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Department for Water

ASSUMPTIONS AND PARAMETERS APPLIED IN THE NUMERIC MODELLING OF PLANTATION FOREST IMPACTS ON THE UNCONFINED GROUNDWATER RESOURCE IN THE WATTLE RANGE REGION OF THE SOUTH EAST OF SOUTH AUSTRALIA

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PREFACE

This paper has been prepared by the Science Unit of the Department for Water to explain the assumptions and parameters that have been applied in the numeric groundwater Wattle Range 2010 model (WR2010).

The WR2010 model was initially developed by the Department of Water, Land and Biodiversity Conservation and adapted to a specific task in 2010 by Aquaterra. The task was to model the impacts of the current plantation forest estate of about 42 000 ha on the groundwater resources in the area west of Penola. The outputs of the WR2010 model task are reported in the Aquaterra report, ***Modelling Forestry effects on Groundwater Resources in the South East of SA*** ref A115\R001c.

Subsequent to this modelling and under direction from The Lower Limestone Coast Task Force, further scenarios were modelled by Aquaterra. The assumptions whilst stated, are not explained, in the Aquaterra report ***Modelled Hydrological Impacts by Plantation Forest on Groundwater Resources in the Lower South East: A Scenario Report*** ref A115B/R002b. The objective of the second project was to predict the impacts of different land management approaches and changed model parameters. A response to a change of model parameters can be considered a sensitivity test for some assumed parameters. Changing land management assumptions in the model scenarios can indicate management options that may be available to achieve a desired hydrogeological outcome.

This paper is presented in two parts; the first part discusses the assumptions applied in the original work commissioned by the Department of Water, Land and Biodiversity Conservation and reported by Aquaterra in the report A115\R001c. The second part discusses the assumptions and parameters applied to 15 management scenarios and 2 sensitivity tests commissioned by the South East Science Review team, on behalf of The Lower Limestone Coast Task Force, and reported by Aquaterra in the report A115B/R002b.

The study area for all the modelling includes the groundwater management areas of Coles, Joyce, Killanoola, Monbulla, Short and Spence.

Science Unit
Department for Water
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SUMMARY

Numeric groundwater models are predictive tools that estimate groundwater responses under various management scenarios. Before a predictive model for groundwater level changes can be run for various scenarios, its predictability must be validated through a calibration process. This is a test of model predictions against an earlier time period for which actual observed groundwater data is available. The closeness of alignment provides a measure of confidence that can be placed in the model predictions. The calibration 'fit' of the WR2010 model, used to model the impacts of about 42 000 ha of plantation forest west of Penola, is considered to be highly satisfactory.

The current annual rainfall trend in the South East is less than the long term mean rainfall and it is accepted that this will have consequences for groundwater recharge. For management and modelling purposes, no recharge is considered to occur on land designated as native vegetation or for areas considered to be lakes. In running the various forest management scenarios with the WR2010 model, the annual extractions values for irrigation are held constant at the 2009 metered values and stock and domestic water extractions are also considered a constant. A comparison of the Drain M floor level in Coles and the depth to watertable in the same vicinity indicates no drain impacts are required in the model confirming the function of the drainage system in the area is to provide an exit of surplus surface water generated in periods of high rainfall.

The plantation forest industry has proposed two basic forest management approaches for the blue gum forest estate; one being coppiced management for a second harvest and the alternative of a full replant after each harvest. For Scenario 1, the first harvest is ten years after planting followed by coppiced regeneration, resulting in a second harvest 18 years after the initial first planting. Scenario 2 is an 11-year forest cycle. To enable the maximum hydrological impact to be observed in the model output, forest groundwater extraction is not depth constrained to 6 metres below ground level but is unrestricted.

From the first two scenarios, it can be concluded that the:

- Extraction characteristic of the plantation forest is a very significant factor with clear felling allowing some immediate recovery in the watertable however, insufficient to allow recovery to a pre-forest condition
- Groundwater drawdown impact extends well beyond the forest footprint
- Greatest drawdown impact is observed just prior to plantation harvest
- Extent of the drawdown zone for Scenario 1 is only marginally wider than for Scenario 2.

At the request of *The Lower Limestone Coast Task Force,* other scenarios were tested and these can be categorised into:

- Changes to hydrological parameters
- Changes to plantation forest management
- Sensitivity testing of some parameters by increasing and decreasing some input values and by providing a depth constraint for groundwater extraction by plantation forests.

A new base case of forest management was established as Scenario 3; a 15-year plant and harvest rotation. With much of the current estate now approaching 12 years, with very little harvesting evident, a 15-year plantation cycle is more likely. For the 'mature 15-year industry' management cycle of Scenario 3, the watertable stabilises and remains relatively constant at 4–5 metres below the pre forest levels. A 'mature' industry is one where harvest and planting of the forest estate is spread equally; similar areas harvested and planted each year. For the base case, the transition from an estate with an age bias to one managed as a 'mature' industry occurs in 2011 in the modelling.

Scenario 4 applies a higher recharge rate in 2011 and onwards, and the recharge rate applied in Scenario 5 is a continuation of recharge rates that have been observed since 1995. In general, the conclusion that can be drawn from Scenarios 4 and 5, while a change in recharge does have an impact on drawdown, the depth and extent of the drawdown impact is relatively minor.

Scenarios 6 and 7 provide a sensitivity test to the plantation forest extraction parameter from shallow watertables; an increase and decrease of 20 per cent in plantation groundwater extraction is modelled. Compared to the base case of Scenario 3, the increased extraction rate deepens the cone of depression by about 1 metre to 6 metres and the 1 metre drawdown level extends outwards by about 1 kilometre. With a decrease in plantation forest extraction, the 1 metre drawdown level boundary moves in about 1 kilometre, and the bottom of the cone of depression recovers or rises by about 1 metre.

Scenarios 8 and 9 test the relative impact of irrigation extractions compared to the total hydrological impact of plantation forest. The conclusion is that current irrigation activity has a negligible impact and the watertable drawdown can mostly be attributed to the impacts of plantation forest.

Scenarios 10 and 11 test the aquifer response to an intensification of plantation forest activity. The scenario is a forest plantation area increased of 50 per cent. The watertable declines a further 1 metre, but the base of the cone of depression widens by 5–6 kilometres while the outer 1 metre drawdown contour moves outward by about 1 kilometre.

Scenarios 12 and 13 are designed to test the aquifer response to a reduction in plantation forest area. Scenario 12 tests the impact of a uniform forest area reduction of 40 per cent (about 16 400 ha) across the current estate, while Scenario 13 tests a specific located area reduction of 13 050 ha of forest. In both scenarios, the land reverts back to dryland farming. Scenario 12 indicates some recovery in the watertable level back to within about 2 metres of the pre forest level. In Scenario 13 the impacted area moves relative to the changed land use location.

Scenario 14 tests a proposal to relocate the removed forest from Scenario 13 into the management area of Fox. Some recovery in the watertable level with stabilisation by about 2016 is indicated however, the centre of the cone of depression migrates about 11 kilometres to the west, shadowing the forest land use.

Scenario 15 tests a proposal to inject 50 GL/year of water into the unconfined aquifer in the management areas of Coles and Short. The watertable partially recovers and stabilises by about 2018 to within about 3 metres of the pre forest levels.

Another model was developed by Aquaterra to test the appropriateness of the 6 metre depth to watertable as a limit for plantation forest extraction of groundwater. The current administrative approach assumes that groundwater extraction by plantation forests ceases if the watertable falls below 6 metres from ground level. A conclusion that can be drawn from this particular model exercise is that groundwater extraction by plantation forests continues from watertables deeper than 6 metres. While more definitive conclusions cannot be drawn, it should be noted that extractions have been observed from watertables as deep as 8–9 metres.

As a result of the testing carried out by the WR2010 model, the impacts of plantation forest on groundwater resources can be summarised as:

- The extraction characteristic of plantation forest has a significant impact on the groundwater resource where there is a shallow table
- There is a very poor model fit in attempting to constrain extraction to 6 metres indicating that plantation forests continue to extract from watertables deeper than 6 metres
- The impact of plantation forests on the water resource can be mitigated to some extent by the removal of any forest age bias from the estate
- Removal of plantation forest can provide a rapid recovery of the watertable

- Relocation of some plantation forest can cause the impacted area to move, shadowing the forest land use.

INTRODUCTION

Numeric groundwater models are predictive tools that estimate groundwater responses under various management scenarios. This requires a number of pre determined input values to be applied; many are held constant while others are varied to reflect the management scenarios being tested. Many inputs are derived from actual observations, such as spatial information and volumes of pumped extractions. Other inputs are based on assumptions such as groundwater recharge and parameters from hydrogeological investigations such as aquifer depth, aquifer storage coefficients and aquifer transmissivity.

For a model to be a useful tool in predicting a groundwater outcome input assumptions must reflect reality as closely as possible, otherwise it is unlikely that calibration (or validation) of the model can occur. Calibration is the essential first task of assessing the value of the model predictions against what has been observed. If the calibration reflects a close relationship between the model prediction and actual observations, a reasonable level of confidence can be placed in the output of the management scenarios being tested.

The following information is intended to explain some of the key management assumptions and inputs applied in the Wattle Range 2010 model (WR2010) for the groundwater management areas of Coles, Joyce, Killanoola, Monbulla, Short, and Spence (the study area). Some comments are made on the model outputs to assist in explaining some assumptions and functions, while others are made on the conclusions that can be drawn from the scenarios tested.

The management scenarios and assumptions chosen for the initial modelling are explained in Part 1 of this Technical Note. The related Aquaterra report is ***Modelling Forestry effects on Groundwater Resources in the South East of SA*** ref A115\R001c.

Scenarios developed to build a risk profile related to plantation forest impacts on groundwater resources are presented in Part 2 of this Technical Note. The Part 2 scenarios were developed under direction from *The Lower Limestone Coast Task Force* and tested by Aquaterra. The related Aquaterra report is ***Modelled Hydrological Impacts by Plantation Forest on Groundwater Resources in the Lower South East; A Scenario Report*** ref A115B/R002b.

Both the above referred to Aquaterra reports specify the assumptions and parameters applied but do not provide discussion on the choice of the assumptions and parameters. This paper is intended to provide information on the determination of assumptions and parameters applied in the model for the scenarios being tested.

The following information should not be used for other purposes as the circumstances may not necessarily apply to other regions, land management or numeric models.

PART 1

MODEL CALIBRATION

Before a predictive model for groundwater level changes can be run for various scenarios, the accuracy of its predictability must be tested through a validation or calibration process. The process tests the model predictions against an earlier time period for which actual observed groundwater data is available. The closeness of alignment between the model output and the actual historic observed data provides a measure of confidence that can be placed on the predictions to be modelled.

It can be seen from the hydrographs in the Aquaterra report, *Modelling Forestry Effects on Groundwater Resources in the Southeast of SA* (A115\R001c), Figures A.2 and A.7, that there is generally good alignment between the model predictions and the actual observed data (from 1970s to 2009) in the study area. The 'fit' exhibited by the hydrographs provides an indication of model suitability. The model output in the calibration period for WR2010 is considered to be highly satisfactory.

The calibration period can be viewed in two parts; one being the period from when watertable level records become first available in the early 1970s to about 1999 and the other from about 2001 to 2009. The period 1999–2000 can be regarded as the change point for pastured land being converted to forest land use change due to the large scale blue gum plantation development in the South East region. The hydrogeological impacts of that change in land use, subject to seasonal conditions, would expect to become visible onwards from about 2001.

During the pre forest period, within the limits of seasonal variability, the hydrological responses in the study area were relatively consistent with the catchment land use being predominately pasture with limited irrigation.[1] The impact of native vegetation on hydrology is also considered a constant as all major clearance of native vegetation had ceased by the early 1960s. By the mid 1970s, native vegetation clearance was a statutory offence.

GROUNDWATER RECHARGE

Recharge is a major input component in the development of a groundwater account. In the case of the shallow unconfined aquifers of the lower South East, the annual vertical recharge from rainfall is the main recharge input. While there is lateral groundwater inflow, this is generally balanced by a corresponding lateral outflow to maintain constant water through flow as near as possible to the natural flow direction and velocity.

For the purpose of establishing a recharge regime for the WR 2010 model, the recharge rates estimated in *Review of groundwater resource condition and management principles for the Tertiary Limestone Aquifer in the South East of South Australia*; DWLBC 2006/02[2] are applied as an annual constant for the model Scenarios 1 and 2. Other possible recharge parameters are discussed in Part 2 of this paper.

The following is a brief summary of information in the report DWLBC 2006/02 related to the estimation of groundwater recharge rates for the study area. The report DWLBC 2006/02 advises that the techniques available to estimate direct recharge to watertable (unconfined) aquifers in 'semi arid' Australia include:

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[1] The groundwater resource was prescribed in 1997 in this area and other than for irrigation activity in the Coonawarra area, irrigation was not a major activity. Whilst there has been water allocations made in the area of interest, the actual uptake of sustained irrigation activity has been limited. There are significant holding water licences and a number of taking water licences were transferred to forest owners or became inactive as a consequence of land acquisitions for forest use since 1999. Metered irrigation water use data is only generally available since 2008.

[2] DWLBC 2006/02; Keith Brown, Glenn Harrington and Jeff Lawson. The recharge rates developed in this investigation are re-stated in DWLBC 2007/11.

- Residual water balance
- Watertable fluctuation
- Lysimeters
- Environmental tracers (such as chloride mass balance).

With the exception of lysimeters, all other methods infer recharge or potential recharge relating it to rainfall.

Lysimeters provide the only direct measurement, but are limited because of potential error in up-scaling from a point observation. Furthermore, lysimeters require 2–3 years of settling after ground disturbance before meaningful data is available.

Many groundwater recharge studies have demonstrated a strong linear relationship between rainfall and the change in groundwater levels. This relationship allows for the estimation of recharge rates from the seasonal fluctuations in watertable levels. This method is known as the ***watertable fluctuation*** method. The measured seasonal rise in watertable elevation is multiplied by the specific yield of the aquifer to obtain an annual recharge rate. It is an indirect approach for determining recharge, but is related to a physical measurement of the subject aquifer.

The watertable fluctuation method is considered particularly effective in areas of relatively high winter rainfall and shallow watertables (generally less than 10 m).

A review of recharge techniques across Australia has concluded that the watertable fluctuation method is possibly the most robust approach, particularly where long term observed data exits (Petheram et al, 2000).[3] The watertable fluctuation method is considered the most suitable approach for estimating recharge in the South East of South Australia, given the current observation well network and database.

The advantages in using the watertable fluctuation method include:

- A hydrograph is a summation of process occurring in the saturated zone at a paddock to catchment scale. The inferred recharge accounts for both differential and preferential flow. The large scale of the method minimises spatial variability. Other assessment approaches rely on point scale measurement.
- The length of a hydrograph record is generally longer than other studies. The hydrograph removes error associated with limited temporal information
- Watertable fluctuation method is based on physical aquifer response; most other approaches rely on numerical, analytical or stochastic modelling.

Limitations of the watertable fluctuation method include:

- Change in watertable level can be influenced by anthropogenic extractions
- Monitoring sequence can miss peaks and troughs in the watertable; however, a continuous 30–40 year record with seasonal readings tends to eliminate such weaknesses. Transition to data loggers rather than seasonal observations allows for further refinement
- The approach requires an accurate assessment of specific yield at the location of the observation well.

In applying the watertable fluctuation method to the South East, the following factors are considered:

- A specific yield of 0.1 is used for all management areas. This value is considered representative of the local limestone aquifers

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[3] Petheram, C., Zhang, L., Walker, G. and Grayson, R. (2000). ***Towards a framework for predicting impacts of land-use on review: a review of recharge studies in Australia***. CSIRO Land and Water Technical Report 28/00 September 2000

- Observation wells with consistent seasonal water fluctuations across a number of years are used for the watertable fluctuation approach to establishing recharge rates
- Wells with significant water level variability, caused by extractions by pumping, are excluded
- The number of wells used in each management area varied considerably; from one to eleven. This is a reflection of geology, land use, irrigation activity and the quality of data available.[4]

Where a watertable is generally deeper than 10 metres below ground level, the seasonal watertable fluctuations are muted, making the watertable fluctuation approach conservative. In areas such as Tatiara, Naracoorte and Padthaway Ranges, alternative approaches are applied. In the area around and south of Mount Gambier, mean annual rates were determined through area weighting rates determined by Allison and Hughes (1978).[5]

To summarise:

- The watertable fluctuation method is considered the most reliable approach to estimating recharge rates for unconfined limestone aquifers, where the watertable is generally at 10 metres, or less, below ground level
- The watertable fluctuation method of assessing groundwater recharge rates is based on actual observed responses to watertable fluctuations
- The continuous period of observations, 30–40 years in the monitoring well network, provides mean recharge values for the observed period. If the observed record is only ten years, the interpreted value only pertains to the observed period
- Location of dedicated wells for the assessment task is important to minimise muted aquifer response to rainfall and extraneous responses caused by pumped extractions.

ESTIMATED RECHARGE RATES

A brief synopsis of data from observation wells that have contributed to the estimation of the recharge rate for the groundwater management area of Short reported in DWLBC 2006/02 is presented below in Table 1. This data is provided as an application example. A summary of all wells contributing to the recharge rates for the other groundwater management areas in the WR2010 study area is presented in the Appendix Table A.

Table 1. Observation wells in Short GMA that contribute to estimation of recharge

SHORT management area observation wells	estimated watertable fluctuation (WTF) metres	observed record 1995–2004 years
SHT011	2.0	10
SHT012	1.3	10
SHT014	1.2	10

- estimated mean WTF in Short groundwater management area: 1.5 m

- estimated annual vertical recharge in Short (using Specific yield (Sy) of 0.10): 150 mm

4 If a management area is highly homogeneous, one representative well can provide adequate information for a management area of about 20 000 ha. If there is a high level of variability with respect to soils, topography and land use, depending upon the scale of variability, more wells are likely be required to provide a representative sample.

[5] Allison, GB and Hughes, MW (1978). ***The use of environmental chloride and tritium to estimate total recharge to an unconfined aquifer***. Australian Journal of Soil Resources , **16**: 181-195

For the purpose of assessing recharge for a management period (of about 5 years) for a water allocation plan, the previous 10 years observations are considered to provide the best indication of recharge expectation. However, any 10 year sequence of climatic data can include values that can bias the mean values for the 10 year period being observed.

The 10 year period ending in 2004 could be considered the end of near to mean annual rainfall. The number of dry years after 2004 have biased the 10-year periods in which they are included, as shown by Table 2. While these recent periods are observed as drier than the long term mean, no conclusion can be drawn about future 10 year sequences.

The annual rainfall for Naracoorte for 2005 and 2006 was 476.4 mm and 266.6 mm respectively, compared to a long term mean of 565 mm. For Kalangadoo, the rainfall for 2005 and 2006 was 561.8 mm and 475.0 mm respectively, compared to a long term mean of 745 mm.

Table 2. Naracoorte and Kalangadoo mean annual rainfall deviations for recent 10-year periods, compared to the long term mean annual rainfall

		1995–2004		1996–2005		1997–2006		1998–2007		1999–2008		2000–2009	
	long term mean mm	mean for the period mm	deviation from the long term mean	mean for the period mm	deviation from the long term mean	mean for the period mm	deviation from the long term mean	mean for the period mm	deviation from the long term mean	mean for the period mm	deviation from the long term mean	mean for the period mm	deviation from the long term mean
Naracoorte	565	534.0	-5%	522.6	-7.5%	493.6	-12.6%	491.6	-13.0%	479.8	-15.1%	482.3	-14.6%
Kalangadoo	745	682.8	-8%	676.9	-9.1%	642.2	-13.8%	643.0	-13.7%	639.6	-14%	644.2	-13.5%

HYDROLOGICAL PARAMETERS APPLIED IN THE WR2010 MODEL

Total recharge

The information in Table 3 summarises the unconfined aquifer recharge rates and effective area of recharge applicable to the WR2010 model. For management and modelling purposes, no recharge is considered to occur on land considered to be covered with native vegetation or considered to be lakes.

Table 3. Recharge areas and recharge rates

Groundwater management area (GMA)	area of GMA	recharge area	adopted recharge rate *
	ha	ha	mm/y
Bool	7355	4675	105
Coles	26873	23359	120
Fox	25997	22634	100
Glenroy	8238	8174	100
Joyce	38868	35351	120
Kennion	25788	23399	120
Killanoola	19271	17119	145
Monbulla	19284	16476	180
Spence	37695	31539	115
Short	25986	22665	150

* from DWLBC 2006/02 and DWBC 2007/11

Aquifer specific yield

The unconfined aquifer specific yield (designated by the term Sy) in the lower South East is assumed to be 0.1. This is based on a history of sampling and application of the value in a number of technical assessments; it is also the same value applied to estimating recharge with the watertable fluctuation method. While a single value is adopted, in reality there are localised variations in aquifer specific yield, but experience indicates that 0.1 remains a reasonable value to adopt at a broad scale. In the case of the WR2010 model a value of 0.08 was required to achieve calibration.

Rainfall and impacts on unconfined aquifer vertical recharge

The annual rainfall trend of the last 10 years in the South East is less than the long term mean rainfall and it is accepted that this will have consequences for groundwater recharge. Whether the current rainfall trend is short term or longer term is a matter of debate, but to assist discussion on the implications for groundwater recharge and what consideration should be given to changes in the recharge inputs to the WR 2010 model, the following discussion is provided.

The following comments are made with respect to annual rainfall observed at Naracoorte and Kalangadoo and the impact for the watertable response at the observation well SHT012. Well SHT012 is located between Naracoorte and Kalangadoo in the Hundred of Short, where the immediate surrounding land use is now mostly blue gum plantation forest.

For discussion, the SHT012 hydrograph in Figure 1 can be visually divided into three parts; the period from water level record commencement in 1973 to about 1992, from 1993 to 2000 and the recent period, 2001 to 2009. In Figure 1, these are represented by three trend lines for the approximate lower values for the watertable; the trend lines are labelled A, B and C respectively.

The character of the oscillation of the hydrograph for the period ending in 1992 (trend line A) is characteristic of a system in balance, with the recharge spikes being offset with the seasonal equalisation processes, but the mean position of the watertable remaining about constant with the previous period.

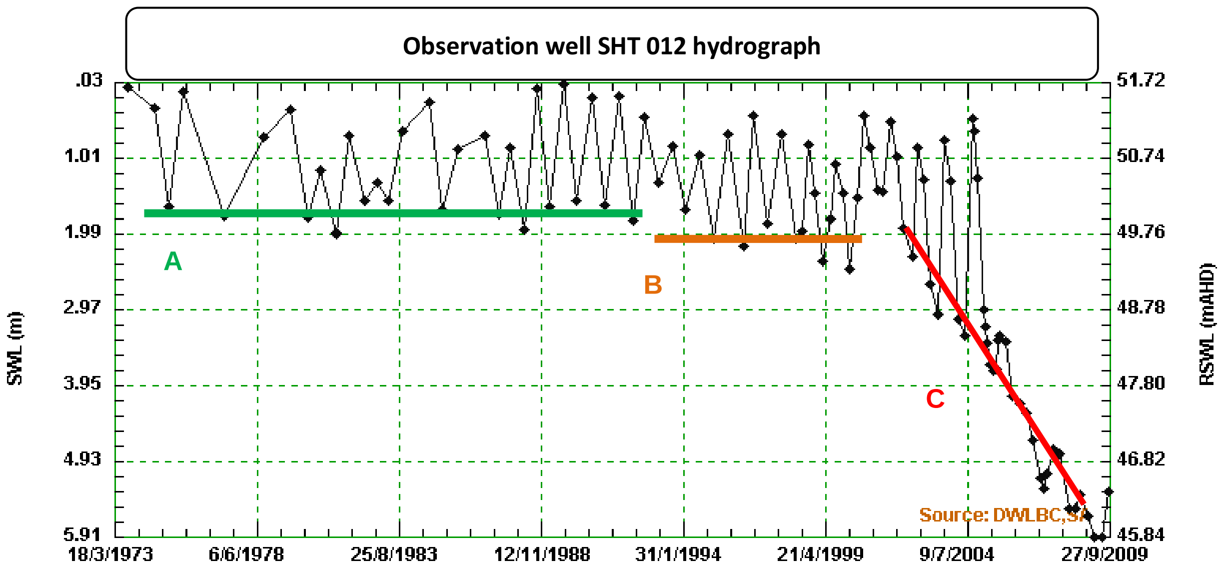

Figure 1. Hydrograph for Observation Well SHT012 located in the Groundwater Management Area of Short

The amplitude of the watertable oscillations at SHT012 (trend lines A and B) are reflective of the nominal recharge rate assigned to the Short groundwater management area in the reports DWLBC 2007/11 and DWLBC 2006/02. In the SHT012 hydrograph (Figure 1) there is an apparent lowering in the average depth to the watertable after about 1993. This period is prior to the forest land use change, but occurring in a period when the annual rainfall in the South East was lower than the long term mean rainfall. The years 1993 and 1994 were consecutive drier years and this is reflected in the hydrograph in Figure 1.[6]

With the benefit of reviewing the historical data, it is now recognised that a lowering of the watertable was occurring widely in the South East region. This raises questions about the possible cause for a general lowering of the watertable when the hydrograph for SHT012 does not indicate any significant recharge reduction at the time. Some of the possibilities for this are:

- Due to data limitations, the recharge at SHT012 for the period pre 1992 (segment A) maybe greater than that indicated by the hydrograph (as discussed below)
- The watertable at SHT012 was responding to a general regional lowering of watertable brought about by a wider and general decrease in regional recharge, in spite of recharge at SHT012 not being significantly reduced
- Other unidentified causes.

The watertable level data for the period pre 1992 is sparse with no comparative values prior to 1975. From 1975 until 1986, watertable level data was collected sporadically, with half yearly collection from 1987. Quarterly data collection began in 1998. The paucity in continuous watertable level data could mean that the actual peaks in the watertable levels may have not been observed; meaning the recharge at SHT012 may be greater than suggested by the hydrograph. The change in data collection frequency is evident in the hydrograph.

In the SHT012 hydrograph (Figure 1), the years 2003 and 2004 exhibit strong recharge spikes and this can be linked to two consecutive wet years when the annual rainfall at Naracoorte was 649 mm in 2003 and 618 mm in 2004, an increase on the long term mean annual rainfall of 84 mm and 53 mm respectively. For Kalangadoo, the rainfall for the same period was about the same as the long term mean.

In considering the characteristics of the hydrological impacts of plantation forest, extraction of groundwater could be expected to commence in about 2003–2004. Although the rainfall for 2003 and 2004 was above the mean annual rainfall, the watertable had already commenced the current downward trend. This is also evident in the WR 2010 model output for Scenarios 1 and 2 and is observed in the hydrograph for SHT012 at Figure 1.

A hydrograph for the observation well SHT014 indicates similar characteristics as SHT012, but groundwater level observations did not commence at the site until 1981.

IRRIGATION EXTRACTIONS

In the absence of any other pertinent information, the annual extractions values for irrigation are held constant in the WR2010 model at the rates reported to the former Department of Water, Land and Biodiversity Conservation (DWLBC) for the year ending in June 2009. This data is based on metered values and is applied to the actual extraction spatial locations. Given that the most significant of land use changes occurred in the period from 1999 to 2003, it is assumed that irrigation use has remained relatively constant since that time. The impact of irrigation on groundwater trends is considered in more detail in Part 2 of this paper where a specific scenario is dedicated to this parameter.

Stock and domestic water extractions are ignored as they are considered to be a constant, albeit insignificant in terms of relative volumes. In reality, domestic and stock water extraction are now probably less due to the loss of grazing land and traditional homesteads to forest land use change.

[6] The rainfall for 1993 and 1994 was 490 mm and 423 mm respectively for Naracoorte, compared to a long term mean of 565 mm. For Kalangadoo, the rainfall was 627 mm and 552 mm in 1993 and 1994 respectively, against a long term mean of 745 mm.

IMPACTS OF DRAINS

There are no drain impacts in the modelling as the drain function is to provide an exit of surplus surface water from the study area generated in periods of high rainfall. For example, it should be noted that adjacent to observation well CLS002, the floor level in Drain M is 42.83 m AHD. This is equivalent to a standing water level of about 2 m below ground level at observation well CLS002, meaning that when the watertable drops below about 2m at CLS002, no significant connection could exist with Drain M at that location, in fact any water within the drain could become localised groundwater recharge.

The hydrograph for CLS002, presented as Figure 2, shows the lowering of watertable below the floor of Drain M after about September 2000, thus eliminating the possibility of any groundwater loss to the drainage system in the study area. Observation well CLS002 is referred to frequently in following discussions as it is located near the centre of the emerging cone of depression and consequently provides a reference point for comparative purposes.

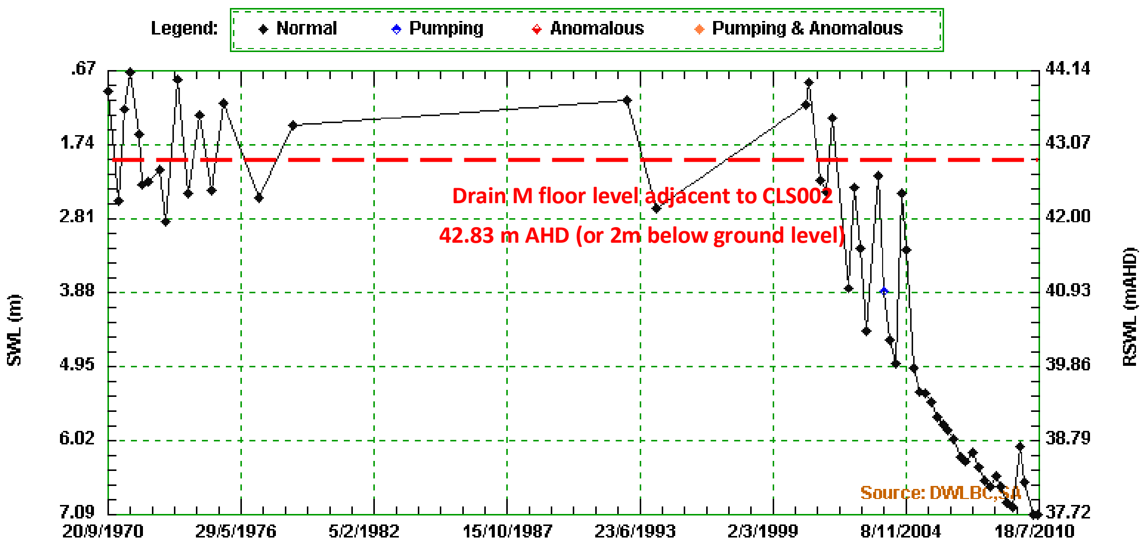

Figure 2. Hydrograph for Observation Well CLS002 situated in Groundwater Management Area of Coles, adjacent to Drain M

FOREST ROTATIONS AND IMPACTS ON GROUNDWATER

Since the introduction of the hardwood plantation forest industry in 1999–2000, the industry has proposed two basic forest management models for the blue gum forest estate; one being coppiced management for a second harvest and the alternative of a full replant after each harvest.

In 2006, the industry redefined its forest rotation management model and advised that the norm would likely be a 10-year period from planting to clear felling, followed by a 12-month break to clean up the felled plantation and preparation for another planting, resulting in an 11-year forest cycle.

The alternative management approach is to fell the first harvest ten years after planting and allow for coppiced regeneration. This would result in a second harvest 18 years after the initial first planting. After the second harvest, the plantation site would be fully replanted one year later for an 11-year standard rotation.

The impacts of blue gum plantations on South East groundwater resources were reviewed collaboratively with the forest industry and other key stakeholders in 2006. The rationale and assigned values for plantation forest impacts on the groundwater resource are described in *Accounting for plantation forest groundwater impacts in the lower South East of South Australia,* DWLBC 2009/13.

For administrative purposes, the forest impacts on groundwater are specified in an annualised accounting form as it was expected that the hardwood (blue gum) industry would rapidly develop and 'mature' to where it had constant harvest and planting cycles, similar to the pine industry. Furthermore, this was considered to be the likely required management approach if a pulp mill became operational at Penola.[7]

The current blue gum estate has a significant age bias with most being planted in the 1999–2002 period. For modelling purposes (and particularly calibration reasons) it was necessary to apply the estimated annual impacts as input parameters to reflect reality rather than use the adopted administrative annualised values. Under a mature industry forest management, a steady state impact on groundwater resources would be expected with a continual felling and replanting program of similar areas distributed throughout the forest estate. This characteristic can be observed in the model hydrograph for Scenario 3 (refer Prediction Scenario 3: Selected Hydrograph _CLS002 in A115B/R002b) when the current forest transitions to 'mature' industry management in 2011. The aggregate of each accounting approach results in the same aggregate water impact value for a full forest cycle. Tables detailing annual and annualised values are appended (as Appendix Tables B to F). The derivation of these tables is documented in the report DWLBC 2009/13.

Due to the uncertainty now associated with the management of the current blue gum forest estate because of ownership and business model changes,[8] it was decided to model two scenarios; a coppiced management option and alternatively a full harvest and replant 11 years after planting.

As many hectares of blue gum plantations have now reached 10 and 11 years of age without any significant harvesting occurring, this raises a question as to whether there is a need to consider an alternative management scenario; one where the forest cycle is extended to about 15 years. This is also consistent with Victorian management thinking for the current hardwood plantation estate in south west Victoria.[9]

The study area also includes about 1 000 ha of pine plantations and as no historic forest management data is readily available for the pines, with respect to the plantation thinning history, the annualised values agreed with the industry (and described in DWLBC 2009/13) are applied to this relatively small area (by percentage) of pine plantation.

PLANTATION FOREST SPATIAL AND TEMPORAL DISTRIBUTION

Due to an inability of the former DWLBC to secure spatial and temporal referenced data for plantation forests in the study area, a dataset suitable for the modelling application was developed. [10] The objective was to assign planting years and areas to the existing plantation estate footprint that approximated the reality of the plantation estate, without resorting to an extensive interrogation of aerial images which would not necessarily accurately resolve the age discrimination of individual plantings.

Using 2002 industry data provided by the Green Triangle Regional Plantation Committee[11] as a starting point,[12] subsequent planning applications provided by the industry and aerial imagery of land use at the

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[7] The Pulp Mill proponent argued it is essential to contract a consistent flow of feed stock for its mill from the local plantation industry for at least twenty years after the Mill became operational. This implies a need for a mature industry with an optimised program for harvesting a wood chip supply.

[8] The main blue gum plantation operators are under administration with asset sales being proposed. The original forest proponents are no longer participants in forest management processes.

[9] The ownership and management of Victorian blue gum plantation forests involves the same parties in South Australia.

[10] The plantation forest industry will not release temporal spatial data of its plantations. It argues that this is 'commercial in confidence'.

[11] The Green Triangle Regional Plantation Committee represented the plantation forest industry at that time.

[12] In 2002, the plantation industry provided data of its estate by forest type and groundwater management area. This formed the foundation for establishing the forest threshold and in particular the forest expansion potential of 59 000

end of 2007 (February 2008 image), a forest structure by age and location was established using the following desktop approach:

- The 2007 delineated forest (February 2008 aerial survey) established a spatial extent 'template' of the current plantation forest location in the WR2010 model
- Each of the groundwater management areas (GMA) in the study area was overlain with a 4 X 4 cell grid, where the 16 subsequent sectors within the GMA are generally of an approximate equal area (estimated area of each cell range from about 1 300 to 2 400 ha depending on the area of the groundwater management area)
- Using the February 2008 aerial survey image, the percentage of forest in each sector was visually estimated and given a value between 0% and 100% (in increments of 5%), where 0% signifies no plantation forest and 100% indicates a totally forested GMA sector; If less than 5% of a sector in a GMA has plantation forest, the sector is considered to have no forest and the estimated value of forest observed is assigned to the nearest adjoining sector with forest in the same GMA
- The forest to agricultural land ratio developed as part of this assessment established a spatial distribution value which was then applied as a constant for the particular GMA. This was then applied to each forest area change, as recorded by the forest development approvals since 2004 or advised by industry prior to 2004, in each of the GMAs.

Blue gum plantation development at a commercial scale did not commence until 1999–2000. During the period from 2000 to 2002, a significant area of forest had received planning approval, or was at some stage in the planning process. It is known the actual plantings did not keep pace with the planning approvals granted and consequently estimates are made for distributing the forest expansion for the year 2001, using data provided by the industry in 2000 and 2002, as a 'boundary' for the estimation. This generalised approach maintains an accurate forest area aggregate for each groundwater management area within the 2007 spatial extent, but may result in some relatively minor misalignment between estimated and actual forest footprint with respect to the age profile of the plantation forest.

A summary of planted areas, with the main data source applied to the WR 2010 model, is presented in Table 4. DFW considers that the areas tabled should be an upper limit as the planning approved area is never tested against the actual area planted. This is a weakness in the current administrative process, with no legal provision for the forest proponent to report what is actually planted and maintained.

Table 4. Aggregated blue gum plantation forest areas in key groundwater management areas

Blue gum plantation aggregate area (ha) by estimated planting date, Wattle Range region in the lower South East

	2000	2001	2002	2003	2004	2005	2006	2007	2008
GMA source	**industry (est.)**	**(est.)**	**GTRPC**	**MEC**	**MEC**	**DWLBC (est.)**	**DWLBC**	**DWLBC**	**DWLBC**
Coles	9505	10630	11754	12198	12302	13934	15180	15180	15180
Joyce	0	132	263	402	402	3162	3162	3162	3162
Killanoola	0	198	395	536	536	1395	2132	3285	3285
Monbulla	0	715	1430	1929	1929	1929	1929	2417	2417
Short	6540	6699	6858	9238	9645	9645	11479	12453	13737
Spence	0	999	1998	2054	2148	2838	2838	3125	3239
aggregate	16045	19372	22698	26357	26962	32903	36720	39622	41020

ha that was adopted formally in 2004 when plantation forests were prescribed by regulation as a water affecting activity.

Part 2 of this paper contains discussions on a scenario to test forest area reduction and redistribution of forested areas. This output helps to inform the discussion on the relevance of an accurate forest location in modelling and the impact of forest area and its general location, relevant to key environmental assets such as Bool Lagoon. In the following discussions, Bool Lagoon is used as a geographic reference for describing the 1 metre watertable contour location and its migration under different scenarios.

PLANTATION FOREST GROUNDWATER USE FROM SHALLOW WATERTABLES

The current management policy for groundwater extraction by plantation forest applies to watertables being 6 metres, or less, from ground level. This is based on the findings presented in the various CSIRO reports related to extraction of groundwater by plantation forests from shallow watertables. However, Benyon *et al* observed groundwater use from a watertable between 8.5 and 8.9 metres. [13]

While the depth to the watertable is regarded as the key factor, it is the behaviour of the zone of capillarity between the saturated zone and the root zone that is significant; trees do not rely on the immersion of roots into a permanently saturated zone to abstract water. There has been no significant research into the capillarity issue and consequently, the depth to the watertable has become a surrogate determinant for management of plantation forest impacts on shallow watertables.

To enable the maximum hydrological impact to be observed, the WR2010 model is not restricted by an extinction depth, that is, the forest groundwater extraction is not depth constrained to the adopted administrative extraction depth of 6 metres or less below ground level. There is further discussion on this parameter and implications in Part 2 of this paper where a sensitivity test with respect to the 6 metre depth to the watertable is discussed.

SCENARIOS REPORTED IN A115\R001C

The two scenarios discussed in the WR2010 model in the Aquaterra report A115\R001c are based on the assumed forest plantings presented in Table 4. Plantings commenced in 1999 and the modelling concludes at 2029.

Two plantation forest management approaches are modelled and they are:

- **Scenario one,** based on coppicing of all plantations following the first harvest 10 years after planting. The second harvest is 18 years after the initial planting, with a full replant one year later. The replanted forest is harvested after 10 years
- **Scenario two,** a continuous 11-year harvest cycle as proposed by the forest industry in 2006.

As previously mentioned, the forest hydrological impacts are applied in annual increments and not as annualised impacts in the two scenarios; this is to reflect reality as closely as possible, particularly as there is a significant age bias in the study area forest estate. Annualised impacts have relevance for a 'mature' industry that provides a reliable and constant flow of raw material to associated value adding industries. This is usually achieved through the estate having relatively equal areas and distribution of tree ages. The 'mature' industry estate results in the aggregate hydrological impact of the forest being relatively constant at a management area scale and aligned with the annualised accounting approach values.

Interpretation of modelling results

The two models appear to align well against actual observations in the calibration period. The small deviations in the calibration period may be due to some variance of actual hydrogeological characteristics

[13] Benyon RG, Theiveyanathan S, and TM Doody: *Impacts of tree plantations on groundwater in south eastern Australia*; Australian Journal of Botany, 2006, **54**, 181-192

to the assumed parameters, some variation in the temporal and spatial location of the forest and/ or natural forest variability. While a refinement of input information is always useful because of the close alignment to reality, the WR2010 can be considered a useful tool for assessing the risk that various forest management scenarios pose for the local groundwater resources.

The results of running the two management scenarios are described in the report A115\R001c, but some other conclusions can be made, providing further value from the WR2010 model. Inferences and conclusions are further tested in the scenario modelling discussed in Part 2 of this paper.

Specific conclusions that can be drawn from the two scenarios of A115\R001c include the following:

- The groundwater extraction characteristic of the plantation forest is a very significant factor with clear felling allowing some immediate recovery in the watertable from lateral inflow and local vertical recharge. However, the recovery period of several years is insufficient to allow for full recovery of the watertable to a pre-forest condition
- From a groundwater resource perspective, the drawdown impact extends well beyond the forest footprint (refer Figures 3.7 and 3.12 in A115\R001c)
- Greatest drawdown impact is observed just prior to harvest, with Scenario 1 (coppiced) management marginally presenting the greatest drawdown (refer Figures 3.4 and 3.9 in A115\R001c)
- Extent of the drawdown zone for Scenario 1 is marginally wider than for Scenario 2 (refer Figures 3.7 and 3.12 in A115\R001c).

For environmental assets such as wetlands, where the watertable has historically been close to the ground surface, a long term groundwater level decline of 1 metre may pose a significant threat to the hydrology that supports a specific environmental asset. While the long term hydrological impacts of plantation forest are assumed to pose some risk to water dependant eco systems and other water users, no comments are tendered with respect to sensitivity for any water dependant ecosystems within the study area.

In considering options to manage the impacts of plantation forests on local hydrology, the modelling results suggests forest extractions from shallow watertables may able to be managed to reduce the impact on the groundwater resource through:

- Reduced areas of plantations
- Wider distribution of plantations
- A distributed harvest and replanting regime.

The impacts of such management regimes could be modelled by applying annualised hydrological impacts to different spatial distributions. A transition to any recommended optimised management may present practical constraints in implementation and review and refinement may be required as new information and monitoring data comes to hand. Alternative management options have been tested to some extent by Aquaterra in the report A115B/R002b, which is discussed in Part 2 of this paper.

PART 2

INTRODUCTION

The calibrated WR2010 model, as presented by Aquaterra in its report ***Modelling Forestry effects on Groundwater Resources in the South East of SA*** ref A115\R001c provides a useful tool with which to test a range of scenarios related to plantation forest hydrological impacts in the study area.

The different scenarios tested, at the request of *The Lower Limestone Coast Task Force,* and reported in ***Modelled Hydrological Impacts by Plantation Forest on Groundwater Resources in the Lower South East: A Scenario Report*** ref A115B/R002b can be categorised into three different groups and these are:

- Changes to hydrological parameters
- Changes to plantation forest management
- Sensitivity testing of some parameters

Whilst some of the scenarios chosen do not appear to relate to practical reality, they have value in respect to testing the sensitivity of an assumption or hydrological parameter. The scenarios tested relate to a change in parameter and do not attempt to address the mechanics of how the changes may be achieved, or if they are possible.

SCENARIO 3: THE NEW BASE CASE

The forest management form that is central to the various scenarios tested under A115B/R002b is a 15-year rotation; that is a plantation that is clear felled 14 years after planting and has a one-year clean and preparation period before replanting for another 15-year cycle. The reason for this change is to reflect what now appears to be a likely management scenario for many blue gum plantations in the lower South East. This is also consistent with current thinking in southwest Victoria which is home to a larger area of blue gum plantation and also with close associations with the South East forest industry. The reality is that much of the current estate is now approaching 12 years and very little harvesting has occurred.

The annualised impacts for a 15-year rotation are different to the 11-year rotation. Applying the same basic agreed principles for estimating the impacts of an 11-year harvest cycle, the revised annual and annualised impacts for the 15-year cycle are set out in Appendix Tables G to J. Given the marginal impact differences between the model outputs for coppiced and 11-year planting cycle plantations, it is considered that the impacts of a 15-year plantation cycle would not deviate far in terms of maximum impact from those presented in Scenarios 1 and 2. Watertable levels for Scenario 3 are presented in Figure B-1 in Aquaterra report A115B/R002b (compare to Figures 3.7 and 3.12 in A115\R001c).

Scenario 3 now becomes the new base case for blue gum forest management. Annualised hydrologic impacts are applied from 2011 in Scenario 3. This is intended to imitate a mature and disciplined forest industry with respect to harvesting and replanting. The transition is immediate and instantaneous and in reality probably unrealistic, but the output is to represent a forest estate managed to minimise hydrologic impacts. The outcome is a stable watertable, albeit 5 metres lower at the centre of the cone of depression compared to the pre forest land use (refer A115B/R002b; Figure B-1). This is compared to 7 metre depth for Scenario 1 and 2 (refer A115\R001c; Figures 3.7 and 3.12). However, the 1 metre contour still passes under Bool Lagoon.

While the drawdown is less with the mature industry management scenario, the watertable remains relatively constant at the lesser depth compared to the Scenarios 1 and 2 where the watertable fluctuates within a broad range due to the current age bias and no harvesting occurring. A mature industry would have a program of constantly harvesting and replanting similar areas of plantation dispersed across the estate and this is represented in the model through the annualised impact values.

For discussion and comparative purposes, the observations at well CLS002 are referred to; this well is located at the centre of the cone of depression of the watertable and is in an area that is surrounded by plantation forest.

Under Scenario 1 and 2, the watertable at CLS002 oscillates through a 6 metre plus range, but never achieves a full recovery to the pre forest watertable level (refer A115\R001c; Figures 3.4 and 3.9). With Scenario 3, the mature 15-year industry management cycle, the watertable stabilises and remains relatively constant at 4–5 metres below the pre forest levels (refer A115B/R002b; Appendix C, Figure 3.4).

To test the sensitivity of the aquifer transmissivity (K) parameter, the K value is varied upwards and downwards by 20 per cent to the base case in Scenario 3. The output does not significantly change the impact of the drawdown. The depth of drawdown remains the same and the boundary of the 1 metre change level moves marginally in for a higher K value and outwards for a lower K value. The extent of movement at Bool Lagoon is in the order of 1 km from the base case. The value of this test is to indicate that the model is relatively robust with respect to the assumed hydrologic parameter.

SCENARIO 4 AND 5

Scenario 4 applies a higher recharge rate from 2011 and onwards. The tested recharge rate is based on a presumption of a recharge rate similar to that would have applied during the wetter period of 1970 to 1995. The rainfall for this period is close to the long term average, which is about 15 per cent higher than the mean rainfall for the last 15 years. [14]

Recharge applied in Scenario 5 is a continuation of recharge rates that have been observed since 1995. In both cases, the changed recharge regime commences in 2011.

In general, the conclusion that can be drawn from Scenarios 4 and 5, is that while a change in recharge does have an impact on drawdown, depth and extent of the drawdown impact is relatively minor, with no significant perceptible change when comparing Scenario 4 with 5 (refer A115B/R002b; Figures B-4 and B-5).

Scenarios 4 and 5 cannot be directly compared with the base case, Scenario 3. The base case uses the same forest footprint as applied in Scenarios 1 and 2. As the Aquaterra report advises, a larger forest foot print was provided by Primary Industries and Resources SA (PIRSA). The PIRSA forest area outer perimeter is similar to that provided by the Department of Water, Land and Biodiversity Conservation (DWLBC) but with less internal definition, resulting in an increase in the forested area of about 14 per cent.[15]

SCENARIO 6 AND 7

Scenarios 6 and 7 provide a sensitivity test to the chosen extraction parameter of the plantation forest from shallow watertables. This is based on an increase and decrease in plantation groundwater extraction from shallow watertables. The variation is an increase and decrease of 20 per cent to the base case of Scenario 3. The base case is 364 mm per year and the upper value is 435 mm per year.

The reason for the 20 per cent variation relates back to the findings of the CSIRO in its investigation into groundwater extraction by plantation forests (refer Benyon *et al*) and the DWLBC decision to adopt an extraction value less than that reported by the CSIRO. The CSIRO reports that plantation forests, regardless of species, extract on average 435 mm per year from a watertable that is 6 metres or less from ground level. The value of 435mm is a mean value of all observations made by the CSIRO. DWLBC chose to use only the values observed in the Wattle Range commercial plantations by CSIRO in its investigations; resulting in a mean value of 364 mm per year from a closed canopy forest (refer DWLBC 2009/13).

It should be noted that for these scenarios, Aquaterra applied the DWLBC forest footprint so a comparison can be made against Scenario 3.

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[14] Long term mean at Kalangadoo and Naracoorte is 745 mm and 565 mm respectively. Since 1995, the mean is observed to be 646 mm and 494 mm respectively.

[15] The data provided by PIRSA appears to be a generalised outer boundary, possibly explaining the increased area. The PIRSA data provided no temporal definition of the forest estate in the study area.

Compared to the base case of Scenario 3, the increased extraction rate deepens the cone of depression by about 1 metre to 6 metres. The 1 metre drawdown level also extends outwards by about a further 1 kilometre (refer A115B/R002b; Figures B-6 and B-3).

The decrease in plantation forest extraction results in a groundwater change; the outer boundary of the 1 metre decline in watertable level moves in about 1 kilometre and the bottom of the cone of depression rises by about 1 metre, compared to the base case in Scenario 3 (refer A115B/R002b; Figures B-7 and B-3).

These scenarios are beginning to reinforce a conclusion that extraction by plantation forests is a far more significant parameter on the underlying groundwater resource with respect to the depth of the impact and its spatial extent than forest recharge impacts.

SCENARIO 8 AND 9

Scenarios 8 and 9 are designed to test the impacts of irrigation extractions compared to the impacts of plantation forest. In Scenario 8, from 2011, all irrigation extractions cease and all forest impacts are removed.

In Scenario 9, from 2011 all irrigation continues at the same level of extraction as advised by the metered extractions for the year ending in June 2009 (the same as base case Scenario 3 and Scenarios 1 and 2) but there is no plantation forest.

The hydrographs for observation well CLS002 show that watertable recovery commences immediately (2011) and a new equilibrium is reached by 2014 (refer A115B/R002b; Appendix C Figure 3.4). The impact of both scenarios is almost identical. The hydrographs indicate that the volume of irrigation groundwater extraction has a negligible impact on the groundwater resource and the watertable drawdown can mostly be attributed to the impacts of plantation forest.

SCENARIO 10 AND 11

Scenarios 10 and 11 are designed to test the aquifer response to an intensification of plantation forest activity. The starting position is the DWLBC forest footprint as used for all scenarios except Scenarios 4 and 5. The forest hydrological impact is increased by 50%, but within the same footprint perimeter. This implies a total infill with forest land use. While this may have practical constraints in the field for land access to forest industry proponents, it is to demonstrate the impact of increasing forest area concentrated within the same spatial extent as the current estate. There is no irrigation extraction applied in these scenarios.

The model hydrographs (ref A115B/R002b; Appendix C Figure 3.4) indicate a further decline in the watertable with stabilisation by about 2019. The decline is a further 1 metre at the observation well CLS002, but the base of the cone of depression has significantly widen by 5–6 kilometres and this is indicated in reference A115B/R002b; Figure B-11 (compared to reference A115B/R002b; Figure B-10). The centre of the cone of depression remains centred near observation well CLS002. The outer 1 metre drawdown contour moves outward by about 1 kilometre.

SCENARIO 12 AND 13

Scenarios 12 and 13 are designed to test the aquifer response to a reduction in plantation forest area. The starting position is the DWLBC forest footprint as used for all scenarios except Scenarios 4 and 5.

Scenario 12 tests for the impact of a forest reduction in area by 40 per cent. This is equivalent to a reduction of about 16 400 ha. The reduction is uniform across the study area and commences in 2011. No consideration is given to the practicality of how such a strategy would be implemented.

Scenario 13 tests a selective reduction in the forest area with a removal of 13 050 ha of forest in particular management areas. This requires the total removal of forest in the management areas of Joyce, Killanoola and Spence and with removal from the north east quarter of Coles. Both strategies are intended to test the groundwater response to a forest area reduction and implications for a water dependant asset such as Bool Lagoon. In both scenarios the land reverts back to dryland farming and grazing and the hydrology applied in the model is that associated with that land use. This reduction in forest area is without consideration to implementation of the action.

The model hydrographs (refer A115B/R002b; Appendix C Figure 3.4) for CSL002 indicate some recovery in the watertable level with stabilisation by about 2016. The recovery brings the watertable back to within about 2 metres of the pre forest level. The centre of the cone of depression remains close to observation well CLS002. The outer 1 metre drawdown contour migrates inwards, locating it about 2 kilometres west of Bool Lagoon in the case of Scenario 12 (a 16 400 ha forest area reduction). In Scenario 13, that of selective removal of 13 050 ha, the 1 metre drawdown contour appears about 4 km west of Bool Lagoon (refer A115B/R002b; fig B-12 and B-13).

SCENARIO 14

Scenario 14 tests a proposal to relocate and establish the forest removed in Scenario 13 into the management area of Fox. This preserves the forest estate area at 41 020 ha, but is relocated to the west, away from Bool Lagoon. The change in forest location occurs in 2011, without consideration to the transitional arrangements.

The model hydrographs (refer A115B/R002b; Appendix C Figure 3.4) for CSL002 indicates some recovery in the watertable level with stabilisation by about 2016. However, the centre of the cone of depression has migrated about 11 kilometres to the west, with the drawdown at the centre being about 5 metres. The overall impact on the watertable is similar to the base case in Scenario 3, but significantly displaced to the west.

The outer 1 metre drawdown contour has migrated westwards with the position relative to Bool Lagoon being similar to that created by Scenario 13; about 4 km west of Bool Lagoon (refer A115B/R002b; Figure B-14).

SCENARIO 15

Scenario 15 tests for a proposal to inject 50 GL/year of water into the management areas of Coles and Short. The injection process commences in 2011 without consideration to the practicalities of sourcing water or implementing the proposition.

Using observation well CLS002 as an indicator, the watertable partially recovers and stabilises by about 2018 (refer A115B/R002b; Appendix C, Scenario 15). The watertable recovers to within about 3 metres of the pre-forest levels. Due to the injection being modelled for the summer season of the WR2010 model, the seasonal fluctuation is muted when compared to other scenarios. Another outcome is the centre of the cone of depression has moved to the north by about 4 kilometres (to the junction of the management areas of Coles, Joyce and Spence). The 1 metre drawdown contour is about 2 kilometres west of Bool Lagoon (refer A115B/R002b; Figure B-15).

The Aquaterra report does not include a Scenario 16, but refers to the following sensitivity tests as 'Scenarios' 17 and 18.

SENSITIVITY TESTING

Another model was developed by Aquaterra to test the appropriateness of the 6 metre depth to watertable as a limit for plantation forest extraction of groundwater. The WR2010 model allows for groundwater extraction by plantation forest regardless of the depth to the watertable, whereas the alternative model developed by Aquaterra constrains extraction to a specific depth to the watertable. The current management assumption is that groundwater extraction by plantation forests ceases if the watertable falls below 6 metres below ground level (6 metres is the extinction depth).

The integrity of the Aquaterra sensitivity model output is not tested because no accurate ground surface (as from a digital elevation model) has been provided and consequently only a generalisation of depth from land surface to the watertable has been applied to the study area. While the model is not validated, using all other parameters and assumptions, other than depth to watertable constraint, the model produced the outputs presented in A115B/R002b; Figures B-17 and B-18.

Case 17 (referred to in the report as Scenario 17) is based on an extinction depth of 6 metres, that is, plantation forest cease groundwater extraction if the watertable lowers to a level deeper than 6 metres below ground level. The watertable contours presented by the model and shown in Figure B-17 do not approximate what is already occurring and validated by the WR2010 model. The only conclusions that can be drawn from the use of this Aquaterra sensitivity model is the application is inappropriate, the land surface to watertable surface generalisation is a limiting factor, or forest extraction of water is not constrained to 6 metres.

Case 18 (referred to in the report as Scenario 18) presented in Figure B-18 is a test for a depth constraint of 9 metres. While not replicating what is actually being observed in the field, the output is a much better fit than the 6 metre depth constraint in Case 17.

A conclusion that can be drawn from these two particular model exercises is that groundwater extraction by plantation forests continues to occur from watertables deeper than 6 metres. While more definitive conclusions cannot be drawn, it should be noted that Benyon *et al* have observed extractions from watertables as deep as 8–9 metres.

CONCLUSIONS FROM THE WR2010 OUTPUTS

As a result of the testing carried out by Aquaterra and in particular with the WR2010 model, the following can be concluded with respect to the impacts of plantation forest on groundwater resources:

- While the impacts of forest on groundwater recharge are relevant, the extraction characteristic of plantation forest has the greatest impact on the groundwater resource in the study area;
- The impact of plantation forests on the water resource can be mitigated to some extent with a constant annual cycle of dispersed harvesting and replanting (removal of any age bias from the forest estate);
- Removal of plantation forest can provide a rapid recovery of the watertable;
- Relocation of some plantation forest can move the impacted area away from important environmental assets; and
- Plantation forests are likely to extract groundwater from watertables deeper than 6 metres.

Science Unit
Department for Water
October 2010

APPENDIX

Table A. Observation wells used to establish average annual recharge rates for groundwater management areas in the subject area

Observation Well	1995–2004 Estimated WTF metres	average WTF for GMA metres	recharge value assigned to GMA
CLS004	0.9		
CLS006	1.2	1.2	Coles 120 mm
CLS009	1.5		
SHT011	2		
SHT012	1.3	1.5	Short 150 mm
SHT014	1.2		
KLN002	1.6		
KLN004	1.4	1.43	Killanoola 145 mm
KLN005	1.3		
MON008	2		
MON016	1.8	1.83	Monbulla 180 mm
MON017	2		
MON018	1.5		
JOY007	1.2	1.2	Joyce 120 mm
JOY010	1.2		
SPE004	0.9	1.15	Spence 115 mm
SPE006	1.4		

Table B. Groundwater recharge model for blue gum plantations *(short rotation hardwood)*

		All values expressed as percentage of management area recharge rate (MARR)		
	forest rotation year	**as per cent of MARR**	**cumulative**	**annualised value**
planting	1	120	120	21.8
	2	80	200	21.8
	3	40	240	21.8
canopy closed	4	0	240	21.8
	5	0	240	21.8
	6	0	240	21.8
	7	0	240	21.8
	8	0	240	21.8
	9	0	240	21.8
harvest	10	0	240	21.8
clean up (single rotation)	11	0	240	21.8
		Recharge impacts for a coppiced regeneration for second harvest		
	12	0	0	0
	13	0	0	0
	14	0	0	0
	15	0	0	0
	16	0	0	0
	17	0	0	0
clear fell	18	0	0	0
clean up	19	0	0	0

Table C. Groundwater recharge model for pine plantations *(long rotation softwood)*

		All values expressed as percentage of management area recharge rate (MARR)		
	forest rotation year	as per cent of MARR	cumulative	annualised value
planting	1	120	120	17.2
	2	100	220	17.2
	3	80	300	17.2
	4	60	360	17.2
	5	40	400	17.2
	6	20	420	17.2
canopy closed	7	0	420	17.2
	8	0	420	17.2
	9	0	420	17.2
	10	0	420	17.2
T1	11	50	470	17.2
	12	0	470	17.2
	13	0	470	17.2
	14	0	470	17.2
	15	0	470	17.2
	16	0	470	17.2
T2	17	50	520	17.2
	18	0	520	17.2
	19	0	520	17.2
	20	0	520	17.2
	21	0	520	17.2
	22	0	520	17.2
T3	23	50	570	17.2
	24	0	570	17.2
	25	0	570	17.2
	26	0	570	17.2
	27	0	570	17.2
	28	0	570	17.2
	29	0	570	17.2
T4	30	50	620	17.2
	31	0	620	17.2
	32	0	620	17.2
	33	0	620	17.2
	34	0	620	17.2
clear fell	35	0	620	17.2
clean up	36	0	620	17.2

Table D. Groundwater extraction model for blue gum plantations *(short rotation hardwood)*

		All values expressed as ML per hectare		
	forest rotation year	**annual extraction**	**cumulative extraction**	**annualised extraction value**
	year	**ML/ha**	**ML/ha**	**ML/ha/year**
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 E. Groundwater extraction model for coppiced blue gum plantations *(coppiced hardwood)*

		All values expressed as ML per hectare		
	forest rotation year	annual extraction	cumulative extraction	annualised extraction value
	year	ML/ha	ML/ha	ML/ha/year
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

Table F. Groundwater extraction model for pine plantations *(long rotation softwood)*

		All values expressed as ML per hectare		
	forest rotation year	**annual extraction**	**cumulative extraction**	**annualised extraction value**
	year	**ML/ha**	**ML/ha**	**ML/ha/year**
planting	1	0	0	1.663
	2	0	0	1.663
	3	0	0	1.663
	4	0	0	1.663
	5	0	0	1.663
	6	0	0	1.663
canopy closed	7	0.73	0.73	1.663
	8	1.46	2.19	1.663
	9	2.19	4.38	1.663
	10	2.91	7.29	1.663
T1	11	3.64	10.93	1.663
	12	1.00	11.93	1.663
	13	2.05	13.98	1.663
	14	2.35	16.33	1.663
	15	2.75	19.08	1.663
	16	3.15	22.23	1.663
T2	17	3.55	25.78	1.663
	18	1.00	26.78	1.663
	19	2.05	28.83	1.663
	20	2.45	31.28	1.663
	21	2.75	34.03	1.663
	22	3.05	37.08	1.663
T3	23	3.35	40.43	1.663
	24	1.00	41.43	1.663
	25	1.90	43.33	1.663
	26	1.95	45.28	1.663
	27	2.00	47.28	1.663
	28	2.10	49.38	1.663
T4	29	2.15	51.53	1.663
	30	1.00	52.53	1.663
	31	1.30	53.83	1.663
	32	1.40	55.23	1.663
	33	1.50	56.73	1.663
	34	1.55	58.28	1.663
clear fell	35	1.60	59.88	1.663
clean up	36	0	59.88	1.663

Table G. Groundwater recharge model for blue gum plantations – 15 year rotation *(short rotation hardwood)*

		All values expressed as percentage of management area recharge rate (MARR)		
	forest rotation year	**as per cent of MARR**	**cumulative**	**annualised value**
planting	1	120	120	16.0
	2	80	200	16.0
	3	40	240	16.0
canopy closed	4	0	240	16.0
	5	0	240	16.0
	6	0	240	16.0
	7	0	240	16.0
	8	0	240	16.0
	9	0	240	16.0
	10	0	240	16.0
	11	0	240	16.0
	12	0	240	16.0
	13	0	240	16.0
clear fell	14	0	240	16.0
clean up	15	0	240	16.0

Table H. Groundwater extraction model for blue gum plantations – 15 year rotation *(at annual rate of 3.64 ML/ha)*

		All values expressed as ML per hectare		
	forest rotation year	annual extraction	cumulative extraction	annualised extraction value
	year	ML/ha	ML/ha	ML/ha/year
planting	1	0	0	2.305
	2	0	0	2.305
	3	0	0	2.305
canopy closed	4	0.91	0.91	2.305
	5	1.82	2.73	2.305
	6	2.73	5.46	2.305
	7	3.64	9.1	2.305
	8	3.64	12.74	2.305
	9	3.64	16.38	2.305
	10	3.64	20.02	2.305
	11	3.64	23.66	2.305
	12	3.64	27.30	2.305
	13	3.64	30.94	2.305
clear fell	14	3.64	34.58	2.305
clean up	15	0	34.50	2.305

Table I. Groundwater extraction model for blue gum plantations – 15 year rotation *(at annual rate of 4.35 ML/ha)*

		All values expressed as ML per hectare		
	forest rotation year	annual extraction	cumulative extraction	annualised extraction value
	year	ML/ha	ML/ha	ML/ha/year
planting	1	0	0	2.755
	2	0	0	2.755
	3	0	0	2.755
canopy closed	4	1.087	1.087	2.755
	5	2.175	3.262	2.755
	6	3.262	6.525	2.755
	7	4.35	10.875	2.755
	8	4.35	15.224	2.755
	9	4.35	19.574	2.755
	10	4.35	23.924	2.755
	11	4.35	28.274	2.755
	12	4.35	32.624	2.755
	13	4.35	36.973	2.755
clear fell	14	4.35	41.323	2.755
clean up	15	0	41.323	2.755

Table J. Groundwater extraction model for blue gum plantations – 15 year rotation *(at annual rate of 2.93 ML/ha)*

		All values expressed as ML per hectare		
	forest rotation year	**annual extraction**	**cumulative extraction**	**annualised extraction value**
	year	**ML/ha**	**ML/ha**	**ML/ha/year**
planting	1	0	0	1.86
	2	0	0	1.86
	3	0	0	1.86
canopy closed	4	0.733	0.733	1.86
	5	1.465	2.198	1.86
	6	2.198	4.395	1.86
	7	2.93	7.326	1.86
	8	2.93	10.256	1.86
	9	2.93	13.186	1.86
	10	2.93	16.116	1.86
	11	2.93	19.046	1.86
	12	2.93	21.977	1.86
	13	2.93	24.907	1.86
clear fell	14	2.93	27.837	1.86
clean up	15	0	27.837	1.86

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Source: Aquaterra report, ***Modelling Forestry effects on Groundwater Resources in the South East of SA*** ref A115\R001c.

- Figure A.2
- Figure A.7
- Figure 3.4
- Figure 3.7
- Figure 3.9
- Figure 3.12

Source: Aquaterra report ***Modelled Hydrological Impacts by Plantation Forest on Groundwater Resources in the Lower South East: A Scenario Report*** ref A115B/R002b.

- Prediction Scenario 3:Selected Hydrograph (CLS002)
- Figure B-1
- Figure B-3
- Figure B-4
- Figure B-5
- Figure B-6
- Figure B-7
- Figure B-10
- Figure B-11
- Figure B-12
- Figure B-17 (Scenario 13)
- Figure B-14
- Figure B-15
- Figure B-17
- Figure B-18
- Appendix C (Scenario 15, CLS002)