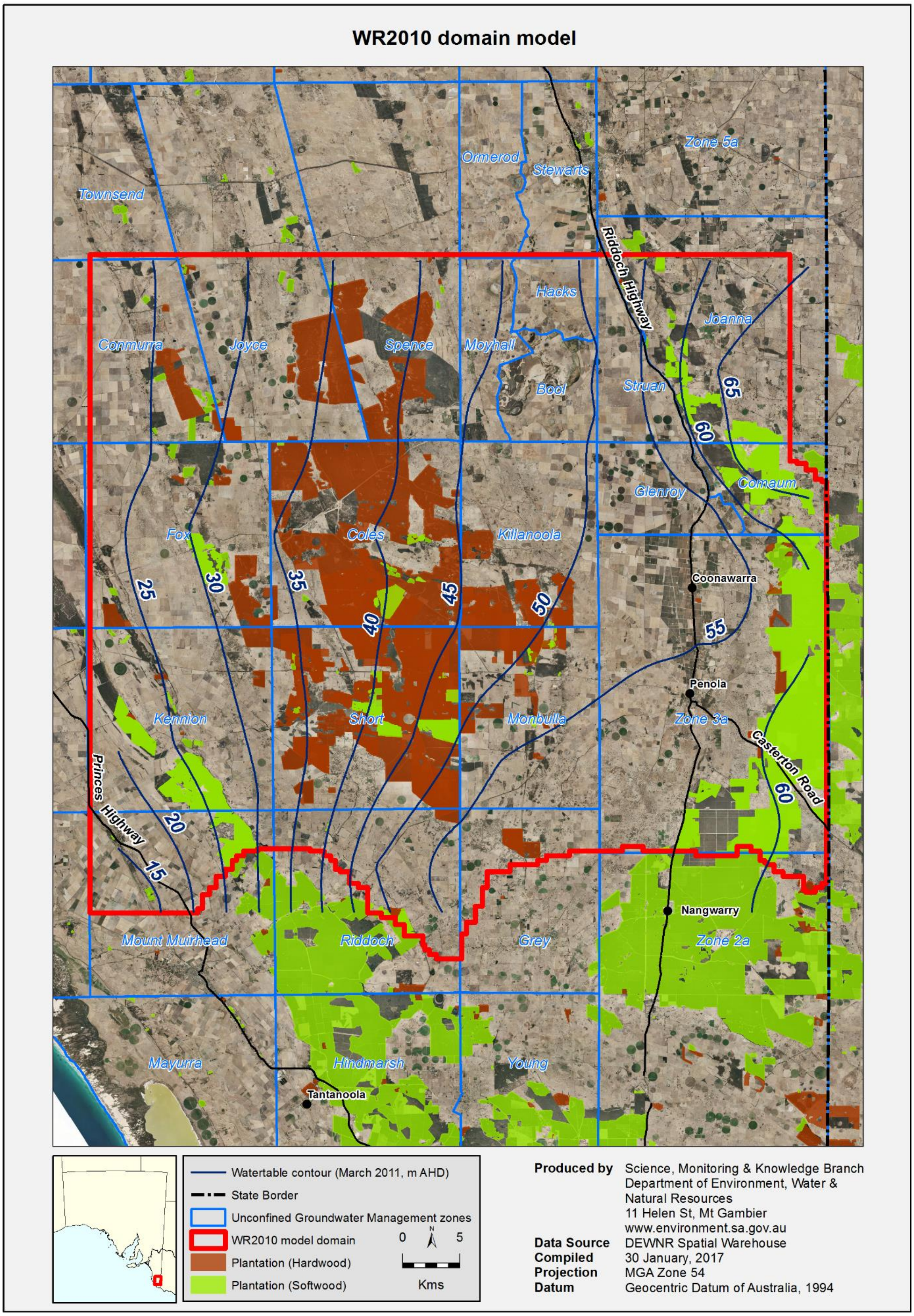

Figure 1.2: WR2010 model domain

2 Methodology

2.1 Analysis approach

The main objective of this study is to test the predictive annual accuracy of the forest water accounting model (Harvey 2009) against the actual annual observed net changes in groundwater storage at seven 5000 ha sites in the LLC PWA over periods up to 40 years. This is undertaken by developing a net annual water-mass-balance account for each study site, using the annual components from the forest water accounting model, and comparing the calculated net annual water-mass-balance to the observed changes in groundwater storage over a number of years. It is anticipated this scale of observation and analysis should provide a reasonable indication of hydrological impacts that can be attributed to plantation forests at a management area scale.

Site selection is confined to areas where there is a history of groundwater level observations for periods approaching 40 years and plantation forests are the predominant land use. At each study site, the forests are considered to be a reasonable representation of the forest industry activity in the general area. Using relevant parameter values adopted and applied by the LLC WAP, the resulting net annual water-mass-balance is then converted to a depth of groundwater in storage and this is then compared to the annual net change in groundwater storage at each location, this being determined by changes in the depth to the watertable.

On identifying a suitable monitoring well where plantation forestry is a major land use, a study site with a 4 km radius is established around the selected monitoring well. The various land use classes within the study area are then assigned groundwater recharge values; these being expressed as mean values that are adjusted for rainfall variability in each year included in the study period.

The adopted mean management area recharge rates are those set out for the region's 61 groundwater management areas in the LLC PWA and specified in Table 1 of the LLC WAP. These are presented as Appendix Table E to this report. These mean management area recharge rates (expressed in mm of rainfall/year) have mostly been determined by the watertable fluctuation method by Brown *et al* (2006), using historic data from the regional observation well network. The forest water model expresses plantation forest recharge impacts as a percentage of the relevant management area recharge rate.

The LLC WAP considers that no groundwater recharge occurs under native vegetation. Based on this assumption, regional diffuse groundwater recharge from rainfall only occurs under grassland and under specific stages of the plantation forest rotation; the period from planting to canopy closure for both plantation types, and after plantation thinning operations in the case of softwood plantations.

The forest water accounting model that estimates groundwater extraction by plantation forests is based on the same plantation forest management regime applied in the recharge calculations for each forest category (hardwood or softwood). The annual forest extraction impact values are expressed as ML/ha. The annual extraction increments are set out in the 2006 forest water accounting model (Harvey 2009) and are presented in Appendix Tables B1, B2 and D1.

By applying the adopted recharge rates under a grassland (from the LLC WAP) and the annual forest recharge values derived from the forest water model, an aggregate annual recharge for a 5000 ha study site can be established. For the same study site, summing any forest extractions and pumped extractions for irrigation and other uses, an aggregate discharge value can be established. The resulting recharge and discharge values for the 5000 ha study site then become the key components for a net annual water-mass-balance calculation.

A radius of 4 km for the study sites is considered sufficient to moderate landscape geophysical variability. This distance is influenced by the Dillon *et al* (2001) reasoning that a distance of at least 2 km is required in this region to allow for groundwater transmissivity lags related to plantation forest impacts on groundwater resource. In addition, a 5000 ha study site provides a representative sample area for considering annual variability in plantation forest cycles, along with other accompanying land uses that are typical of the regional plantation forest landscape.

As the observations at the monitoring well are at the centre of the water-mass-balance calculation study site, it is assumed to provide a reasonable representative sample of what is occurring at a broader scale around the study site.

The objective is to test the accuracy of the net annual water-mass-balance calculation, which is largely based on the predictive capability of the forest water model, against the actual annual net changes in groundwater in storage for each of the 5000 ha study sites. The change in groundwater storage is indicated by the change in depth to the watertable from ground level. Aligning the estimated change in groundwater storage with the actual observed changes needs to consider any spatial redistribution of groundwater due to groundwater mounding or cone of depression related to the changes in groundwater storage.

The net annual impact on groundwater storage is summarised in the following equations:

> ΔS (change in groundwater storage) = Σ Inputs (sum of all inputs) - Σ Outputs (sum of all outputs)
>
> Or, $\Delta S = \sum R - \sum D$, where R is groundwater recharge and D is groundwater discharge (sum of pumped extractions and extraction by plantation forests).
>
> Groundwater recharge (R) can be considered as: $R = P - Et$, where P is precipitation (rainfall) and Et is evapotranspiration. The cyclical annual changes in soil moisture are ignored and due to the site selection, surface water run-off is considered negligible.
>
> In summary: $\Delta S = P - Et - \sum D$, where ΔS is indicated by the observed change in the depth to groundwater for each accounting period.

For consistency and relativity of cause and effect, the autumn groundwater level is observed and that is compared to the net water-mass-balance calculation for the previous calendar year.

At a broad scale, the lateral inflow and outflow of groundwater for the study areas are considered equal. This is based on the principle that groundwater management for the LLC PWA is premised on maintaining lateral through flows of groundwater. No adjustments are made for any changes in groundwater gradients at the study sites.

2.2 Assumptions

2.2.1 Aquifer storage coefficient

Due to the impracticality of precisely determining some variable site factors, a number of assumptions are made. Among these is the assumption that a reasonable storage coefficient default value for the regional unconfined Tertiary Limestone Aquifer (TLA) is 0.10 (Stadter 1989). Simplified, this means that a net discharge or recharge of 0.1 m of free water will represent a change in groundwater level of 1 m. This also represents a net change in groundwater storage of 1 ML/ha. The storage coefficient value of 0.10 is also applied by Brown *et al* (2006) as a robust value for the unconfined aquifer for calculating the management area recharge rates using the watertable fluctuation method, where the watertable is generally 10 m, or less, below ground level.

2.2.2 Management area recharge rates

The LLC WAP assumes that groundwater diffuse recharge, other than that occurring under plantation forests, prior to canopy closure and after thinning operations in softwood plantations, only occurs under the agricultural landscape. To be consistent with the policies in the LLC WAP, this study assumes there is no groundwater recharge under native vegetation land use, or wetlands. The adopted management area recharge rates are set out in Table 1 of the LLC WAP, and the processes applied to establish the values are described by Brown *et al* (2006).

In this study, an annual adjustment is made to the recharge rates adopted by the LLC WAP to reflect seasonal rainfall variability during the May–October period in each year, compared to the long-term mean rainfall for the same seasonal period. Rainfall data from the Bureau of Meteorology observations at Penola (BOM 26025) and Mount Gambier Airport (BOM 26021) is applied for this purpose.

2.2.3 Forest recharge rates

According to the adopted 2006 forest water model, recharge occurs under both forest categories during the period from planting, when weed control is applied, up until canopy closure which is considered to be three years for hardwood after planting and six years for softwood plantations. The forest recharge values are expressed as a percentage of the management area recharge rates on the grassland land use referred to above. Forest recharge impacts are based on the annual increments applied in the 2006 forest water model described by Harvey (2009) and available in Appendixes A and C.

2.2.4 Other recharge impacts

In association with the plantation forest land use throughout the region, a significant area of fire breaks are maintained by plantation forest managers. For groundwater recharge accounting of this land use class in this study, fire breaks are considered as grasslands, but without any allowances for livestock water extractions. Areas of road, rail and drain reserves are treated the same as firebreaks, with respect to recharge inputs.

2.2.5 Pumped extractions

Allowances for groundwater extractions for livestock use has been made on the basis of estimated pasture productivity potential for livestock carrying capacity. Pasture productivity potential is based on a relationship with the mean annual rainfall for the study areas. An aggregate value for stock water use of 0.03 ML/ha for pasture land use is used for Nangwarry and Wattle Range, and 0.035 ML/ha at Caroline. Calculations are available at Appendix F.

An estimated annual domestic groundwater extraction value has been established for each homestead identified in the aerial image of each study site. This value is based on each dwelling unit having 0.4 ha of irrigated land (a value that is generally applied statewide in prescribed areas) and an average domestic water use which is based on SA Water statistics. An aggregate value of 3.55 ML per dwelling is used for Nangwarry and Wattle Range, and 3.50 ML for the higher rainfall area at Caroline.

Licensed pumped extractions are based on the metered annual water returns by licensees. Where there are data deficiencies, a constant volume of 8 ML/ha is applied to the irrigated area for each year of the study period for areas identified as irrigation in the aerial imagery. Irrigation is only observed at the Wattle Range study sites and is a minor land use by area.

2.2.6 Groundwater lateral flows

While there are natural lateral flows of groundwater, for this study, the lateral inflows and outflows for the study areas are considered equal. This is based on the principle that groundwater management for the LLC PWA is premised on maintaining lateral through flows of groundwater.

2.2.7 Extraction by plantation forests

The adopted policy for the region is that plantation forests extract groundwater if they overlie a watertable which is up to 6 m below ground level. In the LLC WAP, the point of reference for this parameter is the depth to the watertable at June 2004, regardless of the age of the plantation, groundwater trends at that time, or site geophysical characteristics. It needs to be recognised that the 2004 reference point is an administrative marker to enable the first-time introduction of plantation forests into a legislated water accounting and management system.

As this study sets out to test the hydrological impacts of plantation forest, and not the policy application, plantation forest extraction is assessed as occurring if the watertable is 10 m or less at 1990, noting that the observations of Benyon *et al* (2006) indicated that extractions may occur where watertables are observed at depths to 8.9 m.

In this study, extraction by plantations is considered to occur across all three Wattle Range sites. Extraction is considered not to occur at the Caroline sites where the depth to the watertable is of the order of 23 to 28 m below ground level. These two assumptions are consistent with the application of policies in the LLC WAP that extraction by plantations occurs where the watertable was up to 6 m below ground level at June 2004.

Due to the significant changes in the depth to the watertable at the Nangwarry sites after 1993, two approaches have been taken. One is to assume that no plantation forest extraction is occurring and this position is consistent with the implementation of the water allocation plan. The second approach is to assume that all plantation forests at the Nangwarry site extract groundwater.

The groundwater extraction parameters are considered to be constant and there is no consideration given to site geophysical variability, or a reducing groundwater take as the watertable lowers towards the plantation forest extraction extinction depth. The outcome is that forests are considered to extract water at the same annual rate, provided the depth to the watertable is less than the threshold depth. This is consistent with the reporting by Benyon and Doody (2004), where a hard pan site was identified among their study sites, but the outcome was incorporated into the concluded mean extraction value for all plantations overlying watertables up to 6 m below ground level.

2.3 Site selection

A key requirement for each investigation site is as near as practical, to have a continuous groundwater monitoring record of water levels extending back up to approximately 40 years. The purpose is to observe the impacts of plantation forest and other related land uses over as long a continuous time period as possible. While there are many groundwater monitoring sites in the LLC PWA, the number with a continuous record is limited in areas where plantation forests are now a significant land use.

Other than the availability of a suitable groundwater level monitoring site, it is also important to remove if practical, the possibility of surface water flows and other extraneous activities within the study sites. For this reason, sites that are significantly undulating or known to have natural streams have been excluded. One exception is the site identified as SHT012 which is dissected by the Bakers Range Drain which transfers surface water from a southern catchment through the study area. Under current conditions, it is not believed to collect any significant surface water from the study site. Due to the relationship of the drain floor elevation and the current watertable level, drain flow is likely to contribute some additional diffuse groundwater recharge to that occurring from rainfall at that location. This relationship between the drain floor level and the watertable at site SHT012 is discussed further in Section 4.10.

Ideally, it is desirable to observe the groundwater level trends at the study sites prior to forest development as this aids in aligning the net annual water-mass-balance with the actual watertable movements. Furthermore, it contributes to the evidence that plantation forest land use has a significant and demonstrable impact on groundwater resources, compared to non-forest land use activities. This has been achieved in the case of the Wattle Range hardwood sites as these plantations have only been established since the late 1990s on land that was previously pasture, with groundwater monitoring in place during the pre-forest period.

In the case of the longer rotation softwood plantations, much of the current plantation forest estate is 2nd or 3rd rotation forests, and there are no relevant groundwater monitoring observations that can be considered representative of any site prior to the transition to broad scale softwood plantation land use. However, the unfortunate occurrence of the Ash Wednesday bushfire in February 1983, led to the destruction of an extensive forested area, but has assisted in aligning the net annual water-mass-balance account with the groundwater levels at the two Nangwarry softwood investigation sites.

The seven selected forest water study sites represent three different geographic areas and include approximately 5000 ha around each of the following observation wells:

1. MON016, SHT012 and SHT014 in the Wattle Range area (west of Penola)
2. NAN009 and NAN012 in the Nangwarry area (south of Penola)
3. GAM079 and CAR042 in the Caroline area (south-east of Mount Gambier)

A map locating the seven study sites is presented in Figure 2.1, and Table 2.1 summarises some of the statistics and characteristics of the forest water study sites.

In addition to the above forested study sites for which net annual water-mass-balances are generated, a number of observation wells in the same vicinity were selected to represent the grassland land use. Some of these sites provide an opportunity for 'paired catchment' observations with the studied forest sites. Such observations add further confirmation that the hydrological impact of plantation forests on the local groundwater resource can be significant. The following observation wells provide data for non-forested sites near to the seven forested sites listed above:

4. Wattle Range area: MON004 and FOX004
5. Nangwarry area: NAN003, MIN009, and MIN020
6. Caroline area: BLA107, CAR019, CAR022, CAR048, GAM009, GAM223, and MAC049

2.4 Data sources

Plantation forest information such as forest type and age, location and net area has been obtained from the plantation forest estate data provided to DEWNR by the plantation forest managers in 2015, as part the forest water licence registration process for the granting of forest water licences for the existing plantation forest estate[2].

Determination of areas of other land uses, such as native vegetation, wetlands, road, rail and drain reserves, and plantation forest fire breaks, etc. have been based on the interpretation of 2013 aerial imagery.

Groundwater level data is sourced from the monitoring network (SA_Geodata). In general, the water level monitoring record for many wells extends back to the 1970s and the observations have generally been quarterly.

Rainfall data is sourced from the nearest Bureau of Meteorology weather station where continuous long term data is available. For this study, rainfall data from Penola (BOM 26025) for the Wattle Range and Nangwarry sites and Mount Gambier Airport (BOM 26021) for Caroline is used. Appendix G summarises the rainfall variability from the long term means.

[2] The forest information relates to the regional forest estate as at December 2014.

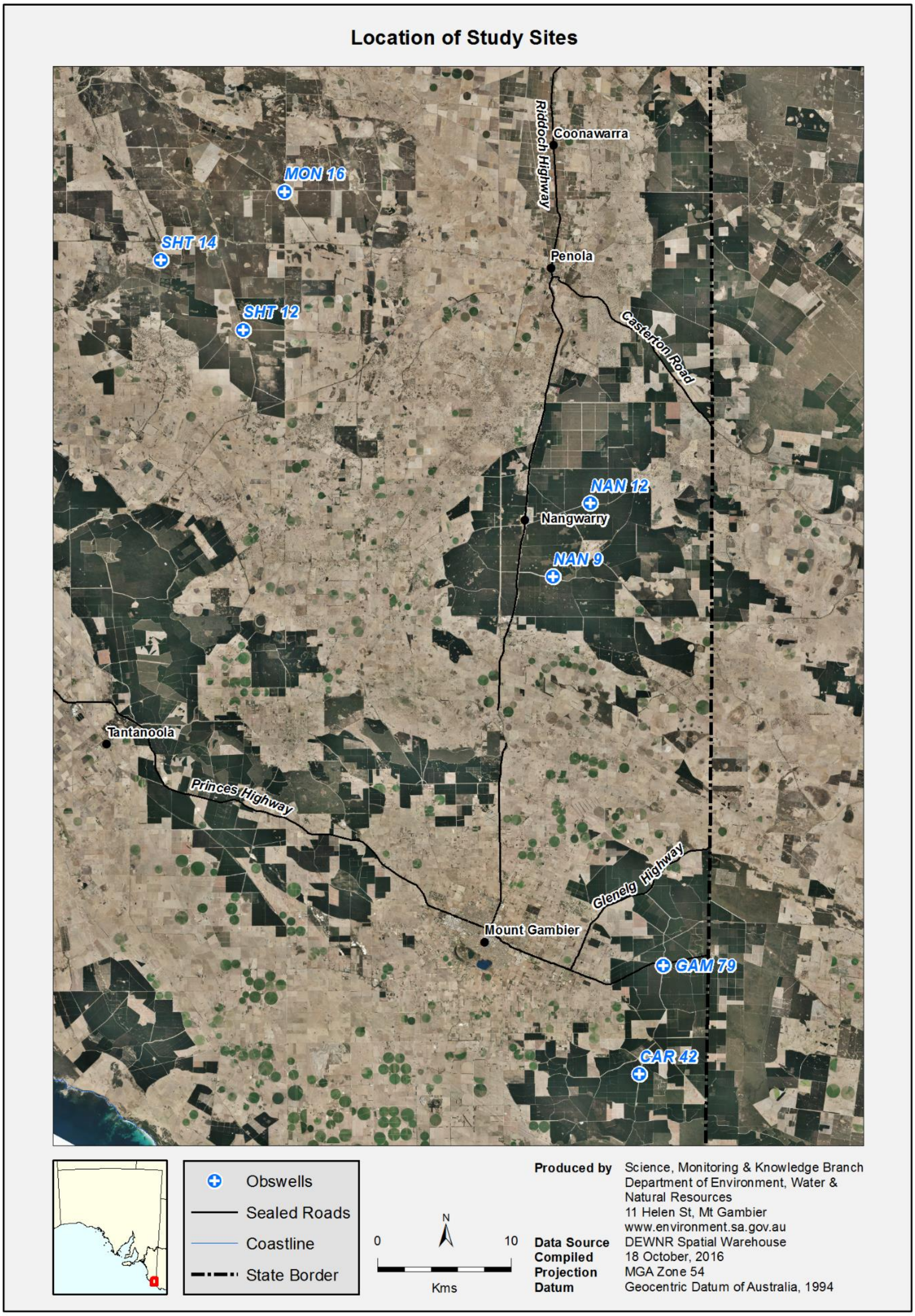

Figure 2.1: Lower Limestone Coast forest water project study sites

2.5 Alignment of water-mass-balance with groundwater levels

As the objective of this study is to test the suitability of the forest water model as adopted by the LLC WAP, the parameters that can be varied have been maintained at the values set out in the 2006 forest water model and consistent with the values adopted by the LLC WAP. The exception to this is the application of a variable recharge factor to provide annual adjustment to reflect as much as possible, rainfall variability during the study period. In this case, a multiplying factor is applied to the adopted groundwater recharge values for each management area. This multiplier is a factor derived from comparing the rainfall occurring in the May–October period of each study year, relative to the mean value for the same period. This approach was applied consistently to all years observed, but it is recognised that a percentage change in rainfall may not be reflected as a comparable percentage change in actual diffuse groundwater recharge.

The net annual water-mass-balance is calculated as a volume in megalitres (ML), and to convert this to a depth of groundwater, a vertical linear measurement in metres, a number of considerations are necessary. A recharge, or discharge of a volume of 'free' water 0.1 m deep across the land surface is equivalent to a volume of 1 ML per ha. Assuming an aquifer storage coefficient of 0.1, this depth of free water represents a 1 m depth of groundwater in storage. To convert an aggregated net volume in ML (after allowing for all recharge and discharge components) to an equivalent volume of stored groundwater, requires the net calculated volume of the water-mass-balance (ML) to be divided by 1000.

The above calculation presumes no spatial redistribution of stored water beneath the 5000 ha study site and the surrounding area. Further adjustment is then required to adjust for the spatial redistribution of the net change of groundwater volume in storage. Dividing the above outcome by three provides for this redistribution of the changes in groundwater in storage.

To achieve an alignment between the change in water balance and a change in water level, a period of relative watertable stability (which also relates to a relative constancy in the landscape land use) is chosen and a constant calibration value unique to each site is added to all the annual net water-mass-balance values so there is closer association with the actual depth to the watertable observations.

This alignment process does not interfere with the net annual water-mass-balance changes, or the change in groundwater storage volumes, but provides for a closer visual alignment of the relationship between the observed autumn watertable values against the calculated net annual water-mass-balance expressed as a depth to the watertable.

Table 2.1: Study site characteristics

Site ID (obswell identification)	**MON016**	**SHT012**	**SHT014**	**NAN009**	**NAN012**	**CAR042**	**GAM079**
General location	Wattle Range	Wattle Range	Wattle Range	Nangwarry	Nangwarry	Caroline	Caroline
Main forest type	hardwood	hardwood	hardwood	softwood	softwood	softwood	softwood
Net area of main forest type	3320 ha	2928 ha	1813 ha	4061 ha	4119 ha	4051 ha	4366 ha
Total area of plantation forest	3320 ha	3551 ha	2166 ha	4064 ha	4119 ha	4051 ha	4366 ha
Plantation forest as a % of site	66%	71%	43%	81%	82%	81%	87%
Native vegetation as a % of site	10%	11%	22%	6%	4%	4%	1%
Study period	1976 to 2014	1983 to 2014	1980 to 2014	1983 to 2014	1983 to 2014	1979 to 2014	1980 to 2014
Rainfall data from relevant BOM station	Penola (BOM 26025)	Penola (BOM 26025)	Penola (BOM 26025)	Penola (BOM 26025)	Penola (BOM 26025)	Mount Gambier (BOM 26021)	Mount Gambier (BOM 26021)
Depth to standing water level during the study period	2.35–6.18 m	1.66–5.74 m	1.79–4.84 m	5.64–8.05 m	12.28–14.37 m	22.93–25.3 m	24.19–27.92 m
Water-mass-balance calculations include forest extraction	yes	yes	yes	yes and no	yes and no	no	no
Irrigation activity in study area	28.5 ha	177.6 ha	46.4 ha	no	no	no	no
Approx. groundwater gradient across the area study sites	0.6/1000 m			0.42/1000 m		0.76/1000 m	
Anomalous characteristics of the site requiring consideration and comment		Study area traversed by Bakers Range Drain		Forest extraction from watertable deeper than 6 m	Forest extraction from watertable deeper than 6 m	Underlying regional groundwater trend	Underlying regional groundwater trend

3 Results

3.1 Introduction

The investigation of the seven forested study sites has resulted in a number of observations. Some observations relate directly to the relationship between the net annual change in the water-mass-balance and the change in groundwater storage, whilst others relate to the character of local plantation forest management and that relativity to the characterised average plantation forest management on which the forest water accounting model parameters are established. For discussion purposes, key observations from the data collected and analysis are grouped into the following categories:

- Historic regional watertable trends
- Correlation between net annual water-mass-balance and changes in groundwater storage
- Threshold depth at which groundwater extraction by plantations could be considered to cease.

In addition to the above, comments on other relevant issues are provided in the Discussion section (Section 4):

3.2 Historic regional watertable trends

3.2.1 Introduction

While it is now generally accepted that plantation forest land use can significantly impact on groundwater resources in those areas where it is a significant land use, this study has provided another line of evidence that the groundwater balance can be significantly influenced by the plantation forest land use, when all other variable factors are considered to be constant.

The impact of plantation forests on groundwater resources can be determined by assessing the watertable responses at sites sufficiently distant from plantation forest land use and where forest land use can be considered inconsequential. Noting groundwater trends at such sites can be considered comparable to 'paired' surface water catchment studies where forest land use impacts are compared with surface water yields in a grassed catchment in the same area and subject to similar rainfall events. The following offers some information and discussion on the observations and conclusion related to this appraisal. The additional observation wells are selected on the basis of being on farming and grazing land, providing a 'grassland' response if considered to be a paired catchment.

The 'paired' relationship can be considered as follows:

- Wattle Range forested sites, MON016, SHT012 and SHT014 can be compared to the non-forested sites of MON004 and FOX004.
- Nangwarry forested sites, NAN009 and NAN012 can be compared to the non-forested sites of NAN003, MIN009 and MIN020.
- Caroline forested sites, CAR042 and GAM079 can be compared to the non-forested sites of BLA106 (an urban site), CAR019, CAR022, CAR039, CAR048, GAM009, GAM223 and MAC049.

3.2.2 Wattle Range

In the Wattle Range area, the two obswells, FOX004 and MON004, are located in, and surrounded by, grassland land use and have a similar monitoring data span as the study wells at the forested sites of, MON016, SHT012 and SHT014. The location of all five wells can be viewed in Figure 3.1.

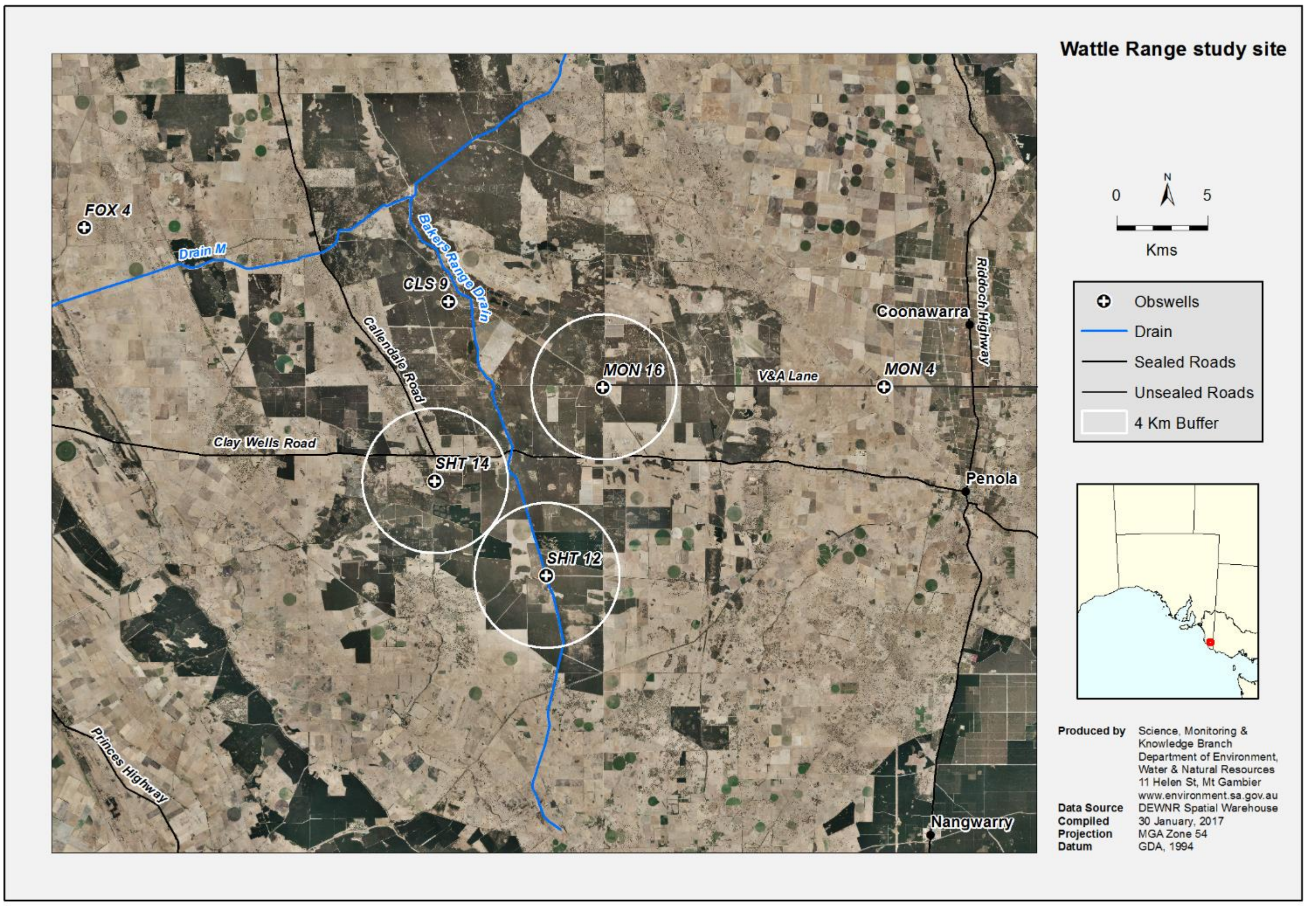

Figure 3.1: Wattle Range observation wells: grassland and study sites

A comparison of the watertable levels (m AHD) of the wells is presented in Figure 3.2. While there are some data gaps, the available data provides an indication of the general watertable trend at each site, and across the Wattle Range area for approximately the same 40-year period. Other than the period of afforestation at MON016, SHT012 and SHT014 commencing in the late 1990s, it is believed all land uses have remained largely unchanged over that period. With all sites being subjected to similar rainfall, it can be concluded that any significant variation in watertable trends between the forest and the grassland land use can be attributed to the change in land use.

The observation well MON004 is upgradient of the three forest investigations sites, while FOX004 is downgradient. Although a very slight declining trend in the watertable can be observed after 2002 at MON004 and FOX004, it is temporary and is followed by recovery in 2010. Other than for the seasonal recharge/discharge fluctuations, the watertable is relatively stable. Monitoring at these two grassland sites ceased in about 2011. The general watertable gradient across the 45 km between wells MON004 and FOX004 is relatively flat with an overall net average gradient of 0.6 m per 1000 m. This extensive and relatively flat gradient in the local watertable indicates a potential for low lateral throughflow rates.

The three investigation wells in the forested landscape all exhibit a similar trend of groundwater level decline which becomes noticeable in about 2000 to 2001, about three years after broad scale afforestation commenced. Well SHT012 shows a slight rise in the watertable in 2010, and then some temporary stabilisation before continuing the downward trend at a similar rate as the other two forested sites. It is considered that the observed recovery at SHT012 can be attributed to additional recharge from the Bakers Range Drain which flows close to this well. This characteristic is discussed in more detail in Section 4.10.

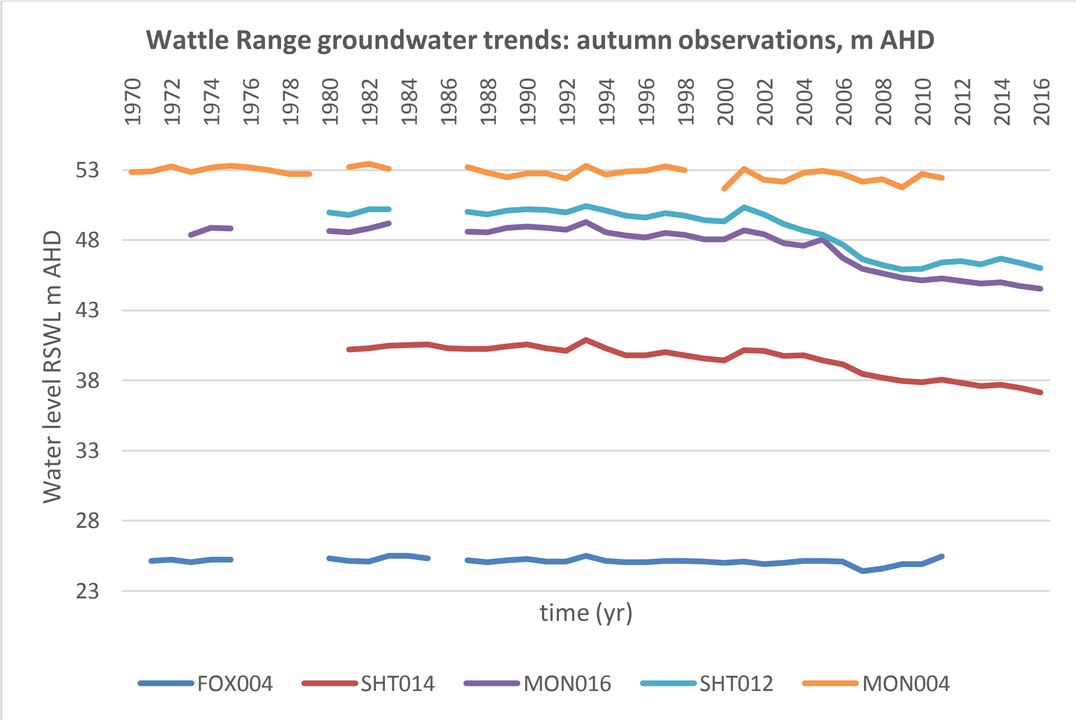

Figure 3.2: Wattle Range groundwater trends

Rainfall is a significant contributing factor in determining groundwater recharge. Figure 3.3 indicates rainfall variability at Penola (BOM 26025) during the May–October period of each year against the period long term mean. While seasonal rainfall variability can cause seasonal fluctuations in the watertable at the grassland sites, the forested sites continue the declining trend with muted seasonal responses, in comparison to the seasonal responses exhibited in the pre-forest period.

Data in Figure 3.3 indicates two significantly wetter consecutive years in 2010 and 2011 which follow a sequence of about seven years that could be considered generally drier than average. These trends are visible in the grassland sites with recovery also apparent in 2010, whereas the forested sites that are situated distant to the drain have maintained the downward trajectory.

From observing this sample of Wattle Range hydrographs, it can be concluded that a land use change to plantation forest can be associated with a declining trend in groundwater level at the extensively forested sites, compared to the generally stable trends observed at the non-forested sites, in the same general area, and over the same time period.

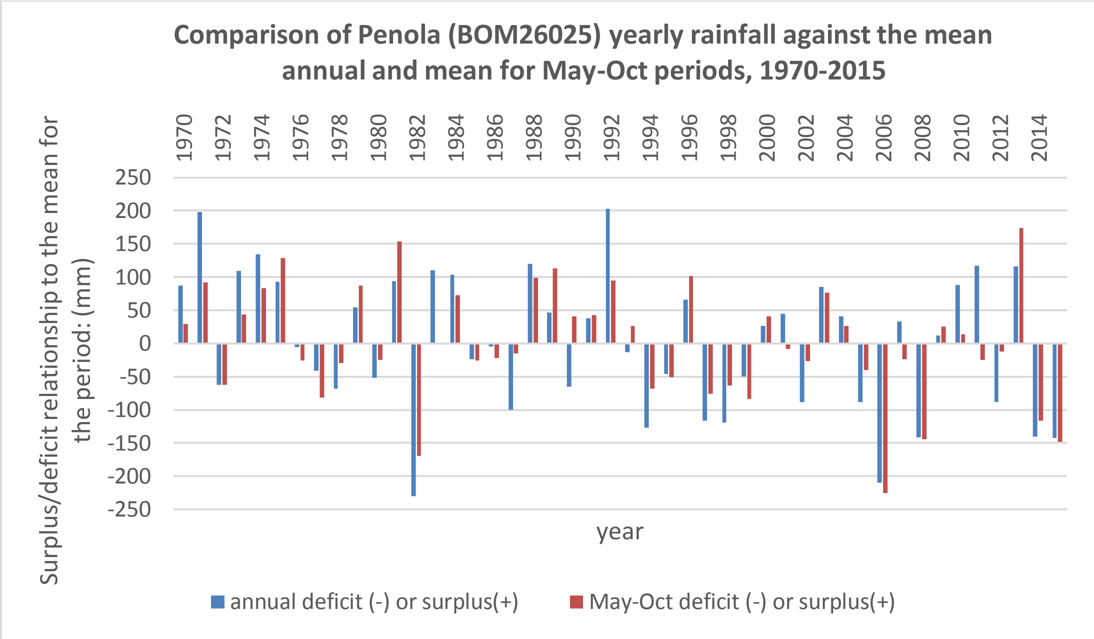

Figure 3.3: Rainfall trends during the May–October period at Penola (BOM 26025)

3.2.3 Nangwarry

A review of the long-term hydrograph for the well NAN009 (Figure. 3.4) reveals a significant rise in the watertable after a bushfire destroyed some 13 000 ha of softwood plantations in the groundwater management area in February 1983. The watertable then exhibited a relatively stable trend for about 10 years before entering a period of continuing decline. According to the forest water accounting model, groundwater recharge under softwood plantations continues, albeit at a reducing rate, until canopy closure, six years after planting. The model indicates plantation extraction does not commence until the seventh year after planting. By 1992, about 1850 ha of replanted, or fire surviving softwood had reached seven years of age, or more. Nearly another 2000 ha of replanting continued at the NAN009 site over the following seven years.

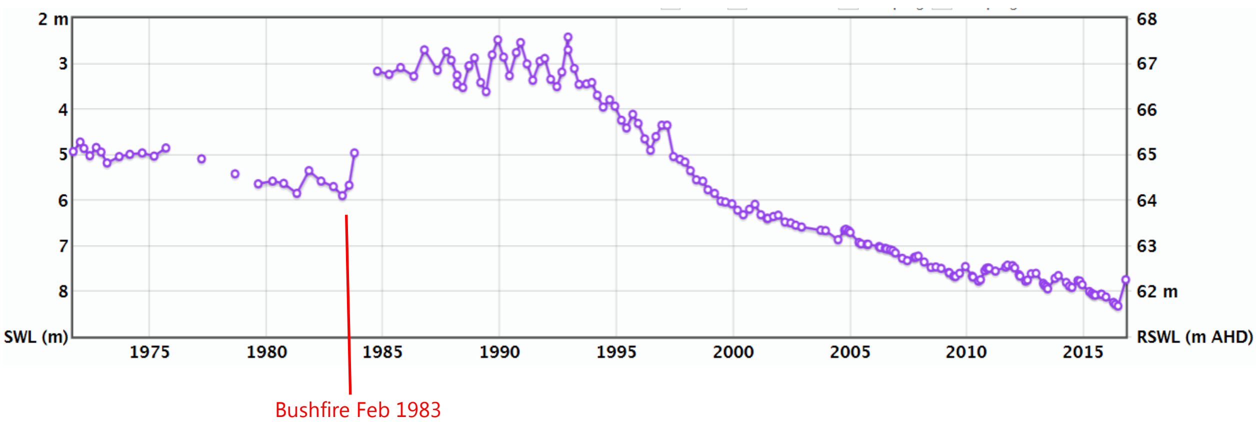

Figure 3.4: NAN009 obswell hydrograph

It should also be noted that the groundwater-level trend prior to the fire was declining, with a rate of decline of approximately 1 m over 10 years which is similar to the 10-year trend concluding in 2015. During the 30-years since the early reforestation in 1986, the groundwater decline at the two forested study sites is of the order of 5.4 m at NAN009 and 3.7 m at NAN012.

In the Nangwarry area, wells NAN003 and MIN020 are located in grassland areas and have a similar period of monitoring observations as the study site wells NAN009 and NAN012, while MIN009 is adjacent to a plantation forest and grassland. The location of all these wells are presented in Figure 3.5 along with the extent of the 1983 Ash Wednesday bushfire.

A comparison of the watertable elevations at all wells is presented in Figure 3.6. Immediately following the 1983 fire, both the forested sites (NAN009 and NAN012) exhibit a significant rise in the watertable level. The higher level is maintained for about 10 years before commencing a downward trajectory. At the grassland sites (NAN003 and MIN020), the trend is relatively stable for about 20 years prior to 1993, while the grassland site of MIN009 is stable until about 1990 when it gradually rises until 1993 before exhibiting a similar downward trajectory as the other grassland wells. The MIN009 and MIN020 grassland sites enter a brief period of water table recovery and relative stability commencing in about 2010, in response to above average rainfall. The NAN009 forested site continues a downward trend with NAN012 exhibiting similar trajectory until 2007 when it presents stability for six years, before reverting to a downward trend. All grassland sites enter a downward trend in 2015 coinciding with a significant decline in rainfall (Figure 3.3).

While the Nangwarry sites are not identical to the Wattle Range sites, it is clear that the forested sites demonstrate a different response to the grassland sites immediately following the loss of an extensive plantation forest area to fire in 1983.

The hydraulic gradient across the general area is relatively flat at 0.42 m per 1000 m.

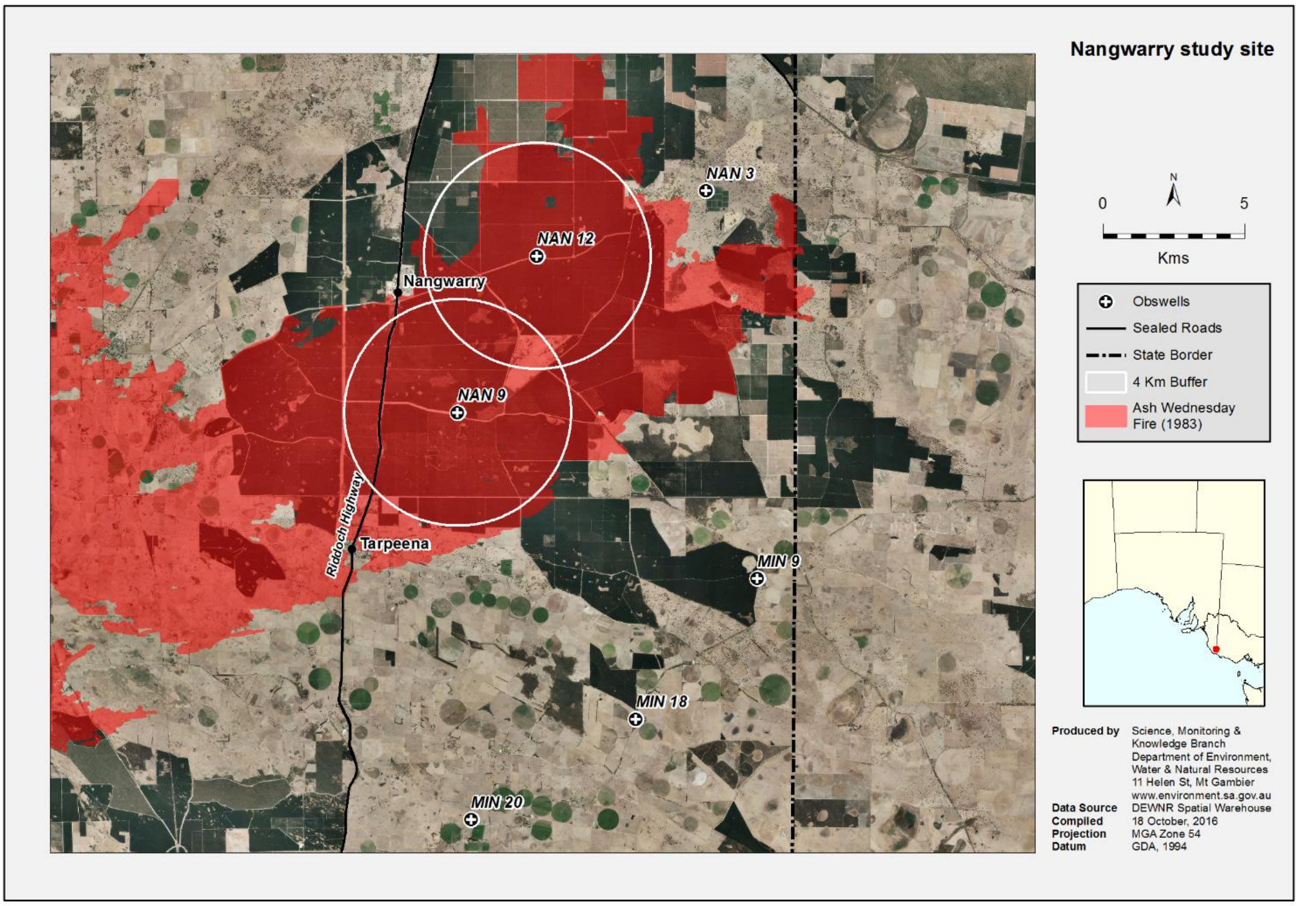

Figure 3.5: Nangwarry observation wells: grassland and study sites

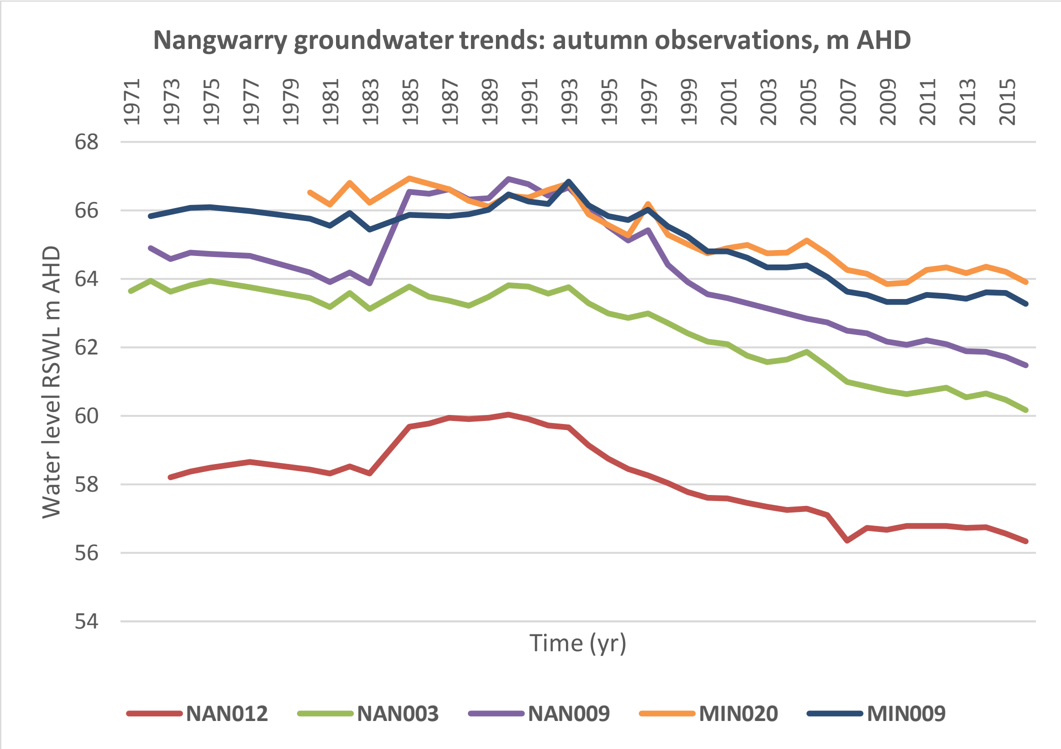

Figure 3.6: Nangwarry groundwater trends

3.2.4 Caroline

In the Caroline area, a number of observation wells are dispersed across a wide range of land uses, including urban and industrial, farming and grazing, plantation forestry and peri-urban areas. The locations are presented in Figure 3.7. The widespread observation points illustrate an consistent regional groundwater trend which is one of a long-term decline, regardless of the overlying land use.

It should be noted that although plantation forests cover a significant area, the depth to the watertable of more than 20 m precludes groundwater extraction by the plantations. Consequently, a mixed aged plantation forest along with the associated firebreaks and roads, would provide a positive net water-mass-balance every year, which should result in relatively stable water levels beneath forested areas.

Figure 3.7: Caroline observation wells: study sites and other land uses

The hydrogeology in this region is complex with extensive solution features resulting in the unconfined aquifer being very transmissive. It is also suggested by Harrington *et al* (1999) that there is a connection between the unconfined and confined aquifers in this area.

A comparison of the watertable levels at the wells identified in Figure 3.7 is presented in Figure 3.8. Not all the data is extensive, or continuous, but is adequate to indicate a general watertable trend at each location.

The observed groundwater level trends of those sites at a higher topographic elevation all present a similar consistent declining trend for over 40 years. The watertable levels at the sites with lower elevation still present a decline, albeit at a reduced rate compared to the wells at a higher elevation. Some moderation of the declining trend appears across all wells in about 2010 in response to higher rainfall; while MAC049 (with a level of less than 2 m AHD) maintains a stable trend.

An even longer term declining trend appears in the record for BLA106 (Blue Lake) which is presented in Figure 3.9. This hydrograph indicates that the water level has been declining for the last 100 years.

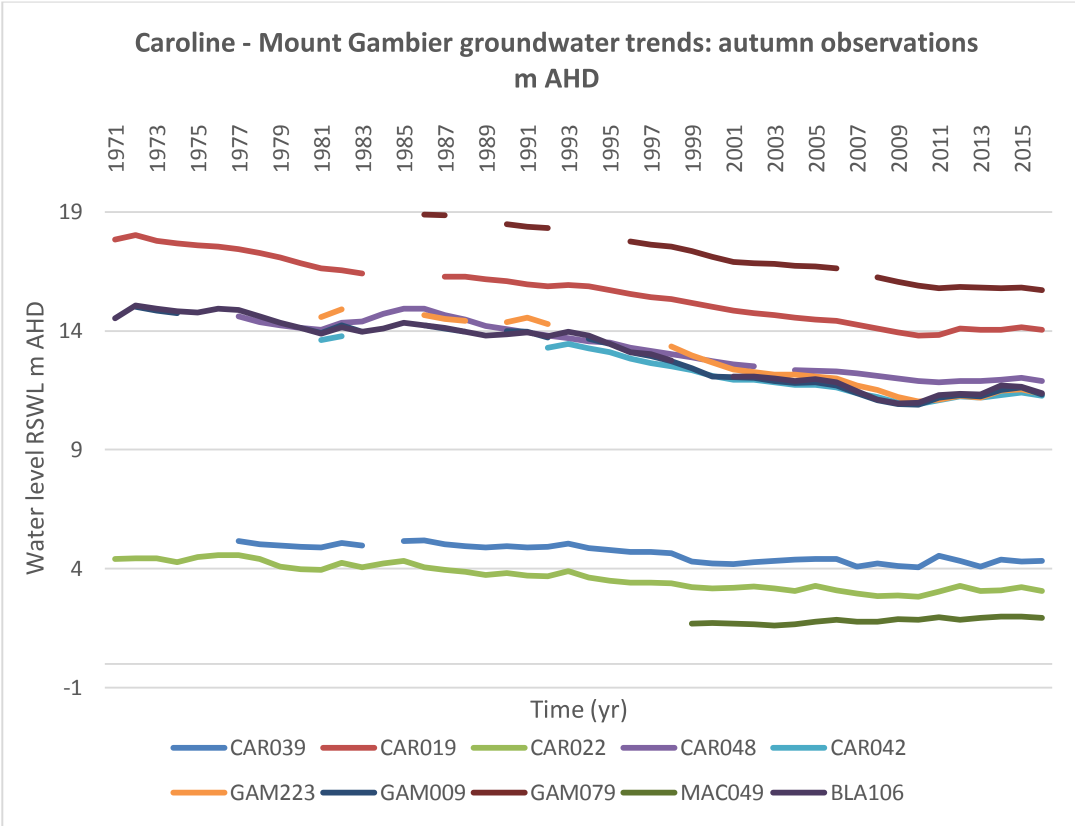

Figure 3.8: Caroline groundwater trends

The general gradient from the Blue Lake (BLA106) to the coast is about 0.76 m per 1000 m.

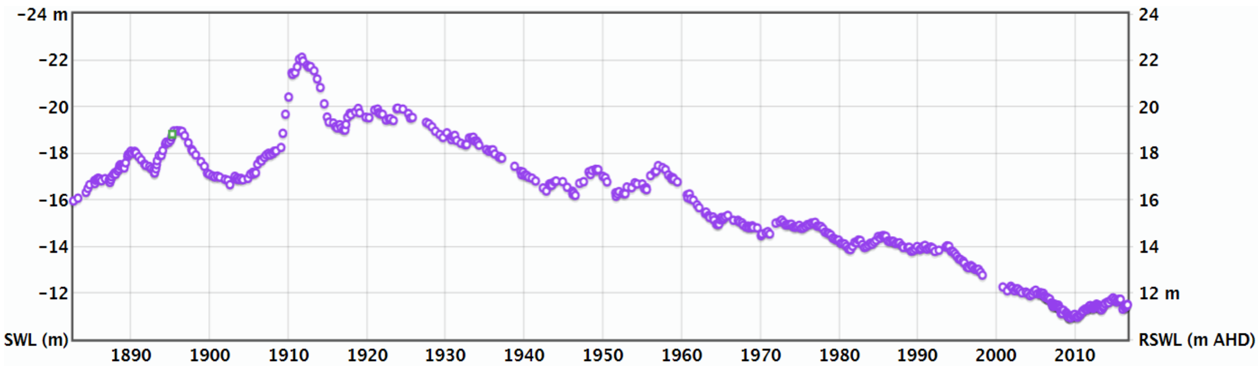

Figure 3.9: Blue Lake (BLA106) water levels

The variability in rainfall at Mount Gambier (BOM 26021) is presented in Figure 3.10. The data compares the variability during the May–October period of each year against the annual rainfall variability for each year.

Due to the proximity of the boundaries to the management areas of Donovans, Glenburnie and Myora, for the purpose of calculating the water-mass-balance accounts, a blended recharge rate of 155 mm per year has been applied to the Caroline study sites instead of the specific management area recharge rates.

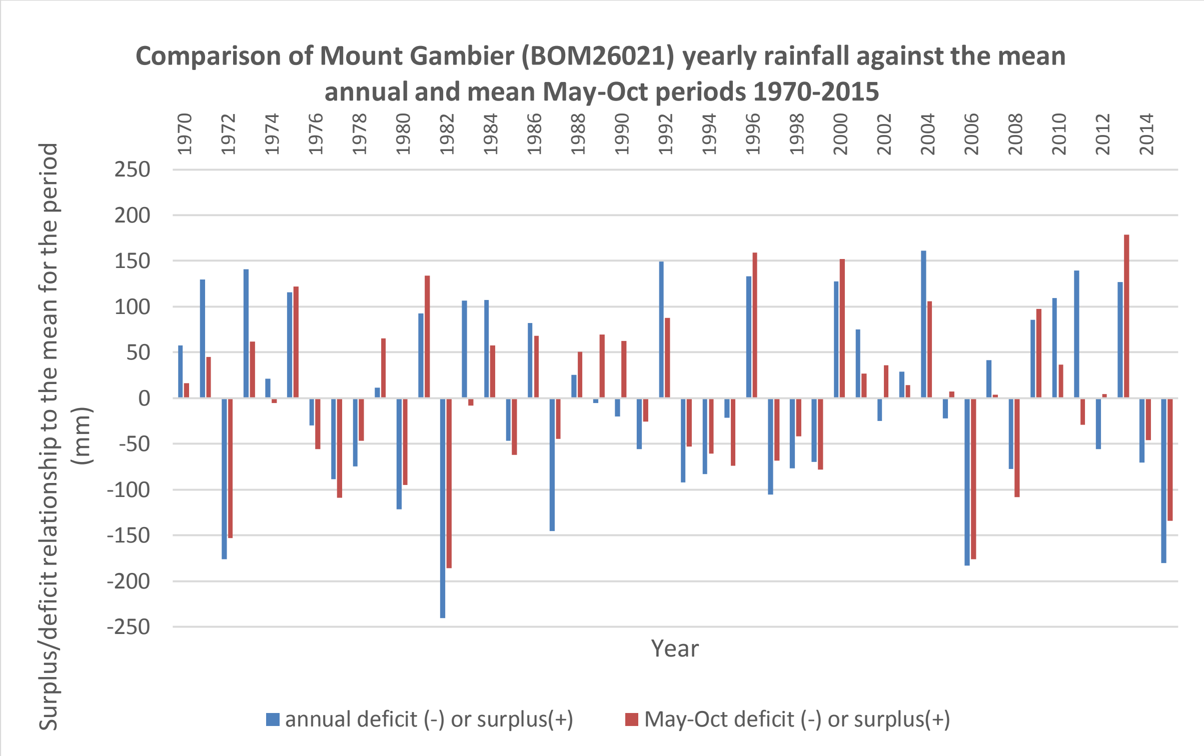

Figure 3.10: Rainfall trends during the May–October period at Mount Gambier (BOM 26021)

3.3 Correlation between the calculated net annual water-mass-balance and changes in groundwater storage

3.3.1 Introduction

The following observations relate to the results from constructing net annual water-mass-balance accounts for each of the seven 5000 ha forested study sites. These accounts are based on the annual values from the forest water accounting model referred to in Section 1.2 and the assumptions outlined in Section 2.2.

Due to the large percentage of plantation forest cover at each study site and the relatively small areas of other land uses that may contribute to the groundwater recharge and discharge, the hydrological impacts of forest should account for a significant component of the resultant net annual water-mass-balance account at the study sites. Consequently, assuming equal lateral inflow and outflow of groundwater if there is a good correlation between the net annual water-mass-balance and the observed net annual change in groundwater storage, the annual accounting values from the forest water accounting model can be considered to provide a relatively accurate indication of hydrological impacts of plantation forests, throughout their life cycle, at a management area scale.

It then follows, if the plantation forest estate is managed in accordance with the characterised forests applied in the forest water model, the model can be considered reasonably accurate for estimating the hydrological impacts of the plantation forest estate on the local groundwater resource, at a management area scale.

At the Wattle Range sites, plantation forests occupy between 43 and 71 per cent of the three 5000 ha study sites where hardwood plantations are the predominant forest type and land use. The study period incorporates nearly 20 years of pre-forest grassland land use, providing significant confidence that the observed groundwater level changes at those sites can be related to the land use change to plantation forests. As advised in the Assumptions section (Section 2.2), for the purpose of analysis, it is considered that all the plantation forests extract groundwater at the Wattle Range sites in accordance with the annual components within the forest water model for hardwood plantation forests.

In the case of the softwood sites, plantation forests represent a very high percentage of the landscape at the four 5000 ha study sites, with plantations accounting for between 81 and 87 per cent of land use. This adds to the confidence that any groundwater trends deviating from the regional norm are related to the impacts of the forests at those sites. As stated earlier in this report (section 2.2.7), the two Nangwarry sites have been assessed in two ways. One is that plantations can extract groundwater regardless of depth, and the second approach is to apply the current policy that no groundwater extraction occurs at these sites where the depth to the watertable at June 2004 exceeded 6 m.

The outcomes of the data analysis at each forest water study site is presented in the following figures:

Wattle Range:	MON016	Figure 3.11
	SHT012	Figure 3.13
	SHT014	Figure 3.15
Nangwarry:	NAN009	Figure 3.17
	NAN012	Figure 3.19
Caroline:	CAR042	Figure 3.23
	GAM079	Figure 3.25

In these figures, the X axis is the time point of the calculated net annual water-mass-balance and the time point for the corresponding observed depth to the watertable, noting that the watertable depth observations relate to the autumn following the year for which the net annual water-mass-balance calculation has been undertaken. The Y-axis is the calculated (predicted) and observed depth to the watertable at the obswell site. The blue graph links the actual observed watertable depth values, while the green graph is the result of the calculated net annual water-mass-balance converted to a depth to the watertable, accounting for a change in groundwater storage.

The change in the calculated net annual water-mass-balance at each site have been statistically tested against the actual observed annual change in groundwater in storage. The coefficient of determination (R^2) provides a measure of how predictable one variable responds to another. The coefficient of determination is the ratio of the explained variation to the total variation. This statistical analysis and the resulting R^2 values are presented for each study site, during the forested period. Appendix H provides a summary of calculated water-mass-balance values for all sites.

3.3.2 Site MON016

The graph of the calculated net annual water-mass-balance converted to a depth to the watertable (green) and the actual autumn observed depth to the watertable (blue), in Figure 3.11 show a close correlation during the pre-forest period at MON016. Intensive forest development commenced in the 2000 to 2001 period when about 2250 ha of hardwood forest was planted at the study site. Most of the 1000 ha balance of the current estate at this site was planted during the following six years.

A steep downward trend of the watertable commences in 2003, generally coinciding with canopy closure of the first plantings three years earlier, and the commencement of extraction by the closed canopy forests which is considered to occur in the fourth year after planting.

The steep downward trend in both curves begins to moderate in 2007. During the following eight-year period during which there is still a strong correlation in the steep downward trend between the two elements, a variation in the rate of change is beginning to emerge with the actual observed groundwater level response not being as pronounced as that predicted by the net annual water-mass-balance accounting.

It is also observed that the direction of annual variations in the net annual water-mass-balance account generally align with the directional moves in the observed water levels. This is observed both in the pre-forest period and during the period of significant water level decline in the forested period.

In general, while the statistical analysis returns an R^2 value of 0.95 during the forested period in Figure 3.12, when comparing the calculated net annual water-mass-balance against changes in depth to the watertable, the hydrological impacts of plantation forestry on the groundwater resource seems to be overstated in the post canopy closure stages at this site.

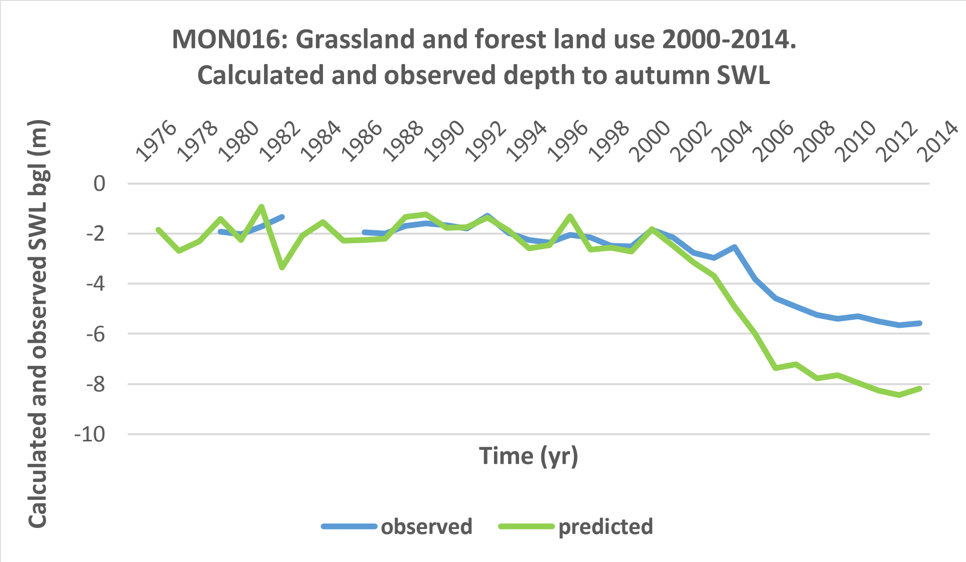

Figure 3.11: Correlation of water account against changes in depth to the watertable at MON016

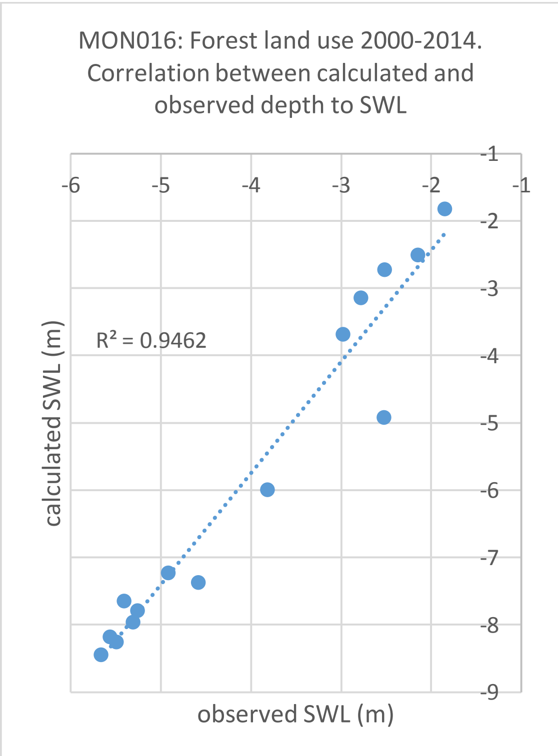

Figure 3.12: MON016: statistical analysis

3.3.3 Site SHT012

The graph of the calculated net annual water-mass-balance (green) converted to a depth to the watertable and the actual autumn observed depths to the watertable below ground level (blue) at SHT012 in Figure 3.13 show a close correlation during the pre-forest period. Intensive forest development commenced in 1997 and peaked in 2001 with 1611 ha of hardwood planted at the study site. This site currently has 2928 ha of hardwood plantations and 623 ha of softwood plantations, with most of the softwood being planted in the 2000 to 2003 period. The last significant planting of hardwood occurred in 2007.

A steeper downward trend of the watertable begins to emerges in 2002 and begins to moderate in 2007. During the following eight-year period, the downward trend of the calculated net annual water-mass-balance continues but at a reduced rate, while the watertable exhibits a rise in about 2010. The watertable continues to gradually rise until 2013 then it again commences a decline.

There is a significant divergence in the two curves in the 2010 to 2011 period. The divergence commencing in 2010 correlates with the re-emergence of surface water flows in the Bakers Range Drain which passes within about 50 m of the SHT012 obswell. Drain flow records indicate flows also occurred in 2013. While groundwater recharge from the drain has not been considered in the net annual water-mass-balance calculation, data analysis returns a R^2 value of 0.91 in Figure 3.14.

Other than for 2010–11, the direction of the net annual water-mass-balance account generally correlates with the directional moves in the observed water levels. This is observed both in the pre-forest period and during the period of significant water level decline in the forested period. During the pre-forest period, when the watertable was in the range of 1.5 to 2 m below ground level, an elevated watertable would have likely facilitated some groundwater discharge into the drain as base flow. Drain flow is generally associated with wet years and as there is no allowance for groundwater discharge into the drain (as baseflow) in the non-forest period, it is possible that observed groundwater levels may be muted in comparison to the calculated net water-mass-balance, which indicates an increased recharge as a result of increased rainfall.

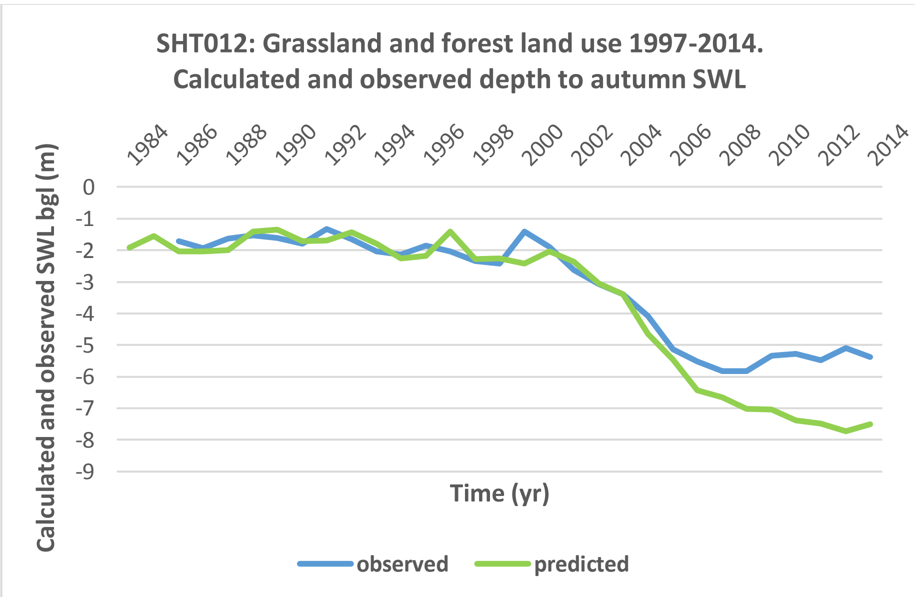

Figure 3.13: Correlation of water account against changes in depth to the watertable at SHT012

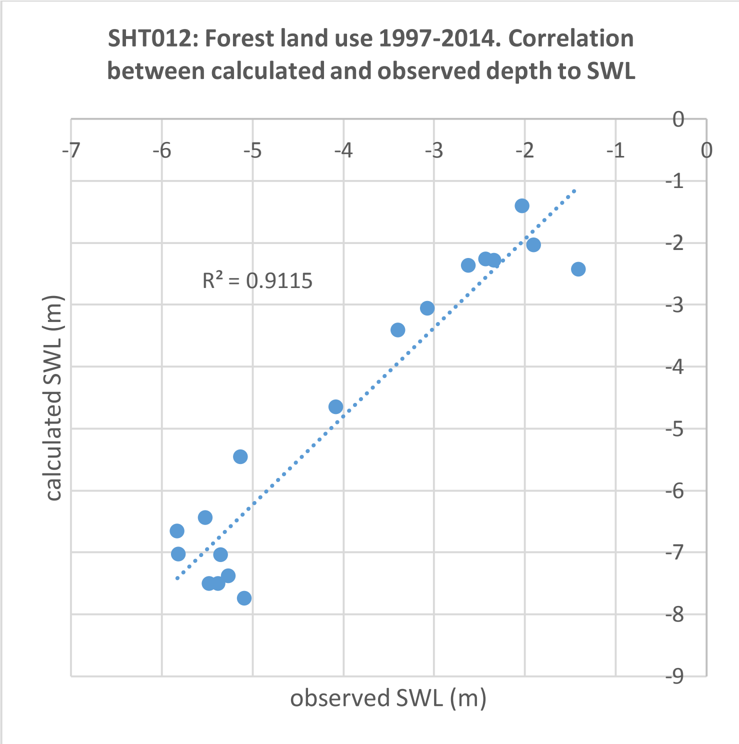

Figure 3.14: SHT012: statistical analysis

3.3.4 Site SHT014

The graph of the calculated net annual water-mass-balance (green), converted to a depth to the watertable, and the actual autumn observed depths to the watertable below ground level (blue) at SHT014 in Figure 3.15 show a close correlation during the pre-forest period and in the period of forest land use.

This is the least intensively forested Wattle Range study site with 1813 ha of hardwood and 353 ha of softwood plantations. Forest development commenced in 1999 with about 100 ha of hardwood forest, with 724 ha in the following year. This was followed by gradual plantings up to and including in 2008 with another 980 ha of hardwood plantation. The softwood plantation development commenced with about 200 ha in the 2000 to 2001 period and the balance of about 150 ha in the 2009 to 2011 period.

A downward trend of the watertable commences in 2001, with a strong correlation maintained between the calculated net annual water-mass-balance and the actual observed groundwater level.

Except for 1982 and 2007, the direction of annual variations in the mass balance correlate closely with the directional moves in the observed water levels. This is observed both in the pre-forest period and the forest period. The rainfall record indicates that 1982 was a very dry year followed by a year of higher than average rainfall and it appears as if the water-mass-balance calculations may overstate both conditions.

The statistical analysis of site SHT014 returns an R^2 value of 0.94 in Figure 3.16.

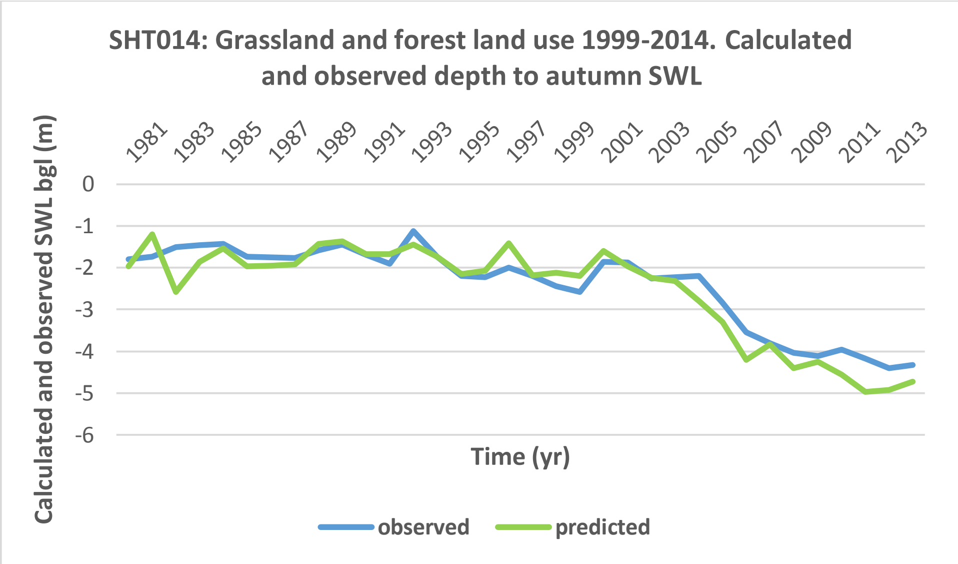

Figure 3.15: Correlation of water account against changes in depth to the watertable at SHT014

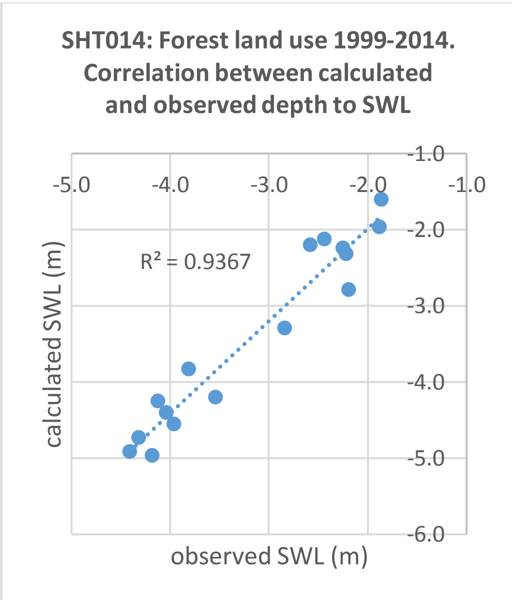

Figure 3.16: SHT014: statistical analysis

3.3.5 Site NAN009

The graph of the calculated net annual water-mass-balance (green), converted to a depth to the water table and the actual observed autumn depth to the watertable below ground level (blue) at NAN009 in Figure 3.17 shows a general correlation in the trend during the forested periods albeit that the strength of correlation varies over the observed period. The calculations behind these results are based on a no constraint condition in respect to forest groundwater extraction.

Due to the limitations with the provided forest estate data, there is no indication of the age structure of the plantation estate that was destroyed by fire in February 1983. As a result of the large-scale destruction at the time and the necessary re-ordering of government priorities during this period, there is also no groundwater level data for the autumn of 1983. Therefore, statistical analysis is under taken for the period post the 1983 fire when reforestation had commenced, providing a known forest structure. Continuous groundwater level data is also available in this period.

About 200 ha of very young plantation survived the 1983 fire and the subsequent reforestation of the site with 4061 ha of softwood and 3 ha of hardwood occurred over a period of about 11 years, with about 2516 ha established in the 1983 to 1989 period and a further 912 ha in the 1992 to 1993 period. While the softwood age classes are 'compressed' relative to the regional plantation age structure, the age/area distribution can be considered as reasonably uniform.

Other than in 2009, the direction of net annual variations in the water-mass-balance align with the directional moves in the observed water levels. In 1990, the calculated water-mass-balance seems to over accentuate the negative hydrological impacts of the reforestation. About four years later in the 1993 to 1995 period, a significant decline in the watertable begins to emerge and other than for 1996, there is good correlation between the calculated net annual water-mass-balance and the actual observed groundwater levels. This continues until 2009 when the calculated net annual water-mass-balance appears to under estimate the negative hydrological impacts of the plantation forest, if compared to the observed changes in groundwater level.

It should be noted that the post fire landscape has been assigned the recharge rate of that applied to a grassland landscape in Zone 2A and this may not be appropriate for a severely burnt landscape and for its transition back to forest production. The R^2 value for this site for unrestricted extraction is 0.75 and is presented in Figure 3.18.

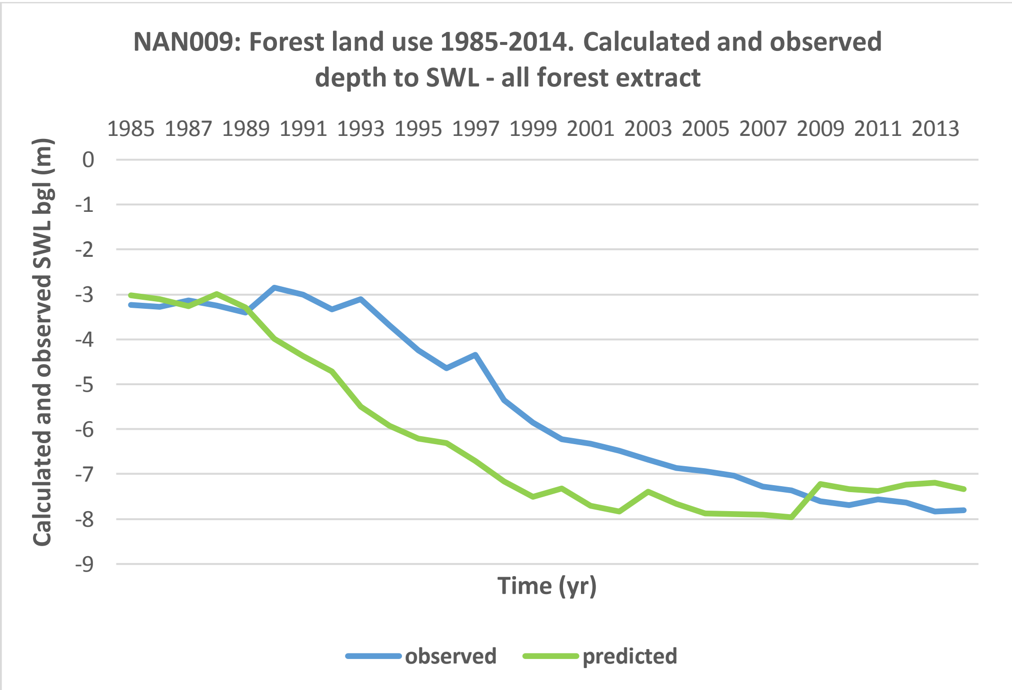

Figure 3.17: Correlation of water account (with extraction) against changes in depth to the watertable at NAN009

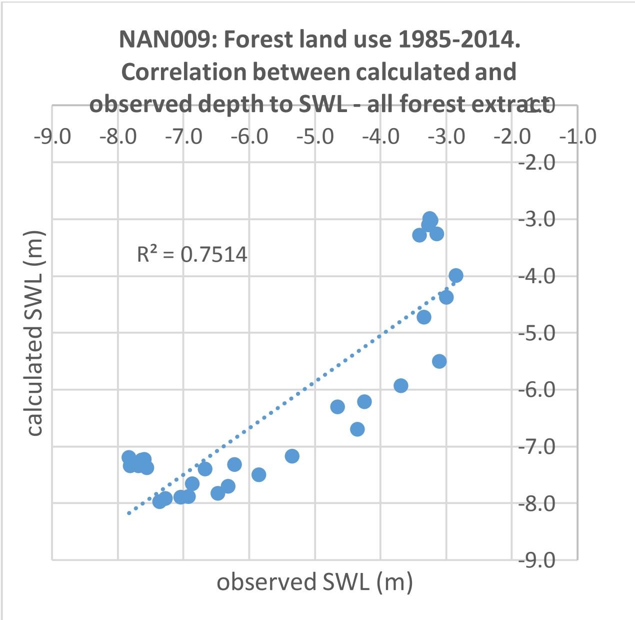

Figure 3.18: NAN009: statistical analysis – all plantation forest extract groundwater

Net annual water-mass calculations were repeated for site NAN009 with an assumption of no extraction, with results presented in Figure 3.19. For the no extraction condition, the R^2 value is 0.52 and presented in Figure 3.20.

A point of interest in this no extraction scenario, is that if recharge reduction under plantation forest is the only hydrological impact, the net annual water-mass-balance assumes an equilibrium relatively soon after afforestation.

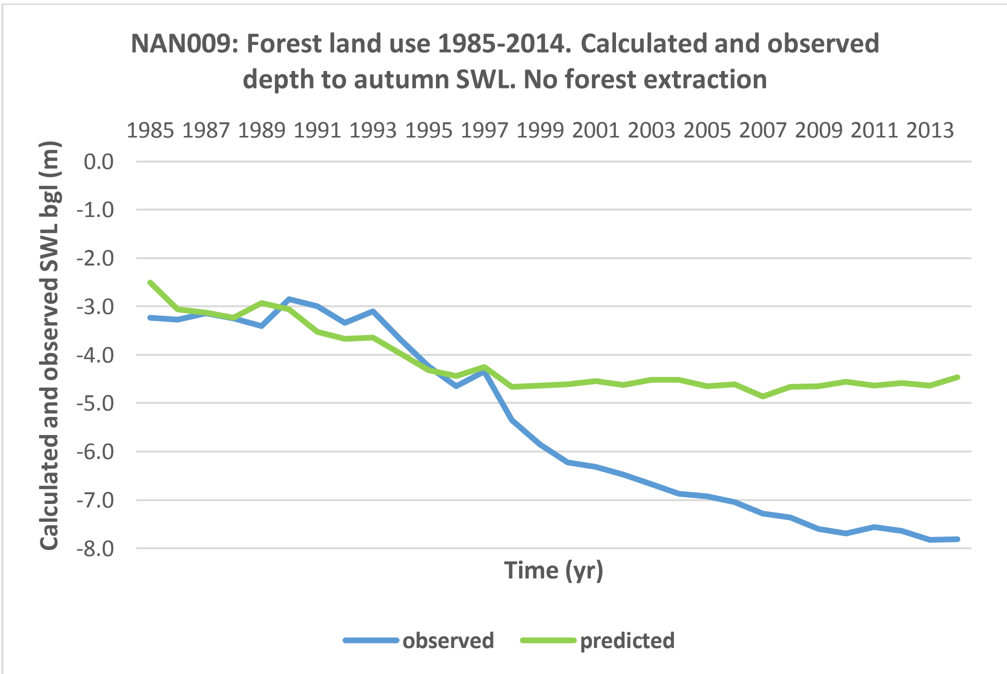

Figure 3.19: Correlation of water account against changes in depth to the watertable at NAN009 with no extraction

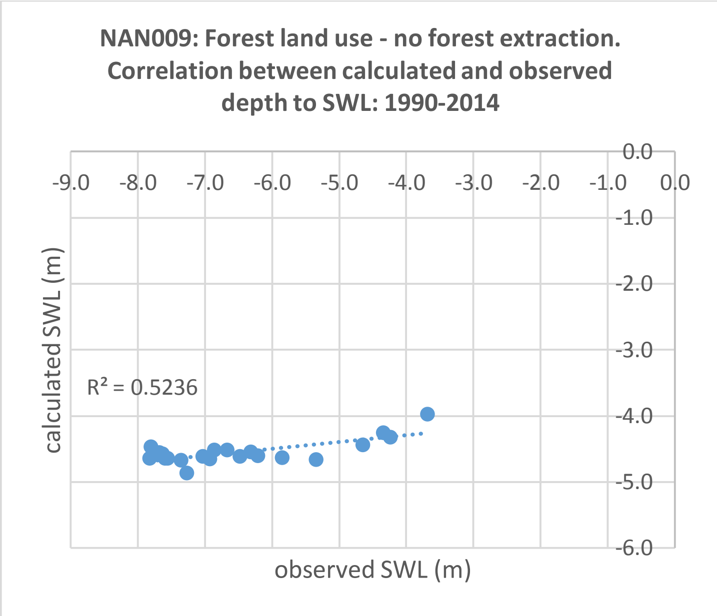

Figure 3.20: NAN009: statistical analysis – no forest groundwater extraction

3.3.6 Site NAN012

The NAN012 study site, presented in Figure 3.21 has a similar land use history to the NAN009 site, with about 300 ha of plantation surviving the 1983 fire. The depth of the watertable below ground level appeared to be significantly deeper than the NAN009 observation well in the period following the 1983 fire; 10.77 m at NAN012 in 1986 compared to 3.14 m at NAN009. Consequently the net annual water-mass-balance was initially assessed as a site where it was considered that the plantation forest is not extracting groundwater, in accordance with the policy position applied to this management area's plantation forest.

A net annual water-mass-balance calculation, converted to a groundwater depth and premised on no forest groundwater extraction, is presented in the green curve and the actual autumn observed depths to the watertable below ground level is blue in Figure 3.21.

Due to the low correlation between the calculated net annual water-mass-balance and changes in groundwater storage, another set of calculations have been undertaken where it is assumed that the plantation forests do extract groundwater. The output of the 'extraction' scenario is presented in Figure 3.22. Incorporating plantation forest groundwater extraction into the net annual water-mass-balance accounting has provided a higher R^2 value of 0.90 and this is illustrated Figure 3.23.

Including extraction in the net annual water-mass-balance calculations has presented better alignment with the watertable movements at NAN012. However, the water-mass-balance at NAN012 seems to overstate the negative hydrological impacts of the plantation forest in the early stages of afforestation, in a similar fashion to NAN009.

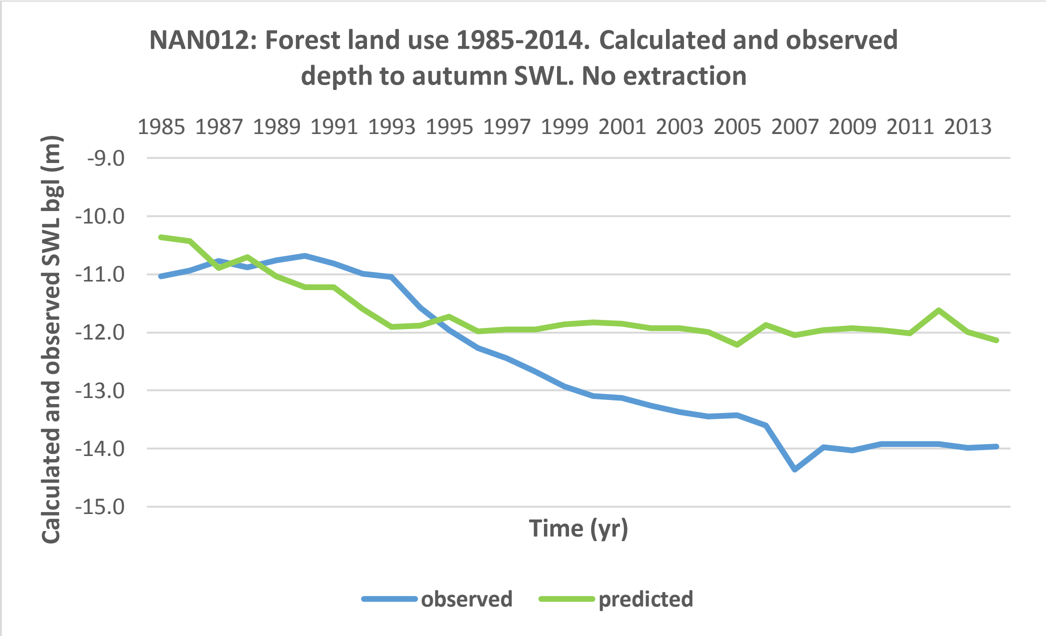

Figure 3.21: Correlation of water account against changes in depth to the watertable at NAN012 with no extraction

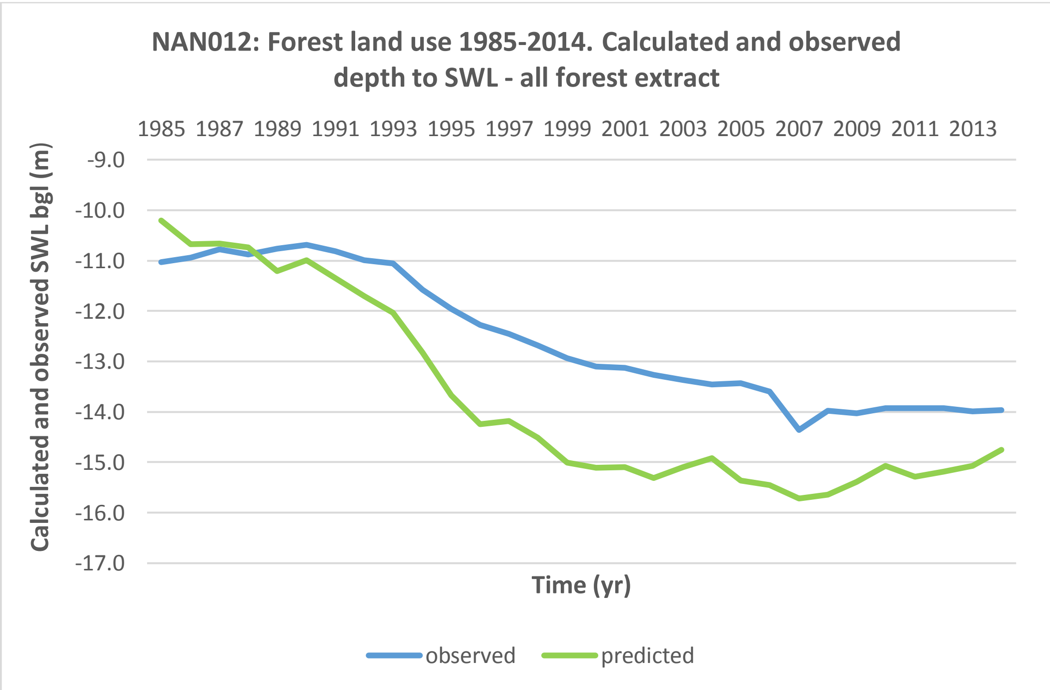

Figure 3.22: Correlation of water account against changes in depth to the watertable at NAN012 with extraction

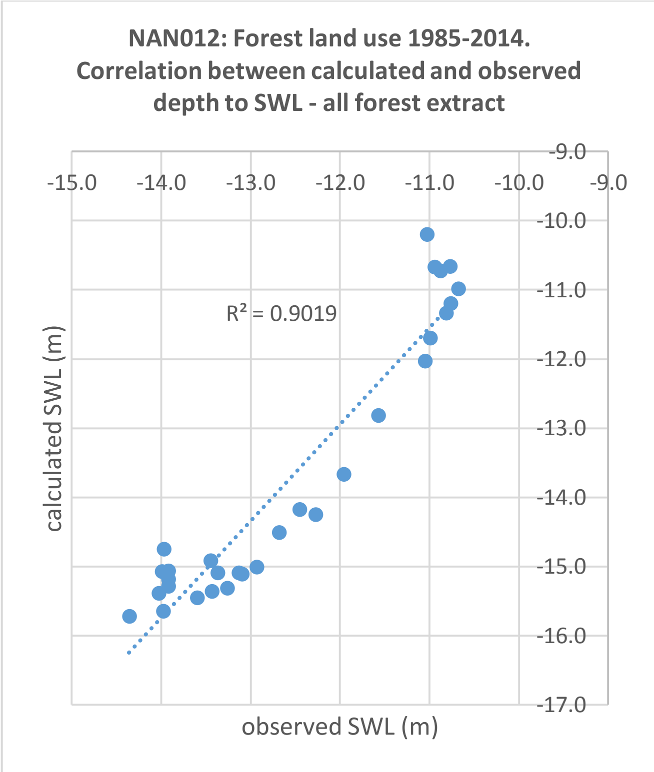

Figure 3.23 NAN012: statistical analysis – with extraction

3.3.7 Site CAR042

The graph of the calculated net annual water-mass-balance (green) is presented as a depth to the watertable and the actual autumn observed depths to the watertable below ground level (blue) in Figure 3.24. Compared with the Wattle Range and Nangwarry sites, a poor correlation was achieved at the Caroline site. While this may appear to be poor outcome for validating the forest water accounting models, knowledge gained from this site has contributed to understandings on the relationship between annual and annualised accounting.

Due to an absence of some water level data for the study period at this site, a trend line is inserted. This trend is consistent with a general underlying trend occurring in the Mount Gambier–Caroline area and is further discussed later in this report.

Softwood plantations at this site account for about 81 per cent of the land use. It is also a site where due to the depth of the watertable, recharge impacts are the only hydrological influence of the plantation forest on the groundwater resource in this area.

A fire in 1979 did enter the southern portion of the study site with about 13 per cent of the area being affected, resulting in some increased re-planting in the early 1980s. Plantations at the study site, and surrounding it, include mostly 2nd and 3rd softwood rotations.

As discussed in a previous section (3.2.4), it is considered that an underlying long term regional groundwater declining trend, in a highly transmissive aquifer, is limiting the establishment of an accurate net annual water-mass-balance at this site where plantation forests are a significant land use, but represent a relatively low percentage of the wate-mass-balance at the study site.

The statistical analysis returns an R^2 value of 0.24 in Figure 3.25.

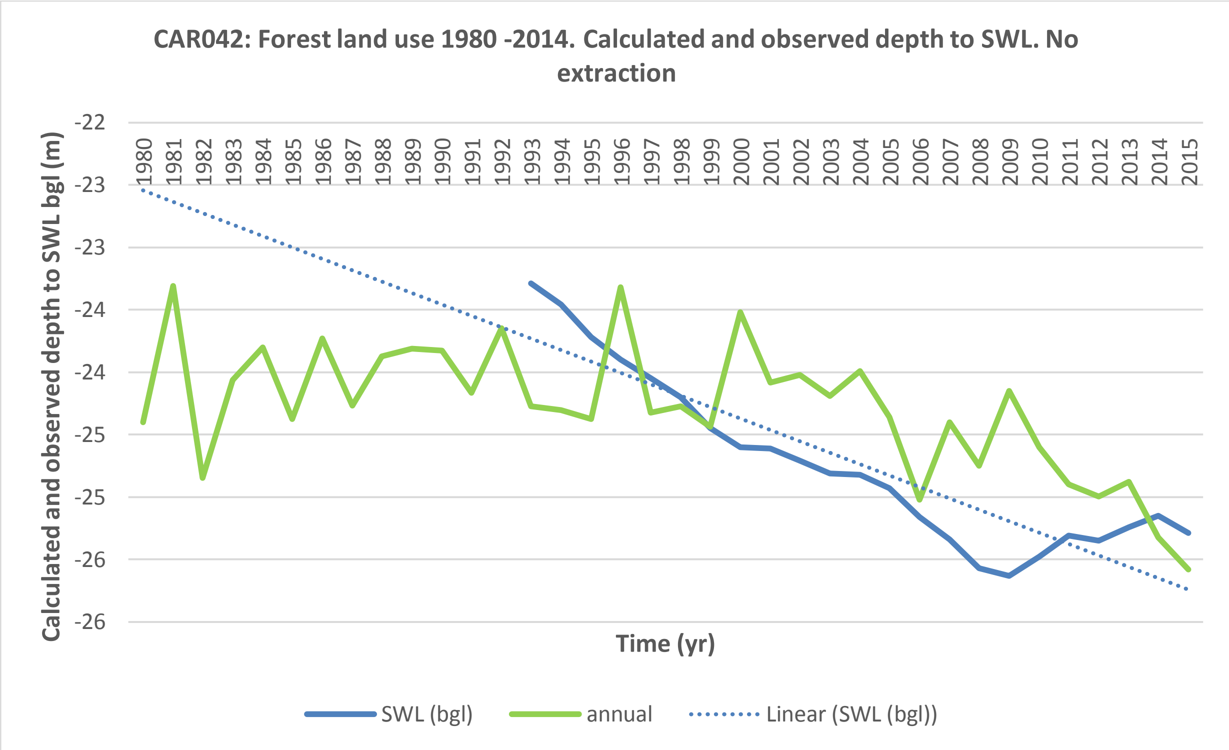

Figure 3.24: Correlation of water account against changes in depth to the watertable at CAR042

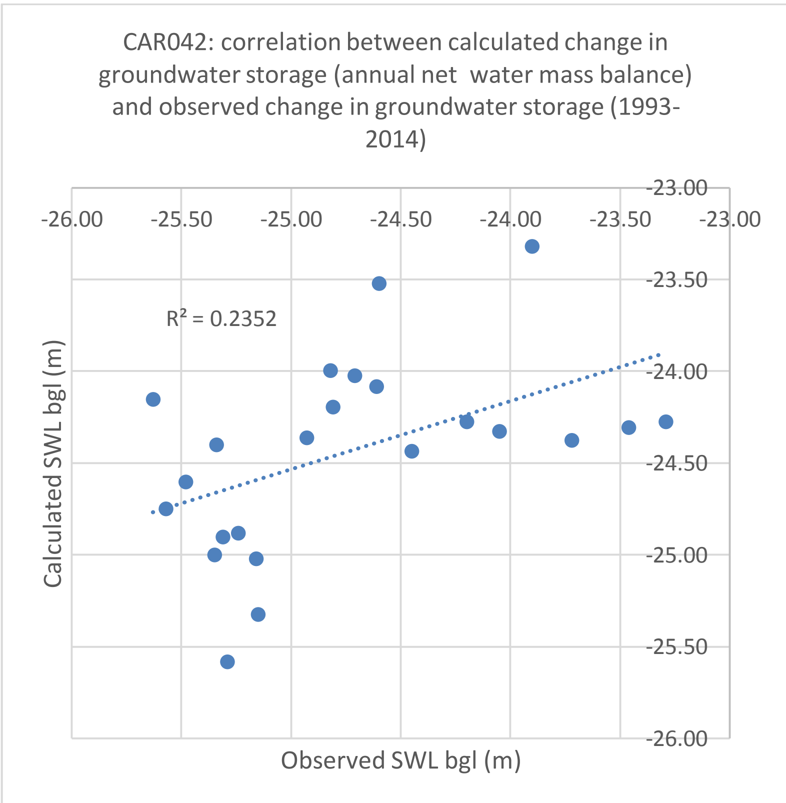

Figure 3.25: CAR042: statistical analysis

3.3.8 Site GAM079

The graph of the calculated net annual water-mass-balance (green), presented as a depth to the watertable and actual autumn observed depths to the watertable below ground level (blue) in Figure 3.26 shows limited correlation at GAM079 during the study period.

Softwood plantations at this site account for about 87 per cent of the land use. It is also a site where it can be considered that due to the depth of the watertable, recharge impacts are the only hydrological influence of plantation forests on the water account in this area. The site can be considered to be representative of a mixed aged mature forest estate and contributes to the discussion on the relationship between annual and annualised hydrological impact accounting.

A standing water level trend line is inserted because of the interrupted water level monitoring during the 1980s and early 1990s.

An analysis of the relationship between the net water-mass-balance and the observed changes in groundwater levels present a low R^2 value of 0.06 in Figure 3.27.

Although there is an interrupted groundwater monitoring record, both Caroline sites, CAR041 and GAM079, appear to exhibit a common watertable trend and this is discussed later in this report.

The statistical analysis for the Caroline sites applies to the period since 1993 for CAR042 and 1995 for GAM079. Figures 3.25 and 3.27 appear to confirm there is no significant correlation between the calculated net annual water-mass-balance and changes in groundwater storage at the sites, due to the underlying regional groundwater trend previously discussed.

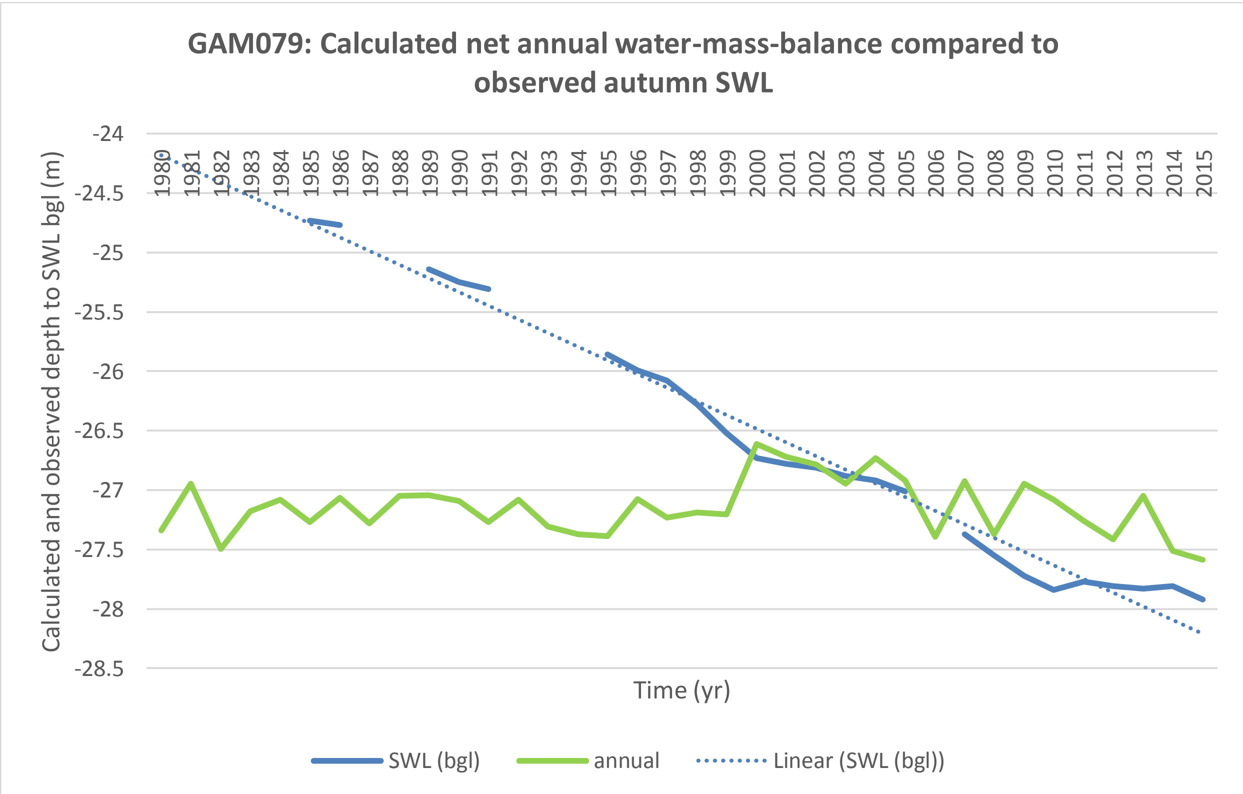

Figure 3.26: Correlation of water account against changes in depth to the watertable at GAM079

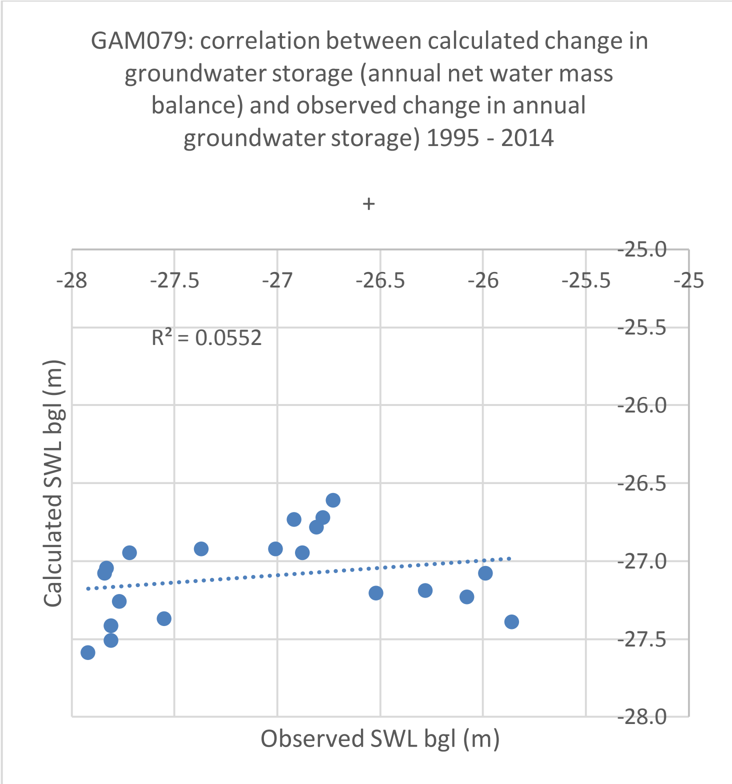

Figure 3.27: GAM079: statistical analysis

4 Discussion

4.1 Introduction

The seven study sites established net annual water-mass-balance accounts over a total area of 35 000 ha. Plantation forestry is the dominant land use in the study areas, covering 25 000 ha (about 17 per cent of the regional plantation forest estate). At the three Wattle Range sites, the hydrological impacts of plantation forests have been observed as the transition from grassland occurs. At the two Nangwarry sites, the impact of extensive bushfire and the subsequent reforestation have been observed, and the management of continuous long term forest activities with second and third rotation plantation forests is present at the two Caroline sites.

While the Caroline sites provide no relevant correlation between the calculated net annual water-mass-balance and change in groundwater storage, an outcome from the study is the forest water accounting models can be considered (within some constraints) to be suitable for the intended purpose of quantifying the hydrological impacts of plantation forests on groundwater resources at a management area scale.

However, some issues have emerged relating to the characterised average plantation management approach and the potential for more accurate forest water accounting. The adoption and application of a more refined accounting approach could have policy implications and will need to be considered by the South East Natural Resources Management Board. Key components that could be improved include :

1. the depth of the watertable at which plantation groundwater extraction is deemed to occur
2. the hydrological impact of the divergence of forest management from the characterised management incorporated in the forest water model.

In addition, new understanding on a variety of processes has been gained from this study. These include:

- Age structure of hardwood plantations and hydrological consequences
- Age structure of softwood plantation and hydrological consequences
- Annualised accounting
- Relationship between confined and unconfined aquifers at study sites
- Impacts of plantation forest on groundwater recharge
- Significance of groundwater extractions by plantations
- Rainfall variability impact on recharge
- Influence of surface water drain at site SHT012.

4.2 Age structure of the hardwood plantations and hydrological consequences

A review of the data from the plantation forest registration process for the existing regional hardwood plantation forest estate does not provide any clarity on the likely average age of trees when clear felled, the land use or reforestation approach that may follow the harvesting of the current hardwood rotations. Data shows that hardwood plantation managers have not achieved their objective of having an average clear felling age of 10 years and an area–age distribution that would be expected from a mature industry; that is, the area of different age classes being generally similar and distributed relatively uniformly throughout the plantation forest estate.

The age profile of the regional hardwood forest estate at December 2014 is presented in Figure 4.1. This data indicates a bimodal age distribution and an estate that is significantly older than the 10-year average age proposed by the plantation industry in 2006 during the review of the plantation forest water accounting model.

The two main age cohorts are plantation compartments which are 7–10 year and 13–15 year. These two groupings, in aggregate, make up 84 per cent of the total hardwood estate, with the 7–10 year age-class representing 31.2 per cent of the estate, while the 13–15 year age-class group makes up 53 per cent of the total estate. Table 4.1 summarises the area of all age classes at December 2014.

From anecdotal information, it is believed that most of 2–6 year age cohort plantations are from coppiced regeneration and not from the planting of new material, as proposed by the plantation forest industry in 2006. As confirmation is not available for the water-mass-balance calculations, all age classes are considered as established from the planting of seedling trees, as proposed by the industry. It should be noted that if the 2–6 year age-classes are from coppiced reforestation, the resulting water account will be under greater stress than previously estimated.

The reality is the regional hardwood plantation estate is significantly older than that proposed and accounted for in the WR2010 numerical model, and by the LLC WAP.

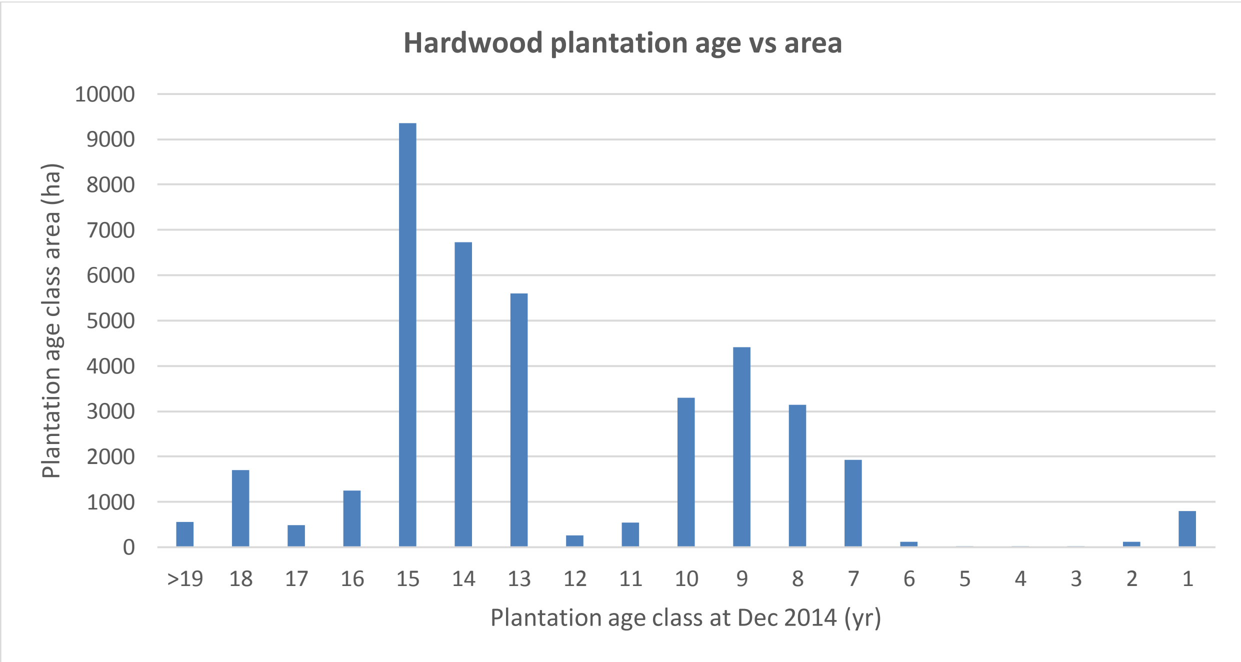

Figure 4.1: Age-class distribution of the regional hardwood plantation estate

Table 4.1: Area of different hardwood age classes

Age (years at 2014)	Area of age-class (ha)	Age class as % of total estate	Cohort % of total estate
1	796	1.9%	
2-6	304	0.7%	
7	1932	4.7%	31.2%
8	3143	7.7%	
9	4417	10.8%	
10	3297	8.0%	
11	539	1.3%	
12	265	0.6%	
13	5605	13.7%	53.0%
14	6730	16.4%	
15	9360	22.8%	
16	1250	3.1%	
17	484	1.2%	
18	1700	4.2%	
>19	551	1.3%	
unknown	589	1.4%	
total	40964	100.0%	

4.2.1 Hardwood age influence on recharge impacts

The data presented in Table 4.2, indicates the impact of increasing the clear-felling age from 10 to 15 years. It results in a total reduction in forest estate annualised recharge of 69 per cent of that budgeted for under a 10-year harvest age regime, as intended by the industry. The Table 4.2 calculations are based on the principles which are applied in the forest water model for hardwood recharge.

Table 4.2: Comparison of total recharge values for different hardwood forest rotation lengths

Planting to clear fell	Water accounting period	Planting to canopy close	MARR* recharge rate	Recharge rate at planting time	Recharge pre-canopy close	Total recharge for rotation	Annualised recharge under plantation	Recharge as % of 2006 model
yr	yr	yr	mm/yr	% of MARR	mm	mm	% of MARR	% of water budget value
10	11	3	100	120	240	240	21.8	100%
11	12	3	100	120	240	240	20.0	92%
12	13	3	100	120	240	240	18.5	85%
13	14	3	100	120	240	240	17.1	79%
14	15	3	100	120	240	240	16.0	73%
15	16	3	100	120	240	240	15.0	69%
16	17	3	100	120	240	240	14.1	65%
17	18	3	100	120	240	240	13.3	61%
18	19	3	100	120	240	240	12.6	58%
19	20	3	100	120	240	240	12.0	55%

* MARR of 100 mm/yr is a notional groundwater Management Area Recharge Rate

The blue shaded row shows calculations for values adopted by the LLC WAP for hardwood plantations.

The tan shaded row is the largest single age-class in the hardwood estate at 2014. For illustration purposes, a management area recharge rate of 100 mm is shown in Table 4.2. While the management area recharge rates range from 115–180 mm/yr in the Wattle Range area, the table illustrates the relativity in recharge between the different rotation time periods that are currently occurring.

4.2.2 Hardwood plantation age structure influence on extraction

In addition to the reduction in recharge, an older hardwood plantation forest estate also results in an increased groundwater extraction than that budgeted for and previously modelled, in the Wattle Range area. The water allocation plan provides for an annualised extraction rate of 1.82 ML/ha/yr for plantations harvested at 10 years of age. Using the same principles applied in the forest water model (Harvey 2009), the extraction calculations for plantations of various ages is presented in Table 4.3. The data indicates that a 15-year old hardwood plantation extracts an aggregate of 38.22 ML during its life, significantly more than the 20.02 ML/ha aggregate for a 10-year rotation. At an annualised rate, this equates to 2.39 ML/ha/yr which is an increase of 31.3 per cent over the annualised budgeted value for a 10-year rotation.

Forest rotation extraction values would increase further if the reforestation is from coppicing of the first rotation.

Table 4.3: Comparison of total extraction values for different hardwood forest rotation lengths

Hardwood plantation groundwater extraction (ML/ha) aggregate and annualised volume vs rotation time from planting to clear felling (yr)										
Rotation age (yr)	10	11	12	13	14	15	16	17	18	19
aggregate to year 6	5.46	5.46	5.46	5.46	5.46	5.46	5.46	5.46	5.46	5.46
7	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64
8	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64
9	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64
10	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64
11		3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64
12			3.64	3.64	3.64	3.64	3.64	3.64	3.64	3.64
13				3.64	3.64	3.64	3.64	3.64	3.64	3.64
14					3.64	3.64	3.64	3.64	3.64	3.64
15						3.64	3.64	3.64	3.64	3.64
16							3.64	3.64	3.64	3.64
17								3.64	3.64	3.64
18									3.64	3.64
19										3.64
total ML/ha)	20.02	23.66	27.3	30.94	34.58	38.22	41.86	45.5	49.14	52.78
annualised (ML/ha/yr)	**1.82**	1.97	2.10	2.21	2.31	**2.39**	2.46	2.53	2.59	2.64
% increase above adopted 1.82		8.3%	15.4%	21.4%	26.7%	31.3%	35.3%	38.9%	42.1%	45.0%

4.3 Age structure of the softwood plantations and hydrological consequences

From data provided by the softwood plantation forest industry, the commercial softwood estate in the LLC PWA was 108 046 ha in 2014. Following a review of this data, it is concluded that the age of most trees when clear felled is probably in a range of 28–37 yr and this is consistent with the industry advice in 2006 that the average rotation length is of an order of 35 years. Trees older than 37 years represent a relatively low percentage of the total softwood plantation estate. Figure 4.2 compares the area of each softwood age-class, as at December 2014.The data provide gives no indication of the number of thinning operations carried out during the forest rotation.

With the exception of the two years immediately prior to 2014, the softwood estate has exhibited a stable to minor area expansion trend.

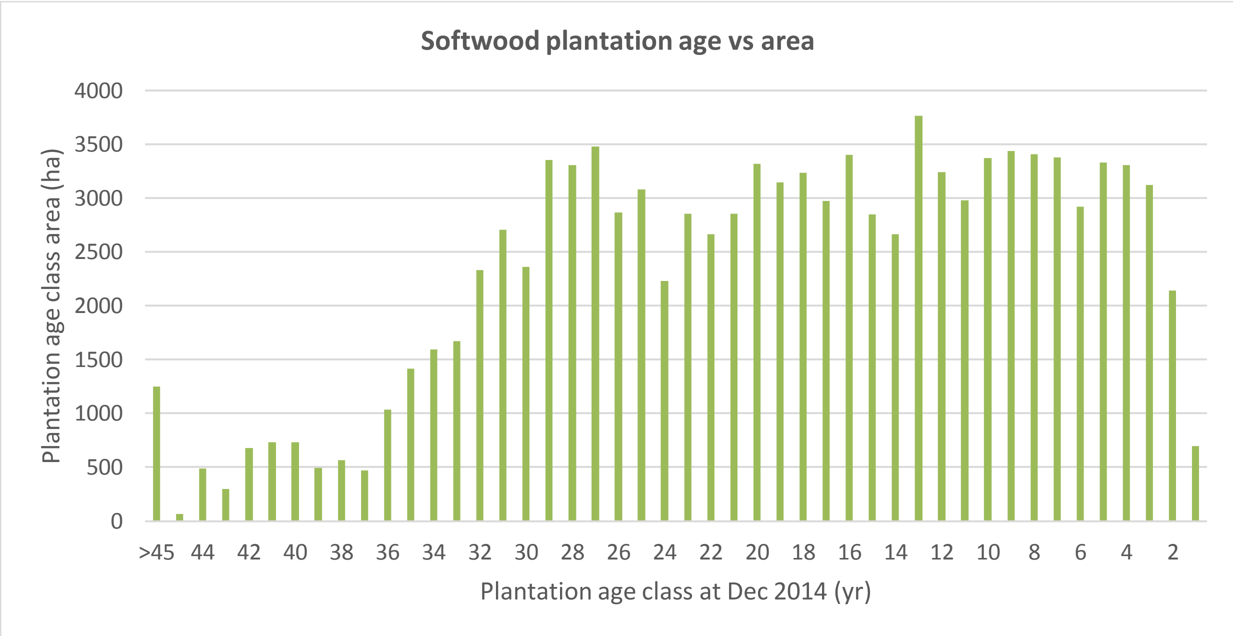

Figure 4.2: Age-class distribution of the regional softwood plantation estate

4.3.1 An assessment of softwood forest management on recharge impacts

The softwood plantation estate data provided by the industry provides no indication of how many thinning operations have occurred, or will occur before each compartment is clear felled. Based on historic industry management practices, there will be between two and four thinning operations for plantations aged 28–37 yr at clear felling. From the age data associated with Figure 4.2, it is estimated the average age of clear felling is in the order of 32–33 yr.

A range of forest thinning regimes have been analysed for assumed groundwater hydrological impacts for trees clear felled in the 28–42 yr age range. These are presented in Table 4.4 to assess the extent of groundwater recharge deviation from the industry's 2006 advised average plantation of 35 yr with four thinning operations presented in the shaded row in table.

A review of the annualised plantation recharge values presented in the last column in Table 4.4 indicates that many of the values for the different forest management options remain in close proximity to the value for industry's characterised average forest, as proposed in the 2006 softwood recharge model.

It should be noted that the annualised recharge impacts of the remaining standing plantations older than 37 years statistically decreases the annualised recharge under the forest estate. Similarly, plantations felled prior to 28 years of age has the effect of statistically increasing the annualised recharge under the forest estate.

On balance, in considering the above factors, it is reasonable to conclude that the deemed recharge impacts for softwood plantations as determined by the forest water model in 2006, should be sufficiently robust for managing the impacts of softwood plantations on groundwater recharge in the region.

Table 4.4: Recharge impacts of various softwood plantation management approaches

Planting to clear fell period	Water accounting period	Thinning operations	Management area recharge rate	Recharge rate at planting time	Planting to canopy close	Aggregate recharge pre-canopy close	Recharge attributed to thinning	Total recharge for rotation	Annualised recharge under plantation
yr	yr	number	mm/yr	% of MARR	yr	mm	mm	mm	% of MARR
28	29	2	100	120	6	420	100	520	17.9
32	33	3	100	120	6	420	150	570	17.3
32	33	4	100	120	6	420	200	620	18.8
33	34	3	100	120	6	420	150	570	16.8
33	34	4	100	120	6	420	200	620	18.2
35	36	3	100	120	6	420	150	570	15.8
35	**36**	**4**	**100**	**120**	**6**	**420**	**200**	**620**	**17.2**
37	38	3	100	120	6	420	150	570	15.0
37	38	4	100	120	6	420	200	620	16.3
38	39	5	100	120	6	420	250	670	17.2
42	43	5	100	120	6	420	250	670	15.6
Average annualised recharge impact for plantations clear felled between 32 and 33 years of age									17.8
Average annualised recharge impact for plantations clear felled between 28 and 37 years of age									17.0

As the management of the softwood plantation estate appears to be consistent with the average characterised forest management regimes described by the industry in 2006, it is reasonable to assume that the 2006 extraction forest water model values provide a similar scope in which forest management variability can be accommodated and accounted for in the values adopted by the LLC WAP.

4.4 Annualised accounting

4.4.1 Introduction

An objective in this study is to calculate a net annual water-mass-balance for each 5000 ha investigation site with annual accounting components for each hectare of land studied. The resulting net annual water-mass-balance, converted to a depth of groundwater, can then be compared to the actual change in groundwater level observed at the investigation site, where the change in groundwater level indicates a net change in groundwater storage for that period.

If the applied parameters, such as annual recharge factors under various land use conditions are appropriate, the annual extraction values are accurate, and the aquifer behaves according to the hydrogeological assumptions, the outcome should be a close correlation between the resulting net annual water-mass-balance and the net annual change in groundwater storage, as indicated by the changes in depth of the groundwater below ground level.

A close correlation in the above analysis would suggest that if all forests were managed in accordance with the characterised average forests descriptions applied to the forest water model in 2006, annualised accounting would provide a relatively accurate indication of the aggregate hydrological impacts of the regional plantation forest estate on the groundwater resource.

Using data from the regional plantation forest inventory and observations from this study, the following discussion is intended to identify hydrological impact differences between the existing forest estate and that assumed to exist in the 2006 forest water model, and relativities between the annual and annualised accounting approaches applied to the current plantation forests at the study sites.

4.4.2 Hardwood plantation age structure

With the age structure of the current hardwood plantation, it is unlikely that the annualised impact values for hardwood plantation forest estate on groundwater resources will reflect reality because of the large percentage of the estate exceeding the average plantation age of 10 years, as demonstrated in Figure 4.1 and supported by Table 4.1.

In Figure 4.3, the calculated annual hydrological impacts (green graph) at MON016 are compared to the annualised accounting (tan graph) using values based on a 10-year hardwood forest management system, as proposed.

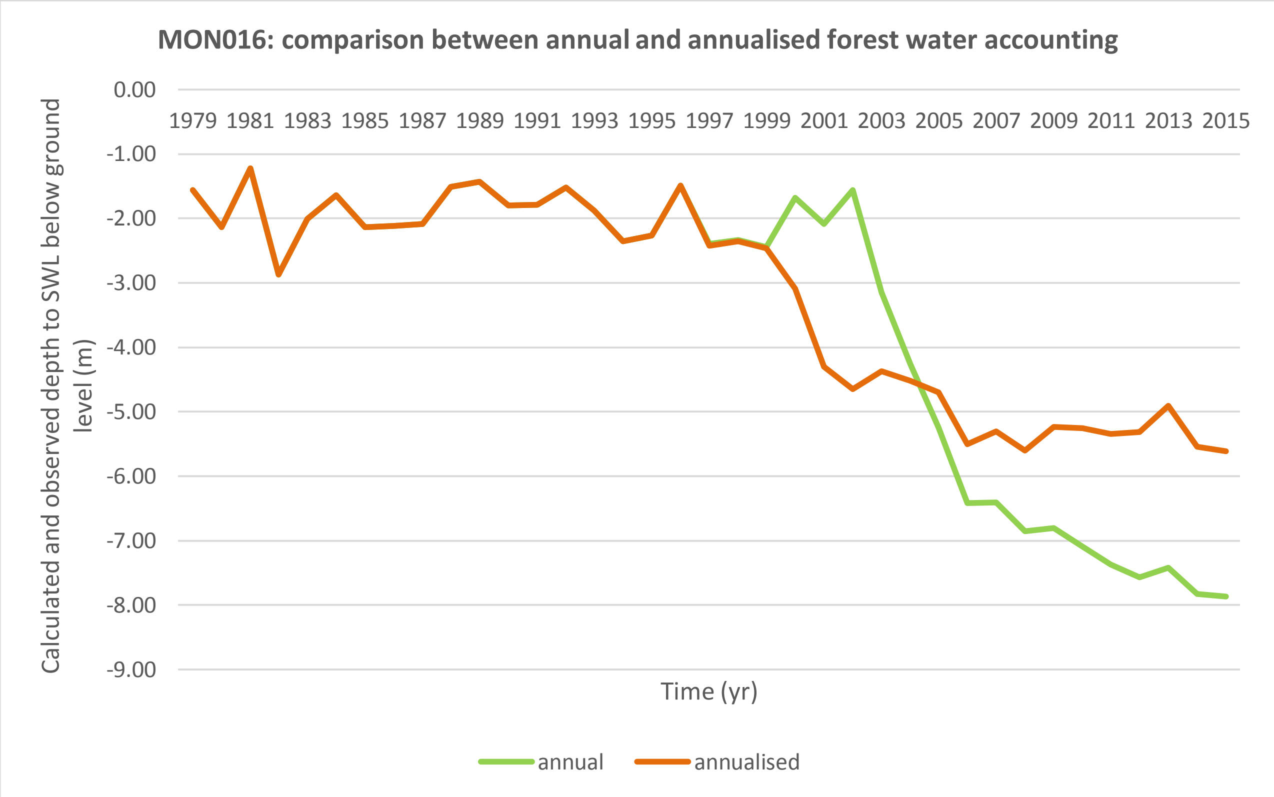

Figure 4.3: Annual and annualised accounting of water account at MON016

At site MON016, the impact of the hardwood plantations being significantly older than the characterised forest results in a divergence beginning to emerge when a significant area of plantation passes the six year age (2006–07), when maximum extraction by hardwood plantations is considered to occur. In the model for hardwood forest extraction, the maximum rate of extraction by the plantations is reached six years after planting and this rate is assumed to continue until clear felled. In Figure 4.3, this divergence continues as the plantations age and there is a lack of plantation renewal as was intended. Plantation renewal provides a period of extraction relief and some recharge recovery immediately after replanting.

4.4.3 Softwood plantation age structure

The regional softwood plantation age structure aligns with the characterised average softwood plantation forest estate proposed by the industry. While plantation forest hydrological impacts are not apparent in the groundwater trends at Caroline, these sites provide an opportunity to compare annual accounting with annualised accounting for a softwood plantation estate over an extended period, where a commercial mixed age plantation estate has been maintained through cycles of clear felling and replanting. At these sites, net water accounts based on annual components (green graph), are compared to an account built on annualised values (tan graph), over the same period for the same plantation forests. The outcome is presented as a graph in Figures 4.4 and 4.5 for CAR042 and GAM079 respectively.

Due to plantation forest estate data limitations, annualised values are applied as a default position for the early years of the analysis at the two sites. It is not until about 1996 that a higher level of confidence can be applied to the calculations and outcomes of the annual accounting approach. It should also be noted that in the case of CAR042, there is a higher rate of clear felling and reforestation in the period from 1998–2014 than described by the characterised average plantation.

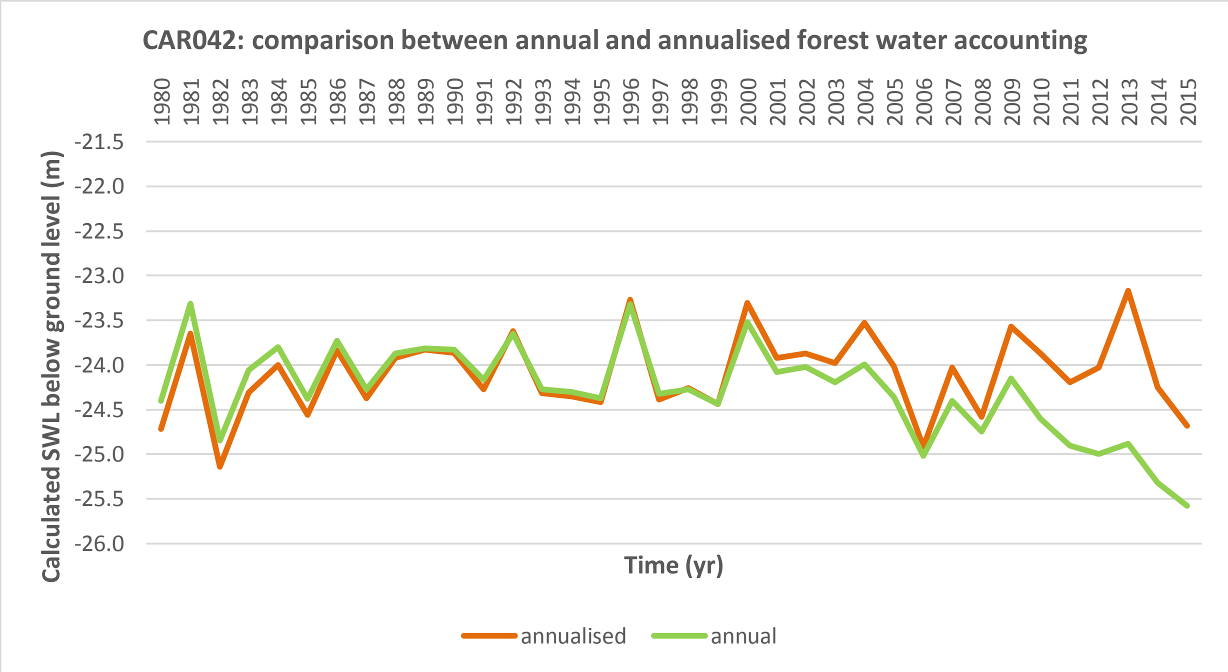

Figure 4.4: Annual and annualised accounting of water account at CAR042

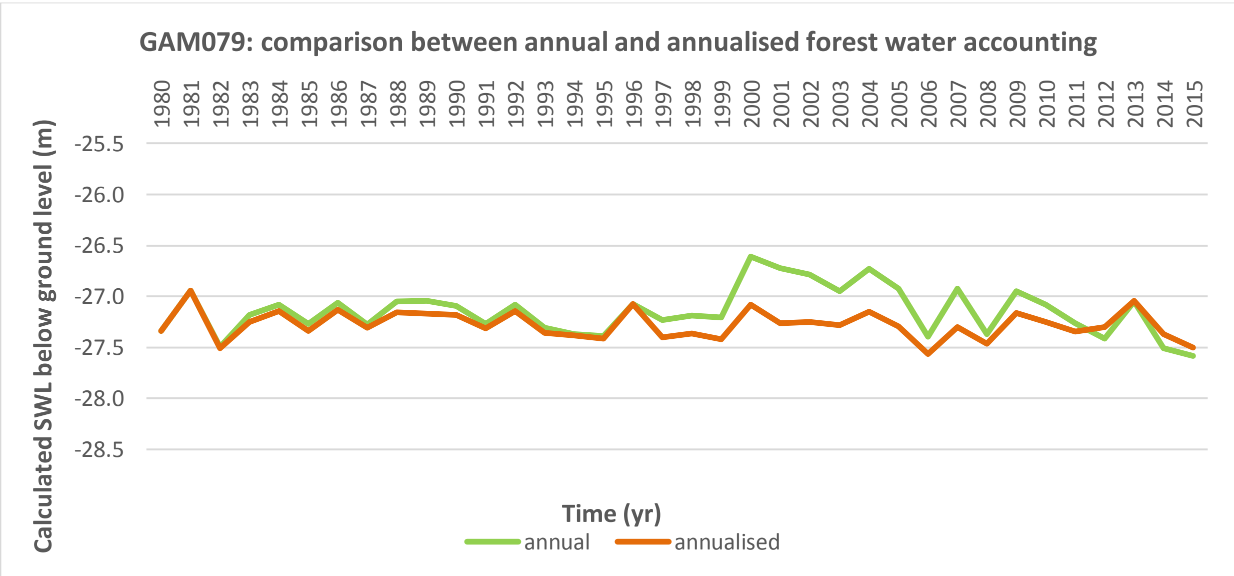

Figure 4.5: Annual and annualised accounting of water account at GAM079

In general, there is a close correlation evident between the annual and annualised approaches in the two figures. The differing correlation in 2007 at CAR042 and 2000 at GAM079, is a temporary result of a higher rate of recharge in the annual account system during the six years after planting and prior to canopy closure. This is related to a period of a high rate of forest clearance and reforestation and it is expected that a convergence will become evident in the near future as observed at GAM079 in about 2011.

As previously noted, this comparison between annual and annualised accounting is only related to recharge impacts as the depth to the watertable is considered to be beyond that at which plantation forests extract groundwater at these sites.

A comparison of annual and annualised accounting is also undertaken for a softwood plantation site where extraction by the plantation forest is considered to occur. The site NAN009 is presented in Figure 4.6.

If the plantation forest estate management closely reflects the characterised average forest, it would be expected the annual account calculation would indicate higher levels of recharge in the early life of the plantation, and before any groundwater extraction commences. An alternative way to consider the relationship between the annualised and annual accounting approaches is that the annualised accounting overstates the negative hydrological impact in the early life of a softwood plantation, then it gradually moves to 'understate' the impact, with a convergence on the annual accounting in the later stage of the rotation. While the NAN009 site commences with mostly a 'no' plantation situation following the fire and the plantation age structure is compressed relative to the characterised forest rotation, the annualised accounting pathway tends to 'smooth' the hydrological impacts following the initial afforestation period.

Most of the NAN009 site plantation forests are now approaching the average clear felling age and this should result in forest renewal and a restarting of the forest water cycle.

In the case of NAN009 and the compressed age structure of the forest estate at that site, the benefits and dis-benefits to the water-mass-balance account for the annual and annualised approaches are approximately equal in area in Figure 4.6. This indicates that over time, the aggregated hydrological outcomes are similar if the age and area distribution of the plantation forests are relatively uniform and the plantations are managed as mature and mixed aged estate at a management area scale,.

For comparison purposes, the outcome of annual and annualised calculations are presented in Figure 4.7 for a no extraction condition at the NAN012 site. Similar to the observations at the Caroline sites when only recharge impacts are observed, there is a close correlation between annual and annualised softwood accounting. Figure 4.7 similarly indicates an 'overstatement' of recharge loss in the annualised accounting approach in the early years of forest establishment followed by a convergence and maintenance of a strong correlation with the annual accounting as the plantation ages.

While the overall regional softwood plantation forest estate reasonably reflects the characterised plantation forest, the age structure at the Nangwarry study sites is not typical of the regional softwood plantation estate age distribution, on which the models are based; this is due to a period of 'compressed' reforestation following the fire that destroyed the softwood plantation estate at that location in February 1983.

A significant difference between the characteristics of the hardwood and softwood extraction examples presented is the continuing divergence between the two accounting calculations in the case of hardwood plantations due to the plantations not being managed to reflect the age structure factored into the 2006 characterised average hardwood forest (refer to Figure 4.3).

Any significant variation in the hydrological impacts between the two accounting systems (annual and annualised) needs to be balanced against the administrative burden for forest managers and agencies if detailed annual reporting was applied at the compartment scale.

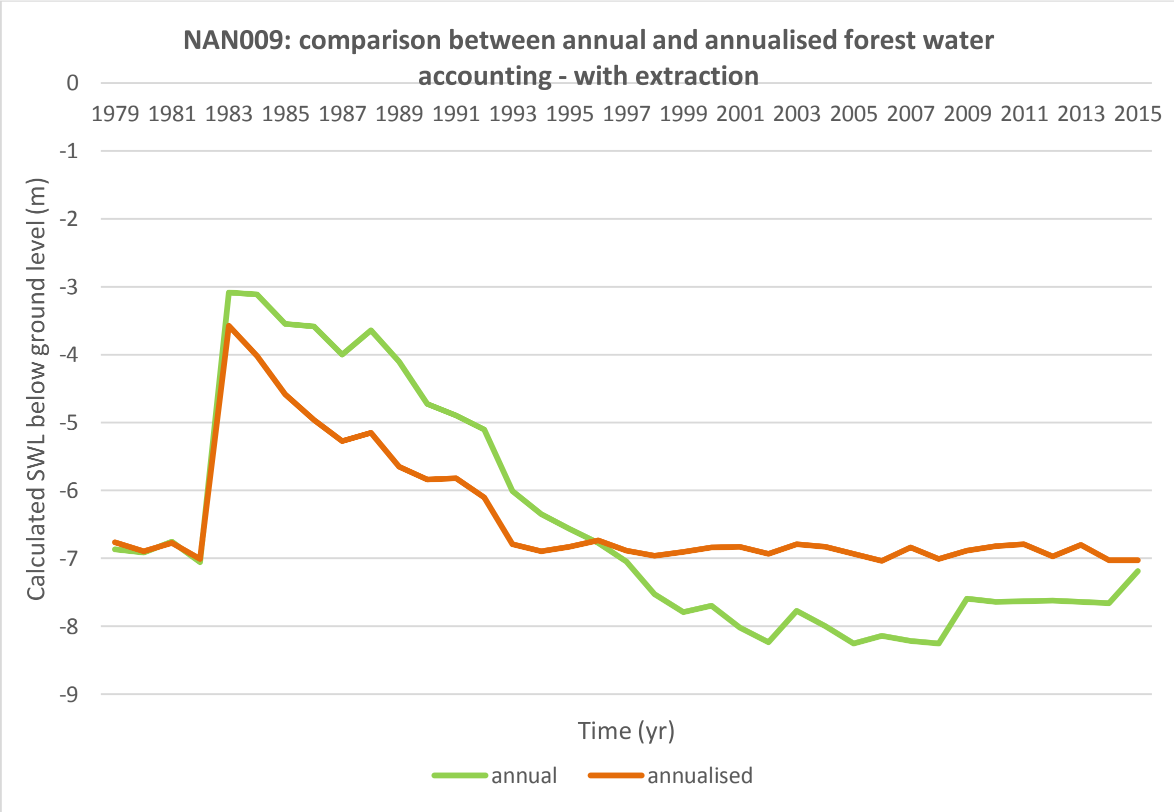

Figure 4.6: Correlation between annual and annualised accounting at NAN009 (with extraction)

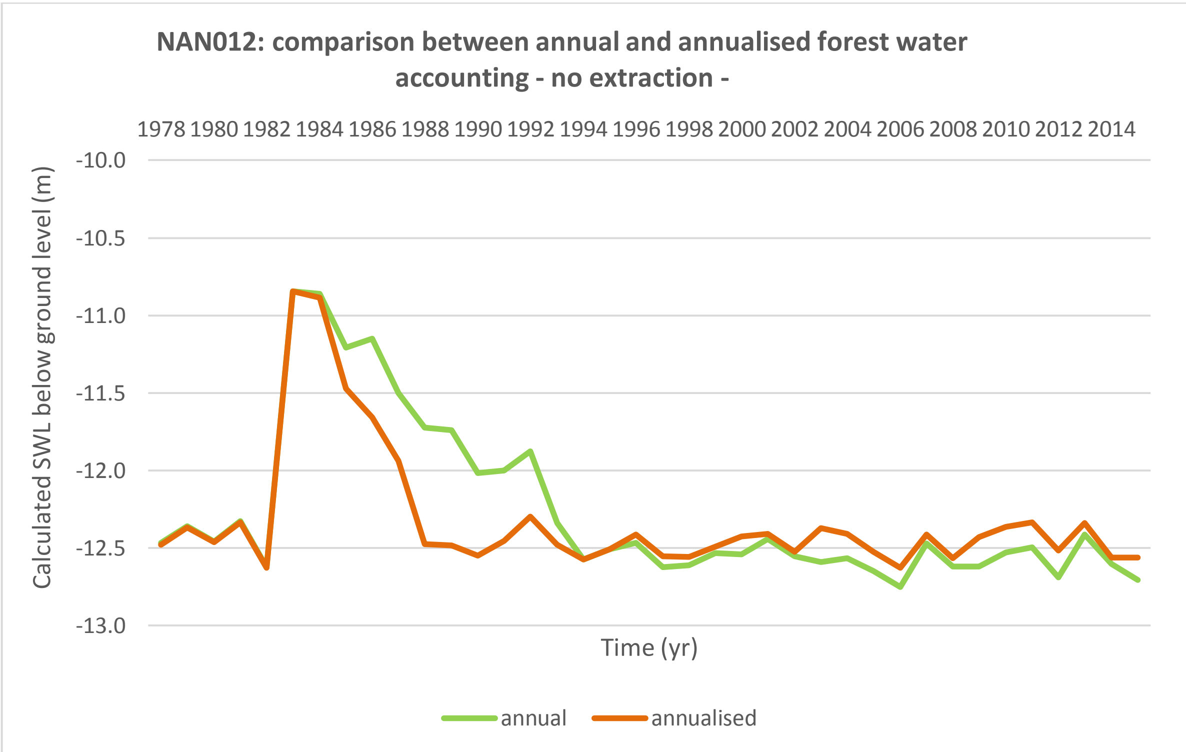

Figure 4.7: Correlation between annual and annualised accounting at NAN012 (no extraction)

4.5 Relationship between confined and unconfined aquifers at study sites

4.5.1 Introduction

The extensive unconfined Tertiary Limestone Aquifer (TLA) of the Lower Limestone Coast region generally overlays the Tertiary Confined Sand Aquifer (TCSA). Although these aquifers are usually separated by a low permeability confining layer, it has been observed that there are similarities in the water level trends in the two aquifers, suggesting a hydraulic interaction at some locations. It is important therefore to determine if the watertable changes in the seven study areas are due solely to land use change, or if inter-aquifer leakage is a significant contributor to those trends.

Joint investigations undertaken by the governments of South Australia and Victoria has established that the two aquifers in the Victorian border area east of the Nangwarry study area, are more highly connected than previously recognised (SKM, 2012). This work found that in some areas east of the border, the confining layer is absent which suggests the TLA contributes directly to the recharge of the TCSA. This is possible given that watertable levels in the unconfined TLA are higher than pressure levels observed in the TCSA in the general Nangwarry border zone.

4.5.2 Nangwarry study sites

The groundwater levels at the study site wells, NAN009 and NAN012, are presented in Figure 4.8. This figure also includes MIN017, a well that is completed in the TCSA in the same general vicinity. It can be seen that the pressure levels at MIN017 are at least 15 m lower the watertable levels at NAN009 and NAN012 and therefore the watertable trends cannot be influenced by upward leakage from the confined TCSA.

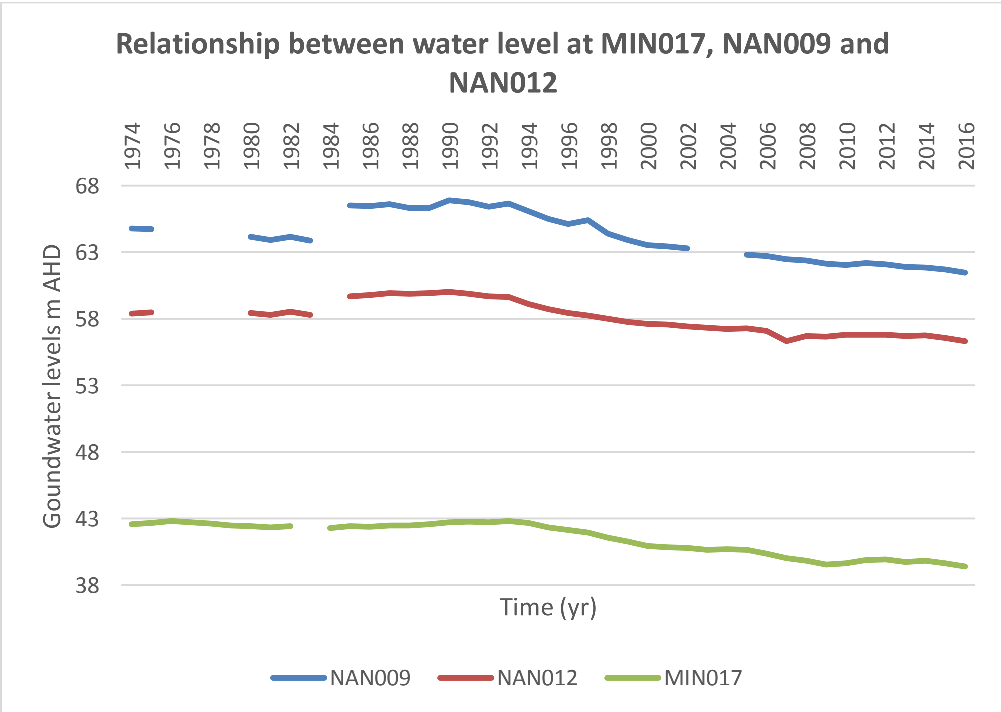

Figure 4.8: Hydrographs for MIN017, NAN009 and NAN012

4.5.3 Caroline study sites

In contrast to the Nangwarry sites, the unconfined TLA watertable levels in the vicinity of the forest sites of CAR042 and GAM079 have a lower elevation than the pressure levels in the TCSA. The hydrographs for the unconfined wells CAR042, GAM079 and BLA106 are compared with a hydrograph for the TCSA observation well GAM075 located about 10 km north-west of GAM079 (Appendix I Map) in Figure 4.9. The pressure level at GAM075 is some 20–25 m higher than the unconfined groundwater levels, meaning that any direct hydraulic connection in the area between the two aquifers would result in upward leakage of water from the confined aquifer to the unconfined aquifer.

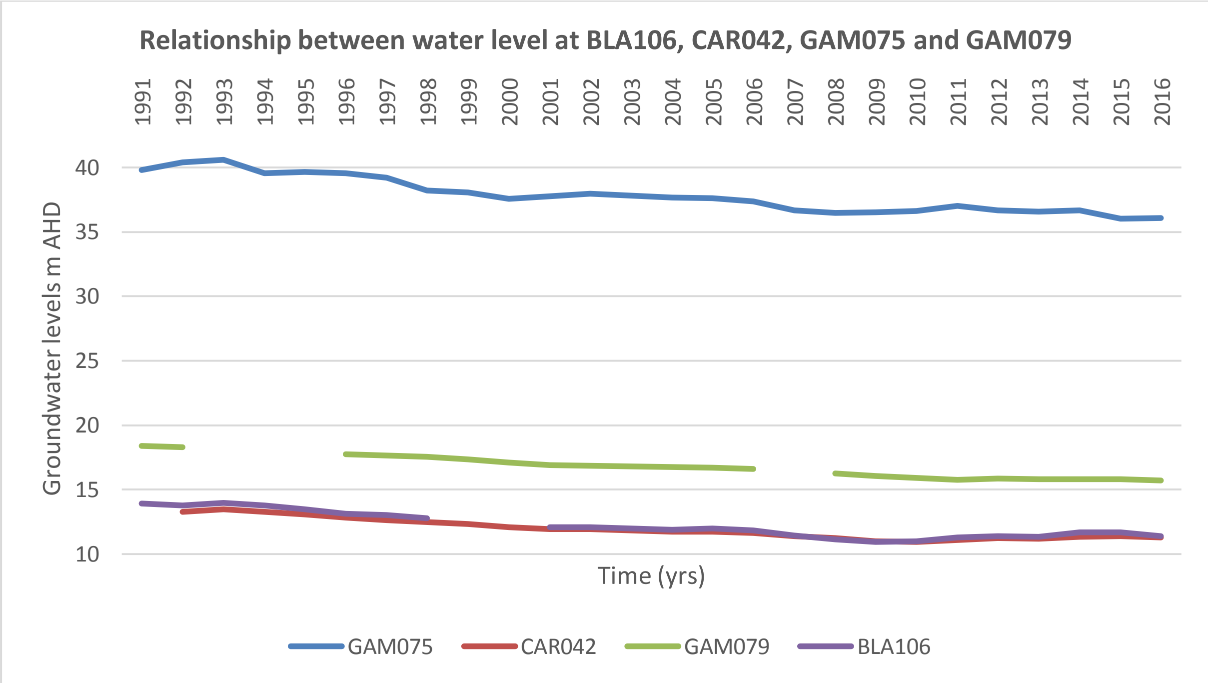

Figure 4.9: Hydrographs for BLA106 (Blue Lake), CAR042, GAM075 and GAM079

Similar widespread declining trends are observed in both the confined and unconfined aquifers. While there is the potential for upward leakage, hydrostatic loading could contribute to the confined pressure levels following the watertable trends which as the Blue Lake records show (Fig. 3.9), have been generally declining over the last 100 years. This consistent long trend which incorporates some below average rainfall seems to surpass other more localised hydrological influences, such as reduced recharge under plantation forests and other land uses.

4.6 The impact of plantation forests on groundwater recharge

Where plantation forestry is a significant land use, the water balance calculations for recharge, either in an annual or annualised form, result in a net positive position for the annual water-mass-balance account where plantation forestry is a significant land use at the studied sites, except where the plantation forests are extracting groundwater.

This is because recharge is occurring under the plantation forest from three sources;

1. Recharge that occurs when a forest is clear-felled and is replaced with a new planting. If the plantations are managed in accordance with the characterised average forest in the water accounting models, there is a continual cycle of these actions which contribute to ongoing groundwater recharge, albeit at a relatively low rate compared to that occurring under agricultural or grassland.
2. Recharge occurring after the thinning of softwood plantations.
3. Recharge that is generated under the fire breaks which accompany responsible forest management. Across the seven study sites, it can be summarised that for every 1000 ha of plantation forest there is about 90 ha of fire break contributing to recharge.

Where plantation forestry is a major land use, there are generally minimal other activities in the area that require significant groundwater extractions. If the hydrological impact of plantation forests was restricted to recharge impacts only (with no extraction by plantations), it is not unreasonable to consider that a mixed aged plantation forest would not significantly contribute to a lowering of the watertable, assuming there are no significant water using activities in the area.

4.7 Groundwater extraction by plantation forests

In 2004, research was carried out to quantify the water use of hardwood plantations in the South East region of South Australia, identify the sources of the water and explore the relationship between water use, tree growth and site factors such as the depth to the watertable for up to a three-year period. The investigation (Benyon and Doody, 2004) considered the rainfall over the study period, an assessment of transpiration (using sap flow sensors in a representative sample of trees at the research sites), while evaporation of canopy interception was derived from subtracting measured through fall from observed rainfall.

In total, nine of the 16 research sites had a median depth to the watertable of less than 6 m, with eight of the sites having a significant water deficit, thus concluding that a portion of water use was from groundwater. Consequently, Benyon and Doody (2004) restricted their conclusions for plantation forest extractions to watertables 6 m or less, below ground level. They observed that closed canopy forests extract groundwater at a mean rate of 435 mm rainfall equivalent per year (alternatively, this can be expressed as 4.35 ML/ha/yr).

Whilst it is a policy decision to choose 6 m as a threshold depth for 'no forest groundwater extraction', it does raise an issue of scientific integrity for the current study. As a result of the bushfire in February 1983 at the Nangwarry sites, much of the plantation re-establishment occurred when the watertable was at a depth significantly less than the 6 m threshold. By June 2004 (the reference point for the plantation forest extraction under the LLC WAP), watertables had lowered to a depth more than 6 m below ground level. Consequently for policy purposes under the LLC WAP these forested sites were considered not to be extracting groundwater.

At the Wattle Range sites, this study considers that extraction by plantation forests occur, and is accordingly accounted for. At the Caroline sites, the watertable is at a depth in the order of 23–28 m and consequently all forest compartments are considered not to extract groundwater.

While this study has completed water-mass-balance calculations for the Nangwarry sites based on the plantations at these sites both extracting and not extracting groundwater, logic would suggest that there could be some form of an extraction gradient as the watertable lowers towards the plantation extraction extinction depth. It is also expected that this could vary from one forest compartment to another, reflecting site geophysical characteristics. While this would require additional investigations, the benefits of pursuing this approach need to be balanced against the administrative burden, relevance, and cost for gaining the information required.

4.8 The significance of groundwater extraction by plantations

While water accounting can demonstrate that the recharge impacts of a mixed-aged plantation forest estate does not place the annual water-mass-balance into a negative position, this cannot be considered the case if the plantation forest extracts groundwater. From both field observations of the change in groundwater storage at forested sites and the calculated net annual water-mass-balances, plantation extractions can cause a significant hydrological deficit in the local water account. This is evident from all sites studied where the watertable is shallow and the plantations extract groundwater.

The site at SHT014 has the lowest percentage of plantation forest area studied (43 per cent), but still incurs a significant negative annual net water-mass-balance. This deficit is further compounded by the aging of the existing plantations beyond 10 years, and the subsequent lack of plantation renewal. At 2014, about half of the hardwood plantation at the SHT014 site was 15 years or older. It is acknowledged that this study site includes 46 ha of irrigation, but extractions for this activity accounts for less than five per cent of the peak total annual forest extraction.

There is less certainty as to the extinction depth of plantation extraction at the study sites, as it is clear from the observations at Nangwarry that extraction by plantations is occurring at depths greater that 6 m. There are a number of highly variable site factors, including the depth to the watertable (and the seasonal fluctuations) and the plantation forest age and productivity, that are likely to be controlling groundwater extraction by plantation forests plantations which has been demonstrated to be the most significant hydrological impact of plantation forests on the regional groundwater resource.

4.9 Rainfall variability impact on recharge

Groundwater recharge in the Lower Limestone Coast region can be generalised as the residual rainfall, after accounting for evapotranspiration and the seasonal adjustments for soil moisture. As advised earlier in this report, the units of annual groundwater recharge adopted for this study are those detailed in the LLC WAP. The recharge values are considered to be indicative of that recharge that is considered to occur under 'mean' seasonal conditions, however in reality, such conditions seldom prevail.

To incorporate some level of seasonal adjustment to the recharge occurring at the study sites and hence increase confidence in the calculated net annual water-mass-balance, a variable factor was applied to the adopted management area recharge rates. This factor reflects the seasonal variability in rainfall during the May–October period, compared to the mean for the same period. In general, the May–October period is considered to be the period of 'effective' rainfall for dryland agriculture in the region when rainfall generally exceeds pan evaporation and consequently, is likely to be the period when most reliable groundwater recharge occurs.

An alternative option, is a variable factor based on annual rainfall variability about the mean annual rainfall.

The data in Figures 3.3 (Penola) and 3.10 (Mount Gambier) illustrates the variation about the mean for both the annual and May–October periods between 1970 and 2015 at Penola and Mount Gambier respectively.

In both cases, the period for establishing the mean rainfall is the period from 1970 to 2015, a period that covers the current study period.

While it can be generalised that there is a reasonable level of consistency between the May–October period observations and annual periods, there are some notable differences and these are summarised in Table 4.5 for the Penola rainfall observations. Full data comparisons, for both Penola and Mount Gambier, are available in Appendix G (Tables G1 and G2).

While there is a speculative component, an attempt is made in Table 4.5 to assess the appropriateness of the May–October variable recharge factor, compared to what would be the situation if an annual factor was applied at the Wattle Range and Nangwarry study sites. The comments in the table are an expectation of the appropriateness of the applied estimated recharge in the calculated water-mass-balance, based on the adjustment for the annual rainfall variability. This assessment is based on the divergence of the actual rainfall from the mean for the annual and May–October periods for Penola rainfall observations where the mean is assigned the value 1.

Table 4.5 indicates that of the 46 years reviewed, recharge in 16 years could be significantly over, or under, estimated, based on rainfall variability from the mean. Regardless of the methodology applied, other factors may override and influence the recharge from rainfall and this will include the sequence and magnitude of rainfall events. As an example, in assessing the year of 1996, applying the annual approach, the recharge variable factor is 1.1 compared to the May–October approach where the variable factor is 1.23. However, it is noticed that if assessing the four consecutive months of June–September, using the same principles, the value would be 1.51. This sequence of wet months, and it may further incorporate a sequence of specific days, has resulted in a recharge spike at the NAN009 site but it is not so noteworthy at other sites. This could also be a function of site condition variability, and or, very localised rainfall events.

Table 4.5: Periods of significant rainfall variability about the mean data for Penola from 1975 to 2015

Comparison of rainfall to the mean for May–Oct and annual periods at Penola. Deviations from the means for the 1970 to 2015 period (expressed as factor of the mean where the mean = 1.0)				
year	annual	May–Oct	disparity in trend (≥ 0.10) *	comment regarding adoption of a May–Oct factor over an annual rainfall variable factor
1975	1.144	1.291	+0.147	could be over estimated
1977	0.936	0.816	-0.120	could be under estimated
1981	1.145	1.347	+0.202	could be over estimated
1983	1.171	0.999	-0.172	could be under estimated
1987	0.845	0.966	+0.121	could be over estimated
1989	1.072	1.256	+0.183	could be over estimated
1990	0.899	1.091	+0.192	could be over estimated
1996	1.102	1.228	+0.126	could be over estimated
1999	0.922	0.812	-0.111	could be under estimated
2006	0.675	0.492	-0.182	could be under estimated
2008	0.782	0.674	-0.108	could be under estimated
2010	1.136	1.030	-0.106	could be under estimated
2011	1.182	0.945	-0.236	could be under estimated
2012	0.863	0.972	+0.109	could be over estimated
2013	1.179	1.392	+0.213	could be over estimated
2015	0.779	0.665	-0.114	could be under estimated

* The table only includes a comparison where the deviation from the means exceeds ±0.1 (10%)

As a further comparison, the net annual water-mass-balance at several sites is recalculated by applying a recharge variable factor based on an annual rainfall for the subject period, compared to the applied May–October variable factor. Comparison for sites MON016 and NAN009 are presented in Figures 4.10 and 4.11 respectively.

In reviewing the two samples (Figures 4.10 and 4.11) it is apparent that when plantation forest hydrological impacts become noticeable, the difference in the two recharge adjustment approaches is not significant as extraction is the dominant feature in the water-mass-balance. In the pre-forest period at the Wattle Range site, there is some small level of variability, with the May–Oct approach generally providing a higher level of recharge into the water-mass-balance in the grassland land use period.

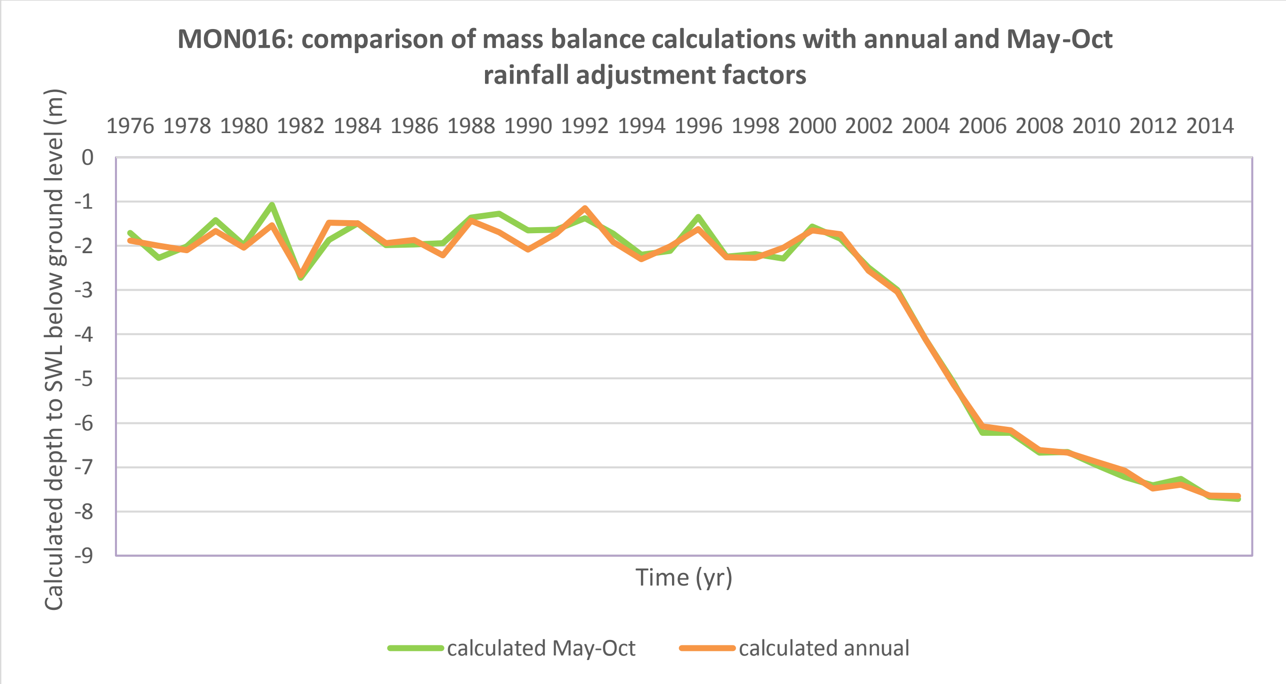

Figure 4.10: MON016: recharge adjustment options for rainfall variability

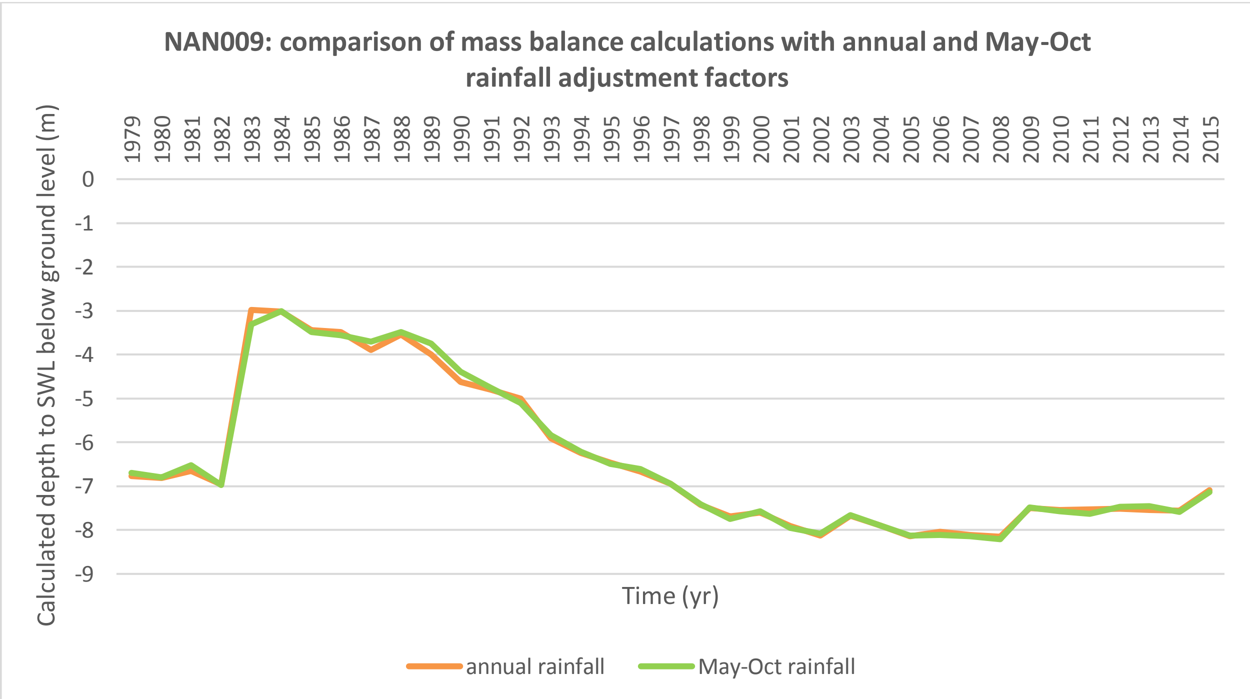

Figure 4.11: NAN009: recharge adjustment for annual rainfall variability

4.10 Influence of surface water drain at SHT012

A review of the hydrograph for the obswell SHT012 (Figure 3.13) indicates some recovery in groundwater storage, with a watertable rise commencing in 2010, continuing to 2011 and maintained to 2013, while the calculated water-mass-balance maintains a general downward trend. The annual net water-mass-balance does not account for any recharge from water present in the Bakers Range Drain, which is about 50 m from the observation well SHT012.

A review of data for the Bakers Range Drain indicates that water was present in the drain during the late winter to spring periods from 2010 to 2014. Table 4.6 is a summary of a presence of water in the drain for the period 2010 to 2014. The presence of drain flow water in 2014 is believed to be from water management associated with the 'reflows' project.

Table 4.6: Days water present in the Bakers Range Drain

Year	Days water present	Year rainfall deviation from the mean (mm)
2010	51	88.0
2011	65	117.1
2012	44	-88.2
2013	91	115.7
2014	50	-140.1

The rainfall data presented in the graph in Figure 3.3 indicates that 2010, 2011 and 2013 were significantly wet years following an extended period of below average rainfall at Penola. Given that the base of the drain is above the current watertable, it is considered that the drain provided additional and unaccounted groundwater recharge at SHT012 during the 2010 to 2014 period. No attempt is made to quantify the net recharge impact.

It should be noted that the watertable rise at SHT012 is localised and is not reflected at the other Wattle Range study sites, MON016 and SHT014, which are located 6 and 4 km respectively away from the drain.

Prior to the introduction of plantation forestry into the local Wattle Range landscape, the watertable regularly peaked at an elevation that was similar to the base level of the drain. While not intended to remove groundwater in this general area, the relationship between the drain base level and an elevated watertable would result in some base flow into the drain following a wet period.[3] This base flow discharge factor may ameliorate the impacts of a locally wet year on the actual groundwater level observed at SHT012. This may account for some of the noticeable deviations in the calculated water-mass-balance at this site, compared to the actual groundwater level observations in the pre-forest period.

[3] Drains located to the northern areas of the South East are constructed to remove saline groundwater. Drains in the southern regions are constructed to remove surplus surface water (sometimes referred to as rejected groundwater recharge).

5 Review of study findings

5.1 Recharge adjustments for seasonal variability

While a standardised approach to adjusting the annual groundwater recharge under different land uses has been applied, a better outcome may be achieved by using a combination of approaches, particularly where there are significant deviations in rainfall from the mean, whether it be during the May–October period, or for the annual period. However, as there is a strong correlation evident between the observed net annual change in the water-mass-balance and net change in groundwater storage, it could be concluded that the adopted approach to establishing the recharge rate is relatively robust and appropriate for the task being under taken at a management area scale.

5.2 Wattle Range

Other than the divergence between the calculated net annual water-mass-balance and the net annual change to groundwater storage at SHT012, due to the localised recharge from Bakers Range Drain in 2010 to 2014, there is a consistent and high correlation at the three Wattle Range sites (refer to Figures 3.11, 3.13 and 3.15). The statistical analysis for the Wattle Range sites provides a range of the R^2 correlation values between 0.91 and 0.95 in Figures 3.12, 3.14 and 3.16.

While it can be generalised that there is good correlation between the calculated net annual water-mass-balance and the observed net annual changes to groundwater storage at the Wattle Range sites, it appears that the extraction impacts of the plantation forests at those sites may be slightly overstated and the annual recharge attributed to plantation forests understated, or, a combination of both factors. It also needs to be considered that if the plantation renewal was more aligned with what was proposed by the industry in 2006, with an average 10-year rotation, better alignment of the hardwood forest water models in the water-mass-balance calculations may follow.

In the case of the hardwood plantation forests, annualised accounting results in a significant divergence from the observed changes in groundwater storage and the calculated net annual water-mass-balance. As previously discussed this is attributed to the current plantation forests not being felled and replanted in accordance with the characterised average forest that is applied in the forest water accounting models and the LLC WAP. This lack of forest renewal results in no relief to the ongoing groundwater extraction by the current estate. Similarly, there is limited reforestation recharge occurring, during the period from planting to canopy closure.

5.3 Nangwarry

An important observation at the Nangwarry sites is that the plantation forests are extracting groundwater, and that appears to be occurring when and where the depth to the watertable is greater than 6 m below ground level; this being contrary to the adopted LLC WAP policy. For both sites, NAN009 and NAN012, net annual water-mass-balance calculations are made for two different conditions; one for no extraction by plantations and the second for a situation of no depth constraint for plantation forest groundwater extraction (for extraction refer to Figures 3.17 and 3.22).

The annual calculations for a no extraction condition indicates that there would be no change in the groundwater storage after about 10 years, following the commencement of replanting after the 1983 bushfire. After 1993, the watertable would remain relatively stable (refer to Figures 3.19 and 3.20). This has not occurred, further supporting the concept that the extraction of groundwater by plantation forests is the characteristic that significantly shifts the groundwater resource account into a negative position.

The significant conclusion reached from the Nangwarry assessments is that groundwater extraction by the plantation forests is occurring at both sites. The correlation is generally good for a total extraction condition with the calculated water-mass-balance appearing to overestimate the negative hydrological impact of the softwood plantations in the first 15 years of plantation life. This is then followed by convergence between the calculated water-mass-balance and groundwater storage, with an understatement of the forest hydrological impact as the forest ages.

There remains a question as to what is the depth at which extraction by plantations ceases and how this may vary from site to site because of other factors. It would seem impractical to depart from a general model that is robust at a management area scale to one that requires site specific annual accounting at the forest compartment scale.

Annual and annualised accounting is discussed for both Nangwarry sites in Section 4.4 and although the plantation ages are 'compressed', as a result of the extensive reforestation following the 1983 fire, there is a consistent relationship between the annual and annualised accounting approaches with a general 'understatement' of recharge and 'overstatement' of extraction under annualised accounting in the early years of forest development (first 6 years prior to canopy closure). This is followed by 'overstatement' of recharge and an 'understatement' of extraction. This is not an unexpected characteristic when comparing annualised accounting with annual accounting. In a mixed aged plantation, managed similarly to the characterised forest in the softwood forest water models, the over and under statements would be expected to balance out over the life of a plantation compartment.

5.4 Caroline

The depth to the watertable at the two Caroline forest obswell sites, CAR042 and GAM079, is 23–28 m below ground level, a depth at which no extraction by plantation forest is considered to occur. The calculated net annual water-mass-balance for both sites exhibit no meaningful correlation with the observed watertable trends. Further investigation has indicated that there is a consistent underlying declining long term trend in the local groundwater resource and this appears to override the influence of any local recharge impacts caused by land use change to plantation forest. However, the Caroline sites have provided another opportunity to compare annualised and annual accounting, where the plantation forest is of a mixed age.

It is worth noting that whilst the Caroline sites have the greatest areas of plantation forest of all sites studied (81 and 87 per cent) due to no extraction by plantation forest considered to occur with the deeper watertables, conceptually, there is sufficient recharge to maintain the calculated net annual water-mass-balance for the study sites as a positive value.

Except in the early years of plantation development, when greater recharge is observed in the annual accounting, there is a close correlation between the annualised and the annual accounting approaches at both sites; this is then followed by a period of reduced recharge, compared to the annualised accounting approach. These characteristics are more pronounced at CAR042 where 63 per cent of the plantation area was clear felled and replanted in a 10-year period after 2005. This compressed age characteristic is similar to the Nangwarry sites, but not quite of the same order where nearly all the plantation was planted in a compressed 10-year period.

5.5 Significant observed hydrological influences

5.5.1 Groundwater extraction by plantation forests

From the sites observed it can be concluded that groundwater extraction by plantation forests is the hydrological characteristic that moves the water-mass-balance into a negative position where plantation forest is a significant land use by area.

The study sites with the highest percentage of plantation forests, relative to other land uses, still have areas of recharge on the ancillary land uses that accompany a plantation forest estate; these include the fire breaks and road reserves. This recharge is in addition to the recharge that is considered to occur under the plantation forest estate, particularly in the period between planting and canopy closure.

If managed as a mature industry, with a reforestation program that is generally uniform in its application, the recharge in the early years of a plantation forest rotation contributes further to a positive water-mass-balance for any study area. As explained by Harvey (2009) this forest recharge for softwood plantations is in the order of 17 per cent (annualised) of the recharge that occurs on the agricultural landscape in the same management area and 22 per cent in the case of hardwood, if managed in accordance the characterised average forest rotation.

In all cases where extraction is believed to occur (at all sites except the Caroline sites), groundwater extraction by plantation forests has the greatest impact on the water-mass-balance. It dominates all other considerations, but there appears to be some variables that could be considered if a review of the models was undertaken. While minor in terms of net impact, one parameter appears to be the rate of extraction by softwood plantations as the plantation ages. The softwood model (Harvey 2009) incorporates a reduction in extraction as the plantation ages. This is to reflect the reduced tree population per unit area as the plantations are progressively thinned, but it does not consider the associated wood productivity per hectare. The analysis undertaken suggests that this extraction component in an aging plantation could benefit from a review.

5.5.2 Threshold depth for extraction

While the important foundation research by Benyon and Doody (2004) has a significant influence in 'limiting' groundwater extraction by plantation forests to where the watertable is 6 m, or less, below ground level, later observations by Benyon *et al* (2006) establish that extraction can occur where the watertable is nearly 9 m below ground level. In comparing the calculated water-mass-balances with the observed changes in the watertable at all sites except Caroline, it is clear that extraction is occurring from depths where the watertable is significantly deeper than the adopted 6 m value. Determining the depth through practical site investigations, at which extraction is extinguished, is likely to be a complex process and may not add much more clarity to forest water accounting when considered against the site variables that may influence this activity. Consequently, an adopted estimated value for extraction extinction may be the most reasonable approach, if a policy review on this issue where to emerge.

5.5.3 Aging plantations with minimal plantation renewal

Throughout the study, a continuing divergence between the annual and annualised accounting is observed where the hardwood plantation age is significantly greater than the age of the characterised plantation applied in the extraction model. As an example, this is apparent in Figure 4.3 where the annual and annualised accounting is compared at MON016. As a comparison of hydrological response, where the plantation management is reasonably consistent with the characterised plantation forest applied in the forest water models, Figure 4.6 compares annual and annualised accounting at NAN009. This indicates the maintenance of a relatively close correlation which has the appearance of a balance between the 'under' and 'over' hydrological impacts implicit in the annualised accounting.

The Wattle Range response is not unexpected as the position posed by the forest water model for hardwood plantations assumes maximum extraction commences in the seventh year and continues for three more years, before entering a four-year period of no extraction associated with reforestation after a 10-year rotation. The character of the current hardwood estate is that trees have been in a state of continuous extraction for nearly 10 years. Whilst, there may be some slight reduction in tree population from natural causes, and a possible reduced water use associated with reduced productivity as the trees age, the calculated water-mass-balance suggests that any actual reduction in the adopted annual extraction value would have a relatively minor impact on the overall net annual water-mass-balance.

5.6 Annual accounting and annualised accounting

5.6.1 Objective of annualised accounting

As advised in the Background (Section 1.2), the annualised approach to accounting is intended to minimise reporting, administration and compliance demands for both the forest and water managers. However, the principle is dependent on the accounting being applied to 'mature' industries, where the plantation forest estate is comprised of mixed aged compartments, with the aggregate of each age-class being of a similar area and clear felling occurring within reasonable proximity of the intended 'average' age.

While annualised accounting may not be reflective of reality at the compartment scale, the study has indicated there can be a high level of confidence in the accounting of hydrological impacts at a larger scale, if the plantation forests are managed similarly to the characterised plantations on which the annualised forest water model is based.

5.6.2 Are forest water models fit for purpose?

As indicated in the beginning of this chapter, the forest water accounting models that account for the hydrological impacts outlined in the LLC WAP can be considered, within some constraints, to be relatively accurate for the intended purpose of quantifying the hydrological impacts of hardwood and softwood plantations at a management area scale in the Lower Limestone Coast PWA. The constraints include the:

1. depth of the watertable at which plantation extraction is deemed to occur, and
2. hydrological impact if plantation forest management diverges significantly from the characterised management that is incorporated in the forest water model.

The exploration into softwood management variability indicates that the softwood plantation recharge model is robust for a reasonable range of management variability, and the observations which include extraction, similarly indicate the softwood model is robust and permit some management variability. This is not the case with hardwood plantation management, which can be attributed to almost doubling the period of actual extraction by the current hardwood plantation estate, due to it being significantly older than originally proposed.

5.7 Review of the forest water models

5.7.1 Extraction depth

From the analysis undertaken it is clear that extraction by plantation forests is occurring where plantations are overlaying watertables deeper than 6 m at June 2004, the current policy under the LLC WAP. On the assumption that extraction is occurring at the NAN009 and NAN012 these calculations appear to provide a reasonable correlation between the net annual calculated water-mass-balance and the observed annual changes in groundwater storage.

While much of the current softwood estate at Nangwarry is deemed not to be extracting groundwater under the LLC WAP, for the integrity of technical assessments and groundwater flow modelling there should be a decision of assuming that many plantation forests in that area, are in fact extracting groundwater, contrary to the current water licence arrangements.

5.7.2 Understatement of softwood groundwater extraction

In developing the 2006 forest water model for softwood extraction, adjustments were made to the extraction rate as the plantations aged. This was a deliberate strategy to accommodate the reduction in tree density per hectare as the plantations were thinned, up to four times before being clear felled at 35 years of age. While the actual maximum annual rate of extraction was based on the Benyon and Doody (2004) observations, the reducing rate was a negotiated position reached with industry stakeholders.

A review of the correlation of the calculated water-mass-balance at the Nangwarry sites suggests that the annual increments should be adjusted with an overall resulting increase in the extraction rate in the later part of the forest rotation. A consequence would be a small increase in the annualised extraction impact.

5.7.3 Understatement of softwood recharge

If the adopted approach to adjusting annual recharge to reflect responses to rainfall variability is appropriate, the recharge under softwood plantations appears to be slightly understated in the period from planting to canopy closure. This can be viewed in Figures 3.17 and 3.22.

5.7.4 Overstatement of annual hardwood extraction

While the net outcome is that the current hardwood plantations are extracting more groundwater than accounted for in the LLC WAP, due to the age issues previously discussed, the actual annual increments may be marginally overstated in the hardwood extraction model. This can be viewed in Figures 3.11, 3.13 and 3.15, however this could be a manifestation of the extended period of uninterrupted extraction due to the hardwood plantations being significantly older than intended.

5.7.5 Under statement of hardwood recharge

In evaluating the recharge under hardwood plantations, it appears as if the recharge in the early years of forest development may be slightly understated. This can be viewed in Figures 3.11, 3.13 and 3.15.

6 Conclusions

6.1 Introduction

The aim of this investigation is to assess whether the model that underpins the forest water accounting system applied in the LLC WAP adequately reflects, for management purposes, the impacts of plantation forests on groundwater resources in the region. Such analysis is necessary for stakeholder confidence in related groundwater technical assessments, groundwater management responses, and the forest water licensing system which involves a valued water property right. For these reasons, it is important that the forest water accounting model is considered to be 'fit for purpose'.

The investigation has concluded that the forest water accounting model can be considered to be sufficiently accurate for quantifying the hydrological impacts of hardwood and softwood plantations at a management area scale. However, there are some constraints which include:

- the depth of the watertable at which plantation extraction is deemed to occur, and
- the hydrological impacts if plantation forest management diverges significantly from the characterised forest management that is incorporated in the adopted forest water model.

6.2 Softwood plantation forests

The study indicates the model for softwood plantation recharge is robust for reasonable variability in forest plantation management. This is relevant for the length of plantation life and the number of thinning operations during that life. It is considered that some minor upward adjustment in the deemed extraction rate of softwood plantations may better reflect reality at the sites studied. Similarly, an increase in the deemed recharge rates for the period prior to canopy closure may provide a more accurate assessment of recharge impacts. The most significant factor to recognise is groundwater extraction by softwood plantations is occurring at depths greater than the adopted policy position, which states it only occurs where watertable was 6 m, or less, at June 2004.

6.3 Hardwood plantation forests

Several issues have been identified in respect to hardwood plantation hydrological accounting. The main factor is the management of the hardwood estate has resulted in an almost doubling of the period of extraction within the rotation by the current plantations. While there is also reduced recharge due to a low level of renewal of plantations, it is the aggregated extraction factor that significantly pushes the groundwater account into a negative position. This results in a greater net annual reduction in groundwater in storage than previously modelled by the Wattle Range 2010 (WR2010) numerical groundwater model. While the extended period of continuous extraction is the main issue, it is considered that the actual annual extraction value (per hectare) may be marginally lower than that assumed by the model for hardwood extraction.

6.4 Implications for technical assessments, modelling and policy

The adjustment of any of the parameters applied in the forest water model, or adjustment of the characterised forest management configurations in the model, will require careful consideration as a policy change may have un-intended implications for the property rights recently granted to the plantation forest industry.

Whether or not there are changes made to the forest water management policy and the associated accounting model, it is suggested that future numerical groundwater modelling considers the observations and findings from this study for greater confidence in the output of the modelling scenarios.

7 Appendices

A. Hardwood recharge: version 2006 (10-year rotation): source Harvey (2009)

Forest management assumptions:

- Weed control (mid row between seedling rows strip sprayed, representing 50% of area) at time of planting seedling trees, with some benefit continuing until canopy closure.
- Canopy closure occurs three years after planting.
- Clear felling occurs 10 years after planting.
- One year 'clean-up' following clear felling.
- An 11-year management cycle for a 10-year forest rotation.

Hydrological impact assumptions based on forest biophysical stage:

- Recharge credit of 120% of management area recharge rate (MARR) in the planting year.
- No recharge under a closed canopy forest.
- Recharge from planting to canopy closure is 120% of MARR for 1st year. In subsequent years until canopy closure, recharge is 80% and 40% respectively.
- No recharge in the clean-up year, but it recommences in the following year, which is the planting year of the next rotation.

Calculation of annualised recharge impact:

- Recharge impacts expressed as a percentage of MARR.
- Recharge credit from planting to canopy closure is [120% + 80% + 40%] MARR
- Sum of all credits divided by 11 (years) is the annualised recharge for hardwood plantations, expressed as a percentage of MARR. [120% + 80% + 40%] /11 = % MARR

  = 21.8% MARR

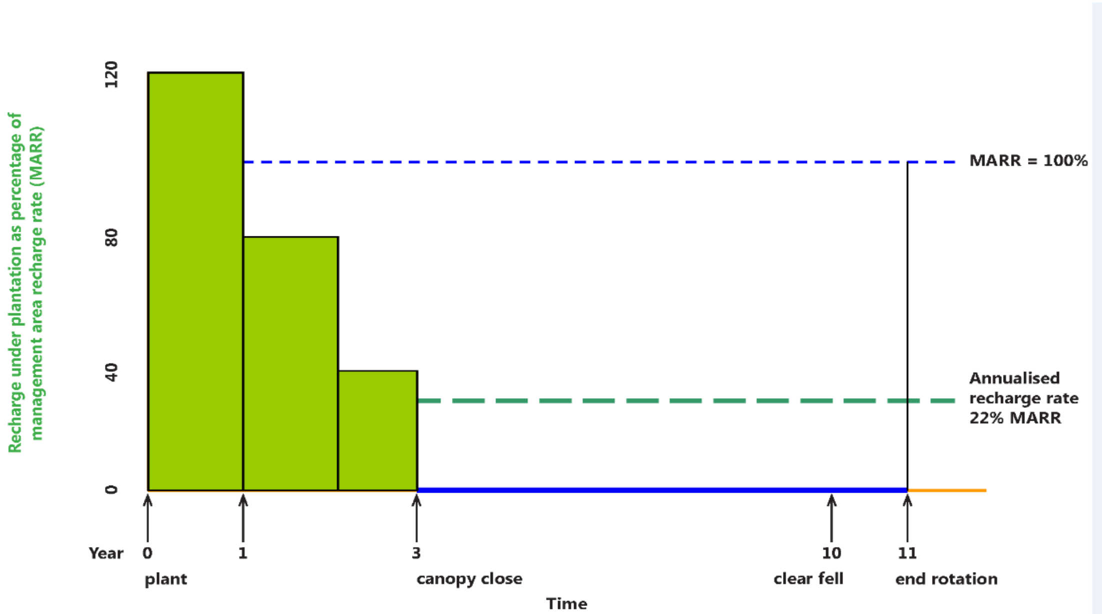

Figure A.1: Deemed model for accounting for the impacts of hardwood plantation forests on groundwater recharge: 2006 version

B. Hardwood extraction: version 2006 (10-year rotation): source Harvey (2009)

Groundwater extraction models were developed in collaboration with industry and key stakeholders, at the time of the recharge model revision in 2006. The water resource regulator adopted 364 mm per year extraction (3.64 ML/ha/yr) in lieu of the Benyon and Doody (2004) value of 435 mm and this is explained by Harvey (2009). Using a peak extraction rate of 364 mm per year, groundwater extraction by hardwood plantations is the annualised to be 1.82 ML/ha/yr. A graphic representation of the hardwood extraction model is presented in **Figure B.1**

The volume of extraction assigned in the model to each age-class of hardwood plantation, where the watertable is assessed as being 6 m, or less, below ground level at June 2004, is presented in **Table B.1**. The June 2004 date is a policy decision and reference point to facilitate the granting licensed water allocations for plantation forests where there was a shallow watertable.

Whilst the hardwood industry insisted that all replacement plantations would be by replanting with new genetic material, a deemed extraction model was also developed to account for the replacement hardwood plantations being established by the coppice method.[4] This increases the annualised extraction value from 1.82 ML/ha/yr to 2.5 ML/ha/yr, for the second rotation, where the established root system facilitates a more rapid return to the forest production phase for the coppiced second rotation. The accounting model for coppiced regeneration is based on the second rotation being for another 8 yr and considers that full extraction occurs at an earlier time than in the first rotation (Harvey 2009). This model makes non-validated assumptions about the evapotranspiration characteristics of the coppiced regeneration of the plantation. Table B.2 sets out the extraction assigned to each age-class.

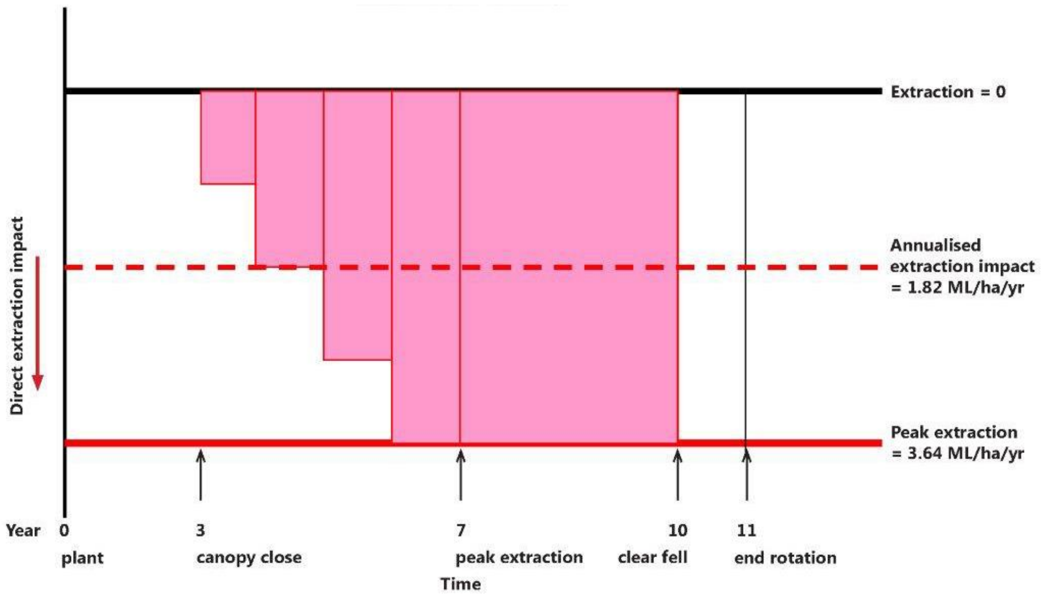

Figure B.1: Deemed model for accounting for the extraction of groundwater by hardwood plantation forests

[4] Coppice or coppicing refers to the practice of allowing new shoots to regenerate from epicormics on the tree stump after clear felling. These coppiced shoots are generally thinned to two or three main stems to develop and provide the wood product for the next rotation. This capability only applies to the *Eucalyptus* plantations; *Pinus* trees do not coppice.

Table B.1: Schedule of hardwood annual groundwater extraction values

	forest rotation year	annual extraction	cumulative extraction	annualised extraction value
	yr	ML/ha	ML/ha	ML/ha/yr
planting	1	0	0	1.82
	2	0	0	1.82
	3	0	0	1.82
canopy closed	4	0.91	0.91	1.82
	5	1.82	2.73	1.82
	6	2.73	5.46	1.82
	7	3.64	9.1	1.82
	8	3.64	12.74	1.82
	9	3.64	16.38	1.82
clear fell	10	3.64	20.02	1.82
clean up	11	0	20.02	1.82

Table B.2: Hardwood annual extraction values for coppiced hardwood plantations

	forest rotation year	annual extraction	cumulative extraction	annualised extraction value
	yr	ML/ha	ML/ha	ML/ha/yr
planting	1	0	0	1.82
	2	0	0	1.82
	3	0	0	1.82
canopy closed	4	0.91	0.91	1.82
	5	1.82	2.73	1.82
	6	2.73	5.46	1.82
	7	3.64	9.1	1.82
	8	3.64	12.74	1.82
	9	3.64	16.38	1.82
1st harvest	10	3.64	20.02	1.82
	11	0	20.02	1.82
	12	0.91	20.93	2.5
	13	1.82	22.75	2.5
	14	2.73	25.48	2.5
	15	3.64	29.12	2.5
	16	3.64	32.76	2.5
	17	3.64	36.4	2.5
2nd harvest	18	3.64	40.04	2.5
clean up	19	0	40.04	2.5

C. Softwood recharge: version 2006: source Harvey (2009)

In the 2006 review of the forest water accounting models, the softwood forest rotation length was increased from 30–35 yr in the model and the number of thinning operations increased from two to four. With the revised recharge rates applying to the period prior to canopy closure, the annualised softwood recharge value was calculated to remain at 17.2%, or a loss of 82.8%, of that recharge occurring on the agricultural landscape, for every year of the forest rotation. A summary of the softwood recharge model is presented below and a graphic interpretation of the model is presented in Figure C.1.

Softwood recharge: version 2006 (35-year rotation x 4 thinnings)

Forest management assumptions:

- Weed control (mid row between seedling rows strip sprayed, representing 50% of area) at time of planting seedling trees, with some benefit continuing until canopy closure.
- Canopy closure occurs six years after planting.
- Clear felling occurs at 35 years after planting.
- Four thinning operations occurring before clear felling.
- One year clean up following clear felling.

Hydrological impact assumptions based on forest biophysical stage:

- Recharge occurs at 120% of management are recharge rate (MARR) in the planting year.
- No recharge under a closed canopy forest.
- Recharge from planting to canopy closure is 120% of MARR for 1st year and in subsequent years to canopy closure; recharge is 100%, 80%, 60%, 40% and 20% respectively.
- No recharge in clean-up year, but recommences in following year, which is the planting year of the next rotation.
- A recharge spike in each year following the four thinning operations is equivalent to 50% of MARR for that year following the thinning operation.
- A 36-year management cycle for a 35-year forest rotation.

Calculation of annualised recharge impact:

- Recharge impacts are expressed as a percentage of MARR.
- Recharge credit from planting to canopy closure is [120% + 100%+ 80% + 60% + 40% + 20%] MARR.
- Recharge credits aggregated following the four thinning operations is [50% + 50% + 50% + 50%] MARR.
- Sum of all credits divided by 36 (years) is the annualised recharge impact of softwood plantations:
- {[120%+100%+80%+60%+40%+20%] + [50%+50%+50%+50%]} /36 = % MARR

  = 17.2% MARR

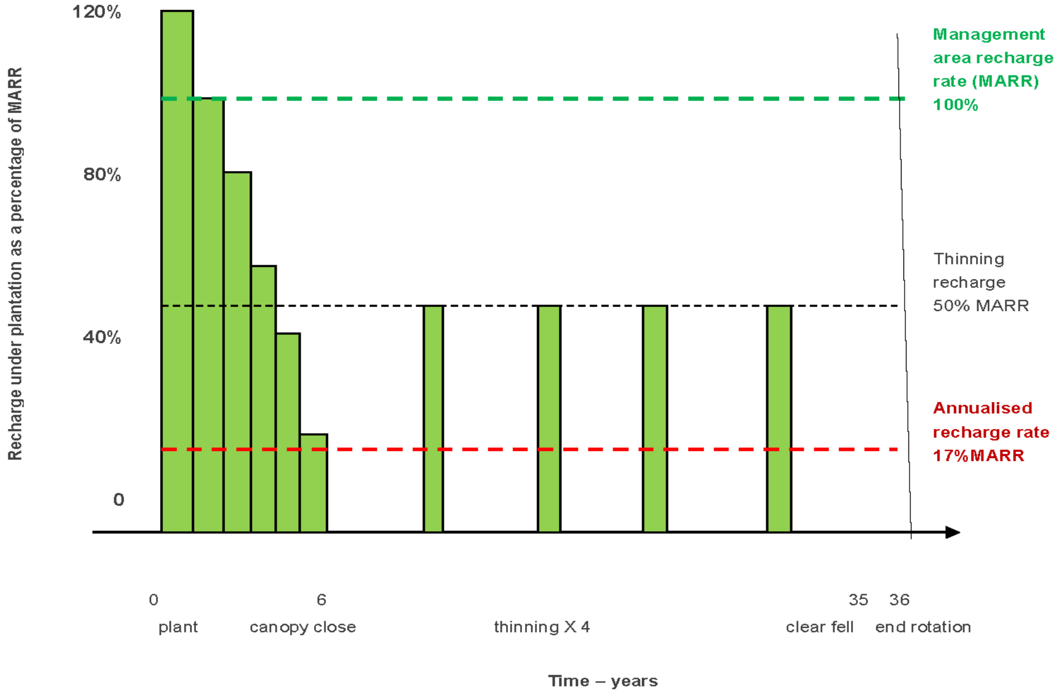

Figure C.1: Deemed model for accounting for the impacts of softwood plantation forests on groundwater recharge: 2006 version

D. Softwood extraction: version 2006: source Harvey (2009)

The softwood extraction model is based more on negotiation rather than principles and technical fact. An annualised extraction value for softwood was agreed with the industry to be 1.66 ML/ha/yr and this lesser extraction by softwood plantations, compared to hardwood, is attributed to the significant reduction in tree population per hectare, as a result of the forest thinning operations carried out during the life of the plantation. Plantations can be established at 1200–1600 stems/ha and thinned to as low as 200 stems by the time of clear felling.

The concept of a reducing tree population (per hectare) reducing actual plantation extraction is presented in a diagrammatic form by Harvey (2009) and this is presented in Figure A.4. This indicates a gradual linear reduction in extraction from a peak of 3.64 ML/ha to 1.0.ML/ha at the time of clear felling, with a brief period of relief immediately following each thinning operation. The intention of the figure is present the concept of a reducing tree population reducing the extraction of groundwater.

The annual extraction and the accumulative annual extraction components are presented in Table A.3. The last column in table details the accumulative difference between the deemed annualised extraction impacts and those annual components believed to occur. It is noted that the widest disparity occurs in the early stages of the plantation, but by the time the trees are 17-years of age, the differences are minimal (less than 5% of the aggregate for the rotation).

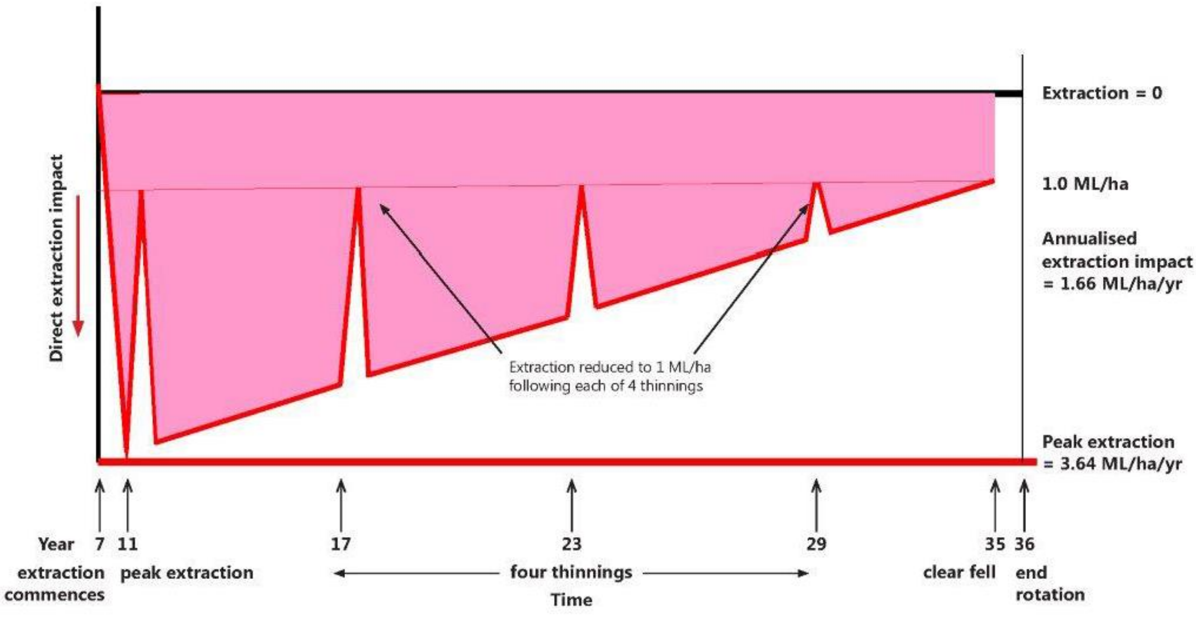

Figure D.1: Deemed model for accounting for the extraction of groundwater by softwood plantation forests

Table D.1: Softwood annual extraction values from DWLBC report 2009/13 (Harvey 2009)

Softwood groundwater extraction of characterised 'average' plantation - 2006						
					impact of shortened rotation	
Thinning status	**year**	**extraction ML/ha/yr**	annualised value	**accumulated actual**	**accumulated annualised**	**differential to credit**
	1	0.00	1.66	0.00	1.66	1.66
	2	0.00	1.66	0.00	3.33	3.33
	3	0.00	1.66	0.00	4.99	4.99
	4	0.00	1.66	0.00	6.65	6.65
	5	0.00	1.66	0.00	8.32	8.32
	6	0.00	1.66	0.00	9.98	9.98
	7	0.73	1.66	0.73	11.64	10.91
	8	1.46	1.66	2.19	13.31	11.12
	9	2.19	1.66	4.38	14.97	10.59
	10	2.91	1.66	7.29	16.63	9.34
T1	11	3.64	1.66	10.93	18.30	7.37
	12	1.00	1.66	11.93	19.96	8.03
	13	2.05	1.66	13.98	21.62	7.64
	14	2.35	1.66	16.33	23.29	6.96
	15	2.75	1.66	19.08	24.95	5.87
	16	3.15	1.66	22.23	26.61	4.38
T2	17	3.55	1.66	25.78	28.28	2.50
	18	1.00	1.66	26.78	29.94	3.16
	19	2.05	1.66	28.83	31.60	**2.77**
	20	2.45	1.66	31.28	33.27	1.99
	21	2.75	1.66	34.03	34.93	0.90
	22	3.05	1.66	37.08	36.59	-0.49
T3	23	3.35	1.66	40.43	38.26	-2.17
	24	1.00	1.66	41.43	39.92	-1.51
	25	1.90	1.66	43.33	41.58	-1.75
	26	1.95	1.66	45.28	43.25	-2.03
	27	2.00	1.66	47.28	44.91	-2.37
	28	2.10	1.66	49.38	46.57	-2.81
T4	29	2.15	1.66	51.53	48.24	-3.29
	30	1.00	1.66	52.53	49.90	-2.63
	31	1.30	1.66	53.83	51.56	-2.27
	32	1.40	1.66	55.23	53.23	-2.00
	33	1.50	1.66	56.73	54.89	-1.84
	34	1.55	1.66	58.28	56.55	-1.73
	35	1.60	1.66	59.88	58.22	-1.66
	36	0.00	1.66	59.88	59.88	0.00
aggregate		59.88				
annualised		**1.663**				

Appendix E. Table 1 from Water Allocation Plan for the Lower Limestone Coast Prescribed Wells Area 2013

TABLE 1: SUMMARY OF THE WATER ACCOUNT FOR THE LOWER LIMESTONE COAST UNCONFINED AQUIFER (DRAFT)

Unconfined Management Area	Adopted Recharge Rate (mm/year)	Target Management Limit (TML) (ML/yr)	Total Available Recharge (if different to TML) (ML/yr)	Indicative Allocation Conversion of IEs (ML/yr) March 2012 + SPRs at June 2012					Existing Volumetric Allocations (ML/yr)	Holding Allocations (ML/yr)	Holding Forestry (ML/yr	Indicative Allocation Non-Forestry (ML/yr)	Forestry Recharge Interception at June 2012 (ML/yr)	Forestry Direct Groundwater Extraction at June 2012 (ML/yr)	Farm Forestry RI & DGE (ML/yr)	Stock & Domestic (ML/yr)	Total losses ((total alloc + farm forestry + S&D)- DS)	Total Account (ML/yr) (total losses + DS)	Water Account Surplus/Deficit (ML/yr)
				Tradeable (ML/yr)	Forestry (ML/yr)	Delivery Supplement (ML/yr)	SPRs 2012 (ML/yr)	Total (ML/yr)											
BANGHAM	20	6,395	5,408	5,378	0	155	96	5,629	35	0	0	5,664	0	0	166	720	6,395	6,550	0
BEEAMMA	20	8,763	4,129	7,945	0	0	178	8,122	0	0	0	8,122	0	0	72	569	8,763	8,763	0
BENARA	170	37,749		7,059	0	510	209	7,778	3,730	2,596	0	14,103	6,569	1,478	47	1,182	22,879	23,388	14,870
BLANCHE CENTRAL	175	12,140		2,871	0	0	70	2,941	43	0	0	2,984	4,321	2	40	340	7,687	7,687	4,453
BOOL	105	4,417		1,382	0	0	0	1,382	268	498	0	2,148	0	0	9	215	2,371	2,371	2,046
BOWAKA	85	16,107		8,427	0	4,171	0	12,597	0	1,568	0	14,165	68	120	44	771	11,017	15,188	5,089
BRAY	90	17,118		1,745	0	492	0	2,237	2,091	3,738	0	8,066	578	151	3	968	9,292	9,784	7,826
COLES	120	25,228		5,318	388	807	0	6,508	683	1,015	911	8,297	15,764	24,492	217	479	50,264	51,161	-25,036
COMAUM	60	4,640	3,388	2,765	0	0	44	2,809	45	0	0	2,874	1,353	157	9	237	4,640	4,640	0
COMPTON	175	5,921		232	0	0	0	232	411	349	0	992	1,229	32	0	222	2,473	2,473	3,448
CONMURRA	95	29,764		10,231	0	3,461	0	13,692	3,832	5,844	0	23,368	1,174	909	694	1,184	24,068	27,529	5,696
DONOVANS	175	34,394		16,931	0	1,296	1,143	19,370	497	0	0	19,867	6,437	0	140	1,043	26,190	27,486	8,203
DUFFIELD	50	9,225		0	0	0	0	0	0	634	0	634	0	0	4	522	1,160	1,160	8,064
FOX	100	22,027	20,370	5,959	0	1,090	153	7,203	3,113	6,357	0	16,673	1,915	3,105	435	989	22,027	23,117	0
FRANCES	30	4,393		5,520	0	9	16	5,546	86	0	0	5,632	0	0	0	611	6,234	6,243	-1,840
GLENBURNIE	150	36,789		14,308	41	0	761	15,110	5,461	0	0	20,571	12,688	0	275	1,072	34,606	34,606	2,183
GLENROY	100	8,888	7,357	7,440	0	145	986	8,571	13	0		8,584	0	0	0	427	8,868	9,011	0
GREY	150	25,044		21,366	0	3,445	459	25,270	568	0	132	25,838	642	657	157	1,043	25,024	28,469	20
HACKS	125	5,229		4,756	0	1,640	0	6,396	0	0	0	6,396	0	0	0	214	4,970	6,610	259
HINDMARSH	150	31,276		7,488	0	0	475	7,962	629	437	0	9,028	15,668	3,606	267	735	29,544	29,544	1,732
HYNAM EAST	25	3,576		6,826	0	0	136	6,962	0	0	0	6,962	0	0	10	597	7,569	7,568	-3,992
HYNAM WEST	60	5,725		5,051	0	4,219	0	9,269	0	0	0	9,269	0	0	0	327	5,377	9,596	348
JOANNA	50	15,442	12,856	13,014	0	21	106	13,140	151	0	0	13,291	813	339	47	973	15,442	15,463	0
JOYCE	120	38,180		8,683	0	1,344	68	10,095	2,880	3,443	0	16,227	3,041	4,598	635	1,185	24,322	25,666	13,857
KENNION	120	25,271		3,324	0	903	54	4,280	1,117	9,981	748	15,378	2,929	2,703	262	1,004	22,113	23,016	3,158
KILLANOOLA	145	23,557	22,340	9,953	840	1,927	554	13,274	1,314	1,403	277	15,990	3,592	4,505	405	716	23,557	25,484	0
KONGORONG	170	32,676		11,438	0	828	778	13,044	496	0	0	13,540	9,571	498	427	908	24,083	24,911	8,593
LACEPEDE	100	18,014		833	0	0	1	833	559	4,506	0	5,898	0	0	0	739	6,637	6,637	11,377
LAKE GEORGE	75	7,975		1,104	0	0	43	1,147	300	2,616	0	4,063	0	0	158	588	4,805	4,805	3,169
LANDSEER	45	7,826		940	0	907	0	1,847	0	1,016	0	2,864	0	0	0	484	2,441	3,348	5,185
LOCHABER	90	18,916		2,533	0	0	0	2,533	2,457	3,220	0	8,210	0	0	68	851	9,130	9,130	9,786
MACDONNELL	150	24,410		19,730	0	1,498	1,226	22,453	538	0	0	22,991	10	0	10	1,043	22,557	24,055	1,853
MARCOLLAT	75	13,262		443	0	679	0	1,122	0	1,319	0	2,441	0	0	74	501	2,337	3,016	10,924
MAYURRA	110	19,430		1,452	0	0	0	1,452	2,620	4,484	0	8,556	0	0	39	1,126	9,721	9,721	9,708
MINECROW	75	18,387		2,750	0	1,988	0	4,738	230	4,033	0	9,001	0	0	232	977	8,222	10,210	10,165
MONBULLA	180	26,892		9,010	0	1,756	215	10,982	909	2,503	0	14,394	4,007	3,905	376	699	21,627	23,383	5,064
MOORAK	175	11,184		3,009	0	217	0	3,226	48	124	0	3,398	146	0	67	438	3,828	4,045	7,339
MOUNT BENSON	60	12,940		3,655	0	97	177	3,928	619	3,603	0	8,151	3,080	211	1	699	12,034	12,130	906
MOUNT MURRHEAD	110	25,066		1,464	0	502	0	1,966	3,091	10,373	0	15,430	2,217	1,700	206	1,324	20,374	20,876	4,692
MOYHALL	105	5,565		1,170	0	978	0	2,148	29	1,039	0	3,211	0	0	8	258	2,496	3,473	3,069
MURRABINNA	90	13,919		98	0	83	0	168	1,388	3,057	0	4,614	0	0	0	642	5,173	5,256	8,746
MYORA	160	20,655		4,004	0	0	208	4,212	75	749	0	5,037	12,456	3,397	77	412	21,378	21,378	-723
ORMEROD	120	8,901		528	0	77	0	604	0	0	0	604	0	0	0	337	865	941	8,037
PEACOCK	70	19,668		0	0	0	0	0	0	2,581	0	2,581	0	0	8	766	3,355	3,355	16,312
RIDDOCH	130	28,633		9,947	0	2,499	114	12,560	814	1,364	0	14,738	9,153	1,040	140	1,003	23,575	26,074	5,087
RIVOLI BAY	100	14,029		196	0	0	33	229	415	5,214	0	5,858	206	103	26	865	7,068	7,068	6,941
ROSS	110	20,538		2,663	0	2,327	0	4,990	1	5,515	0	10,506	0	0	0	764	8,943	11,269	11,898
SHORT	150	30,597		8,268	3,945	5,763	36	18,011	14	313	147	18,338	17,928	21,421	845	531	53,444	59,207	-22,846
SMITH	100	17,154		1,942	0	1,022	0	2,964	0	9,004	0	11,968	617	909	10	895	13,377	14,400	3,777
SPENCE	115	32,643		2,817	0	1,708	0	4,525	1,186	5,218	819	10,929	4,004	5,736	210	1,010	21,000	22,708	11,643
STEWARTS	145	18,330	12,126	17,476	0	24,589	0	42,065	382	0	0	42,447	0	0	102	370	18,330	42,919	0
STRUAN	95	6,147		5,248	0	417	144	5,809	0	0	0	5,809	0	0	0	301	5,693	6,109	454
SYMON	110	22,498		2,418	0	0	0	2,418	1,355	6,575	0	10,348	1,471	557	1,107	1,005	14,487	14,487	8,011
TOWNSEND	85	20,970		5,221	0	2,892	3	8,117	1,401	3,298	0	12,816	0	0	128	988	11,040	13,932	9,930
WATERHOUSE	80	16,102		6,142	0	415	506	7,063	1,713	2,198	0	10,974	341	10	12	1,054	11,975	12,391	4,127
WESTERN FLAT	20	1,548	1,154	1,331	0	0	0	1,331	12	0	0	1,343	0	0	5	201	1,548	1,548	0
WOOLUMBOOL	90	25,162		1,793	0	1,733	0	3,526	20	5,763	0	9,309	0	0	456	1,105	9,137	10,870	16,046
YOUNG	200	30,273		2,361	0	29	98	2,487	848	2,291	337	5,626	8,509	3,129	313	734	18,812	18,841	11,660
ZONE 2A	140	68,015		24,358	101	216	1,043	25,718	1,389	324	0	27,431	29,340	8,610	848	1,754	67,767	67,983	-1,782
ZONE 3A	120	54,158		29,687	172	1,848	2,221	33,928	936	0	0	34,862	14,229	12,528	1,261	1,775	62,823	64,670	-8,666
ZONE 5A	40	18,780		23,902	0	173	695	24,770	618	0	0	25,388	0	0	68	1,832	27,113	27,286	-8,332
TOTAL		1,186,097		393,899	5,486	80,969	13,062	493,398	81,238	130,183	3,268	674,813	197,266	110,868	11,484	47,388	963,868	1,044,828	

Key to Table 1:

Red shaded = very high risk management areas
Orange shaded = high risk management areas

Adopted recharge rate and Total Available Recharge values from Latcham *et al.* (2007)

Forestry recharge interception values are calculated based on 100% recharge interception. The actual volume allocated to existing commercial forests in high and very high risk management areas will be calculated based on 100% recharge interception less a volume equivalent to the reductions required to allocations for that management area, or the deemed rates of recharge interception (78% for hardwoods, 83% for softwoods), whichever is the greater.

F. Pumped extractions

Livestock water needs per ha of grassland

Pasture livestock carrying capacity expressed in dry sheep equivalents (DSE) = DSE/ha

DSE potential equation is based on mean annual rainfall.

DSE/ha = 0.75(annual mean rainfall - 250 mm)/25

Penola

DSE/ha = 0.75 (645 - 250)/25

12 DSE/ha X 7 L/day X 365 = **0.03 ML/ha of pasture**

Mount Gambier

DSE/ha = 0.75 (700 - 250)/25

13.5 DSE/ha X 7 L/day X 365 = **0.035 ML/ha of pasture**

Homestead water consumption estimate

Allow 0.4 ha irrigation at 8 ML/ha/yr	3.20
Average house hold domestic consumption	0.35
Total/homestead	**3.35 ML/yr**

G. Rainfall seasonality

Table G.1: Rainfall deviation about the mean annual and May–October rainfall at Penola (BOM 26025)

Deviations in rainfall at Penola (BOM 26025) for the May–October period and annual period for 1970–2105					
year	annual deficit (-) or surplus (+)	May–Oct deficit (-) or surplus (+)	year	annual deficit (-) or surplus (+)	May-Oct deficit (-) or surplus (+)
period mean	645.0 mm	472.4 mm			
1970	87.4	29.3	**1993**	-13.0	26.1
1971	198.0	92.5	**1994**	-127.2	-67.7
1972	-62.0	-61.9	**1995**	-45.6	-51.1
1973	109.2	44.2	**1996**	66.0	101.3
1974	134.6	83.3	**1997**	-116.5	-75.4
1975	93.0	128.9	**1998**	-118.7	-63.3
1976	-5.4	-25.1	**1999**	-50.1	-83.4
1977	-41.4	-81.7	**2000**	26.2	40.9
1978	-67.6	-29.7	**2001**	44.8	-8.7
1979	54.2	87.5	**2002**	-88.6	-26.3
1980	-51.2	-24.7	**2003**	85.4	77.1
1981	93.6	153.7	**2004**	41.0	26.3
1982	-230.4	-168.9	**2005**	-88.2	-40.2
1983	110.4	-0.3	**2006**	-209.9	-224.9
1984	103.2	72.9	**2007**	33.0	-23.3
1985	-23.4	-25.5	**2008**	-140.9	-144.5
1986	-4.2	-21.9	**2009**	12.1	25.2
1987	-99.8	-14.9	**2010**	88.0	13.5
1988	120.0	98.7	**2011**	117.1	-24.3
1989	46.6	113.3	**2012**	-88.2	-12.3
1990	-65.0	40.5	**2013**	115.7	173.9
1991	38.0	42.7	**2014**	-140.1	-116.1
1992	202.6	94.9	**2015**	-142.6	-148.4

Table G.2: Rainfall deviation about the mean annual and May–October rainfall at Mount Gambier (BOM 26021)

Deviations in rainfall at Mount Gambier (BOM 26021) for the May–October period and annual period for 1970–2105					
year	annual deficit (-) or surplus (+)	May–Oct deficit (-) or surplus (+)	year	annual deficit (-) or surplus (+)	May–Oct deficit (-) or surplus (+)
period mean	708.2 mm	484.5 mm			
1970	57.4	16.1	**1993**	-92.0	-53.3
1971	129.8	44.8	**1994**	-83.4	-60.9
1972	-176.3	-152.8	**1995**	-21.2	-73.9
1973	140.6	61.4	**1996**	133.0	159.1
1974	21.4	-5.3	**1997**	-105.4	-68.1
1975	115.6	122.1	**1998**	-76.6	-41.5
1976	-30.2	-55.9	**1999**	-69.8	-78.5
1977	-88.6	-109.1	**2000**	127.6	151.7
1978	-74.4	-46.5	**2001**	74.8	26.7
1979	11.6	65.3	**2002**	-24.8	36.1
1980	-121.8	-94.9	**2003**	29.2	14.1
1981	92.8	133.5	**2004**	161.2	105.7
1982	-240.2	-186.1	**2005**	-22.4	6.9
1983	106.6	-8.3	**2006**	-182.8	-176.5
1984	107.4	57.5	**2007**	41.2	3.5
1985	-46.6	-62.1	**2008**	-77.8	-108.5
1986	81.8	67.7	**2009**	85.4	97.1
1987	-145.2	-44.5	**2010**	109.6	36.7
1988	25.4	50.7	**2011**	139.2	-28.9
1989	-5.2	69.5	**2012**	-56.0	4.5
1990	-19.8	62.5	**2013**	126.8	178.9
1991	-55.8	-25.7	**2014**	-70.2	-46.3
1992	149.6	87.7	**2015**	-180.6	-134.3

H. Summary of calculated water-mass-balance values for all sites

Summary of calculated depth to SWL and observed depth to autumn SWL for all sites

	MON016		SHT012		SHT014		NAN009 no extract		NAN009 - extract		NAN012 no extract		NAN012 extract		CAR042		GAM079	
year	obs SWL	calc SWL	obs SWL	calc SWL	obs SWL	calc SWL	obs SWL	calc SWL	obs SWL	calc SWL	obs SWL	calc SWL	obs SWL	calc SWL	obs SWL	calc SWL	obs SWL	calc SWL
1977	-1.99	-1.86																
1978		-2.70																
1979		-2.31																
1980	-1.92	-1.42													-22.93	-24.40	-24.19	-27.34
1981	-2.03	-2.27			-1.79	-1.96										-23.31		-26.95
1982	-1.73	-0.92			-1.73	-1.20										-24.85		-27.50
1983	-1.35	-3.36			-1.51	-2.58										-24.06		-27.18
1984		-2.09	-1.66	-1.92	-1.46	-1.86										-23.80		-27.08
1985	-1.86	-1.53		-1.55	-1.43	-1.54	-3.23	-2.51	-3.23	-3.02	-11.03	-10.36	-11.03	-10.20	-22.77	-24.38	-24.73	-27.27
1986		-2.28	-1.72	-2.05	-1.73	-1.96	-3.27	-3.06	-3.27	-3.11	-10.94	-10.43	-10.94	-10.67		-23.73	-24.77	-27.06
1987	-1.96	-2.25	-1.93	-2.03	-1.75	-1.95	-3.14	-3.13	-3.14	-3.26	-10.77	-10.89	-10.77	-10.66		-24.27		-27.28
1988	-2.00	-2.20	-1.63	-1.99	-1.77	-1.92	-3.25	-3.24	-3.25	-3.00	-10.88	-10.71	-10.88	-10.73		-23.87		-27.05
1989	-1.71	-1.34	-1.54	-1.42	-1.58	-1.43	-3.41	-2.92	-3.41	-3.28	-10.76	-11.03	-10.76	-11.20		-23.81	-25.14	-27.04
1990	-1.59	-1.23	-1.61	-1.34	-1.44	-1.37	-2.85	-3.06	-2.85	-3.99	-10.68	-11.22	-10.68	-10.99		-23.83	-25.25	-27.09
1991	-1.68	-1.78	-1.80	-1.71	-1.69	-1.68	-3.00	-3.52	-3.00	-4.38	-10.81	-11.22	-10.81	-11.34	-23.27	-24.17	-25.31	-27.27
1992	-1.81	-1.76	-1.32	-1.70	-1.91	-1.67	-3.34	-3.67	-3.34	-4.72	-10.99	-11.59	-10.99	-11.70		-23.65		-27.08
1993	-1.30	-1.37	-1.66	-1.44	-1.12	-1.45	-3.10	-3.65	-3.10	-5.50	-11.05	-11.90	-11.05	-12.03	-23.29	-24.27		-27.31
1994	-1.99	-1.89	-2.03	-1.79	-1.73	-1.74	-3.69	-3.97	-3.69	-5.93	-11.57	-11.88	-11.57	-12.82	-23.46	-24.30		-27.37
1995	-2.26	-2.60	-2.14	-2.26	-2.20	-2.14	-4.24	-4.32	-4.24	-6.22	-11.96	-11.73	-11.96	-13.67	-23.72	-24.38	-25.86	-27.39
1996	-2.37	-2.47	-1.85	-2.18	-2.23	-2.07	-4.65	-4.44	-4.65	-6.30	-12.27	-11.98	-12.27	-14.25	-23.90	-23.32	-25.99	-27.08
1997	-2.06	-1.32	-2.03	-1.40	-1.99	-1.42	-4.35	-4.25	-4.35	-6.70	-12.45	-11.95	-12.45	-14.18	-24.05	-24.33	-26.08	-27.23
1998	-2.17	-2.65	-2.34	-2.28	-2.20	-2.18	-5.35	-4.66	-5.35	-7.17	-12.68	-11.95	-12.68	-14.51	-24.20	-24.27	-26.28	-27.19
1999	-2.50	-2.57	-2.43	-2.27	-2.44	-2.12	-5.85	-4.64	-5.85	-7.50	-12.93	-11.86	-12.93	-15.01	-24.45	-24.44	-26.52	-27.21
2000	-2.52	-2.73	-1.41	-2.43	-2.58	-2.20	-6.22	-4.61	-6.22	-7.32	-13.10	-11.83	-13.10	-15.11	-24.60	-23.52	-26.73	-26.61
2001	-1.85	-1.82	-1.90	-2.04	-1.86	-1.61	-6.32	-4.55	-6.32	-7.70	-13.13	-11.85	-13.13	-15.10	-24.61	-24.08	-26.78	-26.72
2002	-2.15	-2.50	-2.62	-2.37	-1.88	-1.96	-6.48	-4.62	-6.48	-7.83	-13.26	-11.93	-13.26	-15.32	-24.71	-24.02	-26.81	-26.78
2003	-2.78	-3.14	-3.07	-3.06	-2.25	-2.24	-6.68	-4.51	-6.68	-7.40	-13.37	-11.92	-13.37	-15.10	-24.81	-24.19	-26.88	-26.95
2004	-2.98	-3.68	-3.40	-3.40	-2.22	-2.32	-6.87	-4.52	-6.87	-7.66	-13.45	-11.99	-13.45	-14.92	-24.82	-23.99	-26.92	-26.73
2005	-2.53	-4.92	-4.08	-4.65	-2.19	-2.79	-6.93	-4.65	-6.93	-7.88	-13.43	-12.22	-13.43	-15.36	-24.93	-24.36	-27.01	-26.92
2006	-3.82	-5.99	-5.13	-5.45	-2.84	-3.30	-7.04	-4.61	-7.04	-7.90	-13.60	-11.87	-13.60	-15.46	-25.16	-25.02		-27.40
2007	-4.59	-7.37	-5.52	-6.44	-3.54	-4.20	-7.28	-4.86	-7.28	-7.91	-14.36	-12.05	-14.36	-15.72	-25.34	-24.40	-27.37	-26.92
2008	-4.92	-7.22	-5.83	-6.66	-3.81	-3.84	-7.36	-4.67	-7.36	-7.97	-13.98	-11.96	-13.98	-15.65	-25.57	-24.75	-27.55	-27.37
2009	-5.26	-7.79	-5.82	-7.02	-4.04	-4.41	-7.60	-4.65	-7.60	-7.23	-14.03	-11.93	-14.03	-15.39	-25.63	-24.15	-27.72	-26.95
2010	-5.41	-7.64	-5.35	-7.04	-4.12	-4.25	-7.69	-4.56	-7.69	-7.34	-13.92	-11.96	-13.92	-15.07	-25.48	-24.60	-27.84	-27.08
2011	-5.31	-7.96	-5.27	-7.38	-3.96	-4.56	-7.56	-4.64	-7.56	-7.38	-13.92	-12.02	-13.92	-15.29	-25.31	-24.90	-27.77	-27.26
2012	-5.50	-8.26	-5.48	-7.50	-4.18	-4.96	-7.64	-4.58	-7.64	-7.23	-13.92	-11.62	-13.92	-15.18	-25.35	-25.00	-27.81	-27.42
2013	-5.67	-8.45	-5.09	-7.74	-4.41	-4.92	-7.83	-4.64	-7.83	-7.20	-13.99	-11.99	-13.99	-15.08	-25.24	-24.88	-27.83	-27.05
2014	-5.57	-8.18	-5.38	-7.50	-4.32	-4.73	-7.81	-4.47	-7.81	-7.34	-13.97	-12.14	-13.97	-14.75	-25.15	-25.32	-27.81	-27.51

The column headed 'obs SWL' is the actual annual observed standing water level (below ground level) for each site. The obs SWL relates to the autumn observation. This provides for an observed net change in groundwater storage for successive years.

The column headed 'calc SWL' is the calculated (or predicted) standing water level. This is derived from calculating the net annual change in the water-mass-balance calculated for the 5000 ha study site. This net change in the water-mass-balance is expressed as a change in calculated (or predicted) depth to the SWL below ground level.

In order to establish a relationship between cause and effect, the annual calculations for a specific calendar year are compared to the autumn SWL in the following year.

I. Location of confined obswell GAM075

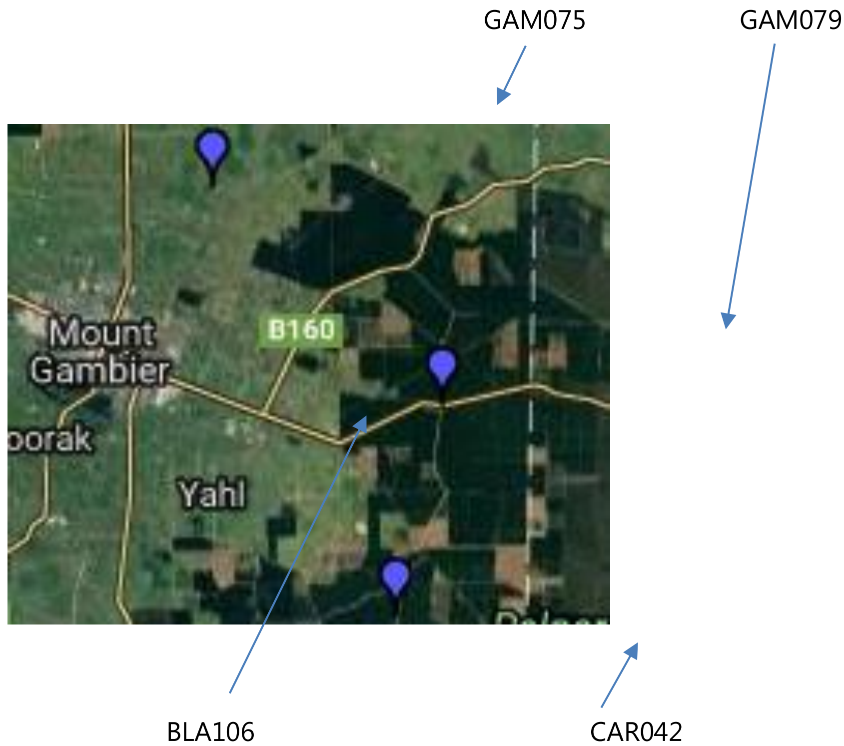

Figure I: Spatial relationship between GAM075 (confined) BLA106 (Blue Lake) with GAM 079 and CAR042 study sites

Units of measurement

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microliter	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	yr	365 or 366 days	time interval

Glossary

Accounted, accounting or accountable — means the process of recording the impact of the plantation forest in the water budget for a management area, or catchment. It does not intend to imply any assignment of responsibility

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004*, which supercedes the *Water Resources (SA) Act 1997*

Adaptive management — A management approach often used in natural resource management where there is little information and/or a lot of complexity, and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Ambient — The background level of an environmental parameter (e.g. a measure of water quality such as salinity)

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resources available for development from the well

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

Artesian — An aquifer in which the water surface is bounded by an impervious rock formation; the water surface is at greater than atmospheric pressure, and hence rises in any well which penetrates the overlying confining aquifer

Artificial recharge — The process of artificially diverting water from the surface to an aquifer; artificial recharge can reduce evaporation losses and increase aquifer yield; see also 'natural recharge', 'aquifer'

Bore — See 'well'

Buffer zone — A neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (e.g. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses)

Catchment — that area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

Commercial forest — the term used in development plans (under the Development Act 1993) for commercial or industrial scale plantation forest land-use. Some members of the plantation forest industry prefer the term 'industrial scale'. Also, refer Plantation forest

Compartment — A forest management unit usually bounded by roads or tracks which have a unique identifier and are typically of the same age and species. The area can vary from several to a few hundred hectares.

Coppicing — The practice of allowing trees to regrow via epicormic buds in the stumps. Eucalyptus species have the ability to produce multiple stems from a cut stump which may be managed to produce another tree crop.

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge; continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

CSIRO — Commonwealth Scientific and Industrial Research Organisation

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

DFW — former Department for Water (Government of South Australia)

Domestic purpose — The taking of water for ordinary household purposes; includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares

Dryland salinity — The process whereby salts stored below the surface of the ground are brought close to the surface by the rising watertable. The accumulation of salt degrades the upper soil profile, with impacts on agriculture, infrastructure and the environment.

DWLBC — former Department of Water, Land and Biodiversity Conservation (Government of South Australia)

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Evapotranspiration — the total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

Filtration — Numerous methods of filtering a water sample or supply to remove suspended sediment and the larger animal and plant life

Forest Estate — A general term describing land used for forestry. It may relate to the aggregation of forests at different scales including at a state or regional level or a forest company's portfolio.

Fully-penetrating well — In theory this is a wellhole that is screened throughout the full thickness of the target aquifer; in practice, any screen that is open to at least the mid 80% of a confined aquifer is regarded as fully-penetrating

Geological features — Include geological monuments, landscape amenity and the substrate of land systems and ecosystems

Geomorphic — Related to the physical properties of the rock, soil and water in and around a stream

Geomorphology — The scientific study of the landforms on the Earth's surface and of the processes that have fashioned them

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Groundwater management area — a zone described in a water allocation plan for a prescribed wells area in the South East. Many are the cadastral Hundred

Hardwood plantation forest — for the purpose of South East management, this term refers to Tasmanian blue gum (Eucalyptus globulus) plantations grown expressly for wood chip production. South East stakeholders consider this forest type has a planting to harvest period of ten years and second rotation plantations are established with new seedling stock. It is noted that the life cycle can be up to 12 years, but ten years is a weighted mean value recommended by the plantation industry in 2006

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Hydrography — The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

Impact — A change in the chemical, physical, or biological quality or condition of a water body caused by external sources

Implementation monitoring — Documents whether or not management practices were applied as designed; project and contract administration is a part of implementation monitoring

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment

Injection well — An artificial recharge well through which water is pumped or gravity-fed into the ground

Intensive farming — A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or mechanical means

Interception — term used in the Intergovernmental Agreement on a National Water Initiative (NWI), paragraphs 55-57. This is interpreted as meaning any interruption to the natural water cycle, resulting in a diversion of natural water movement, or a reduction in the consumptive pool by a particular activity. In this document the use of the term interception refers to the impact of plantation forest in:

- reducing surface water catchment yield
- reducing groundwater recharge, and
- extraction of groundwater from shallow watertables

Irrigation — Watering land by any means for the purpose of growing plants

Irrigation season — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May

Lake — A natural lake, pond, lagoon, wetland or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

Land capability — The ability of the land to accept a type and intensity of use without sustaining long-term damage

Licence — A licence to take water in accordance with the Act; see also 'water licence'

Licensee — A person who holds a water licence

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change

MODFLOW — A three-dimensional, finite difference code developed by the USGS to simulate groundwater flow

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

Natural resources — Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

Non-point-source pollution — A contributory factor to water pollution that cannot be traced to a specific location, for example, pollution that results from water run-off from urban areas, construction sites, agricultural and silvicultural operations, etc

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Occupier of land — A person who has, or is entitled to, possession or control of the land

Owner of land — In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Sustainability, Environment and Conservation.

Pasture — Grassland used for the production of grazing animals such as sheep and cattle

Penetrating well — See 'fully-penetrating well'

Percentile — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Perennial streams — Permanently inundated surface stream courses. Surface water flows throughout the year except in years of infrequent drought.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m^2/d

Plantation forest area — for management purposes, the area of plantation forest considered to be relevant for water resource management is the area of the plantation compartment. It is based on the 'stump to stump' measurement of the outer boundary. It may include minor access tracks, but excludes firebreaks and easements for electricity transmission lines and protective buffers around native vegetation and wetlands. It is the area that a forest owner/manager reports for fire information surveys and considers to be the productive forest area

Piezometer — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc.

Pluviometer — An automated rain gauge consisting of an instrument to measure the quantity of precipitation over a set period of time

Pollution, diffuse source — Pollution from sources such as an eroding paddock, urban or suburban lands and forests; spread out, and often not easily identified or managed

Pollution, point source — Pollution discharged through a pipe or some other discrete source from municipal water treatment plants, factories, confined animal feedlots, or combined sewers

Population — (1) For the purposes of natural resources planning, the set of individuals of the same species that occurs within the natural resource of interest. (2) An aggregate of interbreeding individuals of a biological species within a specified location

Porosity — The ratio of an unconsolidated material that contains pores or voids, commonly expressed as a volume (L^3 / L^3)

Potable water — Water suitable for human consumption such as drinking or cooking water

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface.

Prescribed area, surface water — Part of the state declared to be a surface water prescribed area under the Act

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the Act

Production well — The pumped well in an aquifer test, as opposed to observation wells; a wide-hole well, fully developed and screened for water supply, drilled on the basis of previous exploration wells

Property right — A right of ownership or some other right to property, whether real property or personal property

Proponent — The person or persons (who may be a body corporate) seeking approval to take water from prescribed water

PWA — Prescribed Wells Area

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. See also artificial recharge, natural recharge

Run-off — Something which runs off, as rain which flows off from the land in streams.

SA Geodata — A collection of linked databases storing geological and hydrogeological data, which the public can access through the offices of PIRSA. Custodianship of data related to minerals and petroleum, and groundwater, is vested in PIRSA and DWLBC, respectively. DWLBC should be contacted for database extracts related to groundwater

Salinity — The concentration of dissolved salts in water or soil, expressed in terms of concentration (mg/L) or electrical conductivity (EC)

SA Water — South Australian Water Corporation (Government of South Australia)

Softwood plantation forest — for the purpose of South East water resource management, this description refers to pine plantations (mostly Pinus radiata) grown mainly for sawlog production. South East stakeholders consider this forest type has a planting to harvest period of 35 years, with four plantation thinning operations prior to clear felling. The life cycle is generally between 25 and 50 years, but 35 years is a weighted mean value recommended by the plantation industry in 2006

Specific storage (S_s) — Specific storativity; the amount of stored water realised from a unit volume of aquifer per unit decline in head; measured in m^{-1}

Specific yield (S_y) — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless

State Water Plan — Policy document prepared by the Minister that sets the strategic direction for water resource management in the State and policies for achieving the objects of the *Natural Resources Management (SA) Act 2004*

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

(S) — Storativity; storage coefficient; the volume of groundwater released or taken into storage per unit plan area of aquifer per unit change of head; it is dimensionless

Stormwater — Run-off in an urban area

Sub-catchment — The area of land determined by topographical features within which rainfall will contribute to run-off at a particular point

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago)

Threatened waters — Waters that fully support their designated uses, but may not support uses in the future unless pollution control action is taken because of anticipated sources or adverse pollution trends

Timelag — broadly refers to the an interval of time between two related phenomena (such as cause and its effect); more specifically for the Mallee it refers to the period of time between water passing the root zone and recharging the regional watertable

To take water — From a water resource includes (a) to take water by pumping or siphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir

Transfer — A transfer of a licence (including its water allocation) to another person, or the whole or part of the water allocation of a licence to another licensee or the Minister under Part 5, Division 3, s. 38 of the Act, the transfer may be absolute or for a limited period

Transmissivity (T) — A parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m^2/d

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Volumetric allocation — An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation)

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

Water allocation, area based — An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water-use year

WAP — Water Allocation Plan; a plan prepared by a water resources planning committee and adopted by the Minister in accordance with the Act

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water licence — A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area; this grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water; a water licence confers a property right on the holder of the licence and this right is separate from land title

Water plans — The State Water Plan, water allocation plans and local water management plans prepared under Part 7 of the Act

Water resource monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water resources, including (1) surface waters, groundwaters, estuaries, and near-coastal waters; and (2) associated aquatic communities and physical habitats, which include wetlands

Water resource quality — (1) The condition of water or some water-related resource as measured by biological surveys, habitat-quality assessments, chemical-specific analyses of pollutants in water bodies, and toxicity tests. (2) The condition of water or some water-related resource as measured by habitat quality, energy dynamics, chemical quality, hydrological regime, and biotic factors

Water service provider — A person or corporate body that supplies water for domestic, industrial or irrigation purposes or manages wastewater

Watershed — The land area that drains into a stream, river, lake, estuary, or coastal zone

Water-use year — The period between 1 July in any given calendar year and 30 June the following calendar year; also called a licensing year

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

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