Accounting for plantation forest groundwater impacts in the lower South East of South Australia

DWLBC 2009/13

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ISBN: 978-1-921528-44-6

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Introduction

This report has been prepared to provide a record of the development of the annualised plantation forest accounting models used in the water budgets of the lower South East of South Australia. While the models appear to be suitable tools for accounting and managing the South East groundwater resource, they may have some application in for other managed water resources.

The initial annualised groundwater impact models developed for the South East were always intended to be interim; at least until improved technical knowledge or a change in context suggested a different accounting approach were appropriate. However, as a result of a review in 2006, the conceptual models with the underpinning rationale and assumptions have proven to be sufficiently robust for the current context.

The report is set out in three parts, a background to the issue in a lower South East context, development of assumptions applied in the forest groundwater models and the actual development of the annualised forest water accounting models.

Executive summary

Plantation forests are an extensive land use in the lower South East, covering nearly 16 per cent of the available landscape with about 103 000 ha of softwood and 43 000 ha of hardwood plantations. The region is also home to important grazing and irrigation industries with significant investments based on an assumption that extractions from the extensive unconfined limestone aquifer will remain sustainable. Rainfall percolating past the root zone of the vegetation cover provides most of the recharge to the local groundwater system.

The lower South East water resource can be considered at, or approaching, full allocation, with some groundwater management areas over allocated. As plantation forests impact directly on groundwater recharge and can extract groundwater where the water table is shallow, it is important there is an accounting system which incorporates all water uses. Some over allocation is historical and other is caused by the first time accounting for direct extraction of groundwater by about 60 000 ha of plantation forest overlaying shallow water tables. All over allocation however requires a management response.

It is impractical to measure actual forest water consumption, whether in terms of impacts on surface water yield, groundwater recharge, or by direct extraction from shallow water tables. Based on biophysical principles and assumptions, a system of forest water models with outputs expressed in annualised deemed values have been developed. The annualised deemed values are not point impact measurements, but an estimation of diffuse impacts based on a characterisation of plantation forests of the same type in the same groundwater management area. The values 'smooth' the hydrologic impacts of the forest over the full forest rotation period. The deemed annualised values, while appropriate for South East groundwater accounting and management purposes may have some application for water accounting in other regions.

In the case of hardwood plantations, the annualised forest water recharge model indicates forests reduce the groundwater recharge that would normally occur to 22 per cent of that occurring if the site were committed to a dryland agricultural land use. This represents a loss of recharge on that site of 78 per cent. In the case of softwood forest plantations, the recharge loss to any forest site is 83 per cent of that occurring in a dryland agricultural landscape. Where the median water table is 6 metres, or less, from ground level, hardwood plantations are deemed to extract 1.82 ML/ha/year, on an annualised basis, and softwood plantations are considered to extract 1.66 ML/ha/year.

The forest water recharge and extraction models minimise administrative complexity by managing each forest type as a single class for its life, providing administrative benefit for both forest owners and the water resource manager.

The following table provides a summary of key dates for issues of interest or significance either in the assessment of plantation forest impacts on the lower South East groundwater resources or the development of the annualised deemed models. The table also indicates where in the report the issue is discussed in further detail.

Date	Issue	Section in text
1999	Assumption of no recharge under closed canopy forests in technical assessments	12
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BACKGROUND

1. Extent of plantation forest in lower South East

In the lower South East of South Australia, plantation forest industry activity and interest lies in the land receiving 600 mm, or more, of mean annual rainfall. The area consists of approximately 1 million hectares of land zoned as general farming or commercial forest in the various local development plans.[1] The industry also has an interest in neighbouring western Victoria which combined with the South East of South Australia is recognised as the Green Triangle Region.[2]

Excluding special land use zones, native vegetation, national parks, non-arable land and permanent lakes, plantation forests currently occupy nearly 16 per cent of the landmass that could be used for plantation forestry. The current forest estate is approximately 146 000 ha,[3] with 103 000 ha being softwood (long rotation pine) mainly for sawlog production and 43 000 ha of hardwood (short rotation Tasmanian blue gum [*Eucalyptus globulus*]) for wood chip production.

Figure 1 indicates the distribution of softwood and hardwood plantations in the lower South East and the current groundwater management boundaries.

2. Other land uses

The dryland agricultural landscape generally comprises improved pastures for grazing with some areas of annual cropping of oats, oilseed crops and other broad acre crops such as beans and canola. The area and intensity of irrigated agriculture varies seasonally, but is of the order 100 000 ha. It includes perennial pastures, fodder crops, potatoes, onions, viticulture and specialised small seed production. The irrigation activity is widely dispersed but there are areas of high value intense activity around Mount Gambier, Naracoorte and Coonawarra.

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[1] Local government areas include District Council of Grant, District Council of Robe, Kingston Regional Council, Naracoorte Lucindale Council, and Wattle Range Council

[2] Green Triangle is an economic development region with numerous internal and informal links; it is not an administrative zone, but it is a National Plantation Inventory region.

[3] Source: SERIC, at December 2007

3. Physical characteristics of the region

The topography of the region is relatively flat to gently undulating and the soils are mostly sandy. There are over 20 low relief stranded ancient coastal dunes running approximately parallel to the coast. The underlying regional geology is generally karstic limestone and in combination with the surface features, results in no significant surface water streams draining to the marine environment.

The area around Mount Gambier has experienced volcanic activity, with a number of dormant remnant craters evident in the landscape, including the Mount Gambier complex, Mount Schank, and Lake Leake. The Blue Lake crater at Mount Gambier provides a 'window' into the local unconfined aquifer.

The depth from ground surface to the unconfined aquifer water level ranges from 2-3 metres to about 60 metres in areas of higher relief.

Following early land clearance, a number of surface water drains were constructed to move excess surface water to the coast (this water is considered as rejected groundwater recharge). These drainage systems should not be confused with the mid and upper South East groundwater drains recently constructed to help mitigate rising groundwater and increasing salinity.

4. Lower South East hydrogeology

There are two main aquifers under formal management in the lower South East, the unconfined Tertiary Limestone Aquifer that overlies the Tertiary Confined Sand Aquifer. In some parts of the region, the confined aquifer is not always clearly distinguishable or its water accessible for beneficial use.

4.1 Tertiary Confined Sand Aquifer

The Tertiary Confined Sand Aquifer occurs within an interbedded sequence of sands, gravel and clays. Minor sand horizons of the Mepunga Formation are considered to be a part of the confined sand aquifer. The Tertiary Confined Sand Aquifer increases in thickness towards the south with a maximum recorded thickness of 800 m, off-shore.

Artesian supplies of groundwater of up to 100 litres per second are available from some parts of the Tertiary Confined Sand Aquifer. Salinity ranges from approximately 500 mg/L near Mount Gambier to about 800 mg/L in the Kingston area.

Groundwater from the Tertiary Confined Sand Aquifer of the Dilwyn Formation is utilised mainly for municipal and industrial water supplies in the southern portion and by agriculture in the Kingston -

Lucindale - Beachport area for irrigation, and stock and domestic requirements. An industrial allocation has also been made to the proposed Penola Pulp Mill, south of Penola.

4.2 Tertiary Unconfined Limestone Aquifer

The unconfined Tertiary Limestone Aquifer occurs within fossiliferous marine limestone, with interbeds of marl, calcite and dolomite, and flint horizons. The thickness of the aquifer varies regionally with the largest vertical sequence of about 300 m occurring in the area south of Mount Gambier.

Figures 2a and 2b provide characterised cross sections of the Lower South East aquifer system.

Generally the unconfined Tertiary Limestone Aquifer has a dual porosity, with a primary inter-granular porosity (which acts hydraulically as a porous medium) and secondary fracture porosity resulting from dissolution of the limestone. The secondary porosity forms conduits for preferred flow. A wide range of transmissivities are a reflection of the karstic nature of the limestone aquifer.

Salinity of the unconfined Tertiary Limestone Aquifer varies from less than 500 mg/L in the southern part of the Otway Basin to greater than 3000 mg/L in the northern part of the Otway Basin. The groundwater is used for a wide range of purposes, ranging from municipal supplies for Mount Gambier and Millicent, stock and domestic water supplies, industrial use, and widespread irrigation throughout the region.

5. Aquifer recharge

Recharge to the Tertiary Confined Sand Aquifer in South Australia is highly reliant on the downward percolation of water from the overlying unconfined aquifer. Separating the two aquifers is a ubiquitous carbonaceous clay aquitard. The degree of connection between the two aquifers is controlled by the ability of the aquitard to transmit water vertically. Low permeability may mean little or no recharge to the confined aquifer is occurring through the aquitard via vertical leakage from the overlying unconfined aquifer. However, there are some areas of preferential recharge from the unconfined aquifer to the confined aquifer in the eastern area of the region due to geologic faulting and or absence of a separating aquitard.

Recharge to the unconfined Tertiary Limestone Aquifer is largely from locally occurring rainfall which percolates past the root zone of the vegetation. In some areas there are paths of preferential recharge from occasionally occurring surface water. This can be through features locally known as ‘run away holes’, which are a characteristic of the lower South East karstic limestone geology. The limestone geology, and in particular its connection to the aquifer, is evident in features such as the Mount Gambier Cave Gardens, Umpherston Cave, Englebrecht Cave and the Naracoorte Cave complex.

In addition to local rainfall recharging the unconfined Tertiary Limestone Aquifer, there is a natural through flow of groundwater, generally towards the coast, but with a northwest direction in the upper regions. For groundwater management purposes, the extractable volume of water available for allocation from the unconfined aquifer is considered to be a function of the local vertical recharge from rainfall outside the Border Designated Area. The quantity of recharge for a groundwater management area is generally reduced by 10 per cent and the balance is referred to as the total available recharge (TAR). The 10 per cent reduction is a nominal allowance to ensure natural lateral groundwater through flow to maintain salt transport towards the coast.

In the Border Designated Area, the Border Groundwaters Agreement Review Committee has determined the permissible annual volumes (PAV) for licensed allocation based on observed trends and risks to the groundwater resource.

6. Groundwater recharge values

Groundwater recharge rates for the unconfined Tertiary Limestone Aquifer have been established and refined over a number of years for the different groundwater management areas. The recharge rates are generally based on the water table fluctuation methodology, with isotope analysis in some management areas contributing to the recharge information.

Under this approach, the land-use associated with the groundwater management area recharge is treated as homogenous and is not described or differentiated. The dryland agricultural landscape of the lower South East is in constant change around the main activity of pasture. There is some broad acre cropping interspersed with various forms of fallow in the transition from pasture to cropping. [4] Within this dryland agricultural landscape, point descriptions can vary significantly and consequently the contribution to groundwater recharge at that point can also vary. Within the context of seasonal variability, this homogeneous approach is considered both practical and robust for the purpose of water budgeting and resource management.

However, should a significant change to land-use, land management, and or, seasonal rainfall trends be observed, it may be necessary to re-evaluate the approach and the associated assigned groundwater recharge values to ensure an appropriate accounting regime to maintain sustainable

[4] Fallows can be in the form of a cultivated fallow or a weed free condition brought about herbicide applications, or some variation, or combination of both. The significant feature being the conservation of soil moisture which can result in an increase in groundwater recharge

management of the groundwater resource. Currently, a review of all water allocation plans is required, at least every five years.[5]

7. Groundwater management

The regional groundwater resources of the lower South East are prescribed under the *Natural Resources Management Act 2004.* The lower South East is part of the Lower Limestone Coast Prescribed Wells Area. The area previously comprised the three separate administrative areas of Comaum-Caroline, Lacepede-Kongorong, and the Naracoorte Ranges Prescribed Wells Areas.[6]

The eastern Otway Basin that lays within the 20 km zone each side of the Victorian - South Australia Border is also subject to management under the *Groundwater (Border Agreement) Act 1985*, which takes precedence over the *Natural Resources Management Act 2004*.

8. Licensed water allocations

Approximately 600 000 ML of groundwater has been allocated for licensed extraction in the 46 individual groundwater management areas of the lower South East.[7] The current water allocation system is predominately area based for irrigation allocations, and in the past, the volumes pumped were estimated.[8] Flow recording meters for all licensed water allocations are now mandatory and the existing area based allocations are to be converted to, and expressed, as volumes. This will provide more accurate information for future technical assessments of resource capability and subsequent management policies to ensure ongoing groundwater sustainability.

9. Allocation status of the unconfined water resource

Of the 46-groundwater management areas, 11 do not have any commercial plantation forest activity. This is mainly due to a range of reasons, singular, or collective, and can include:

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5 Requirement of the *Natural Resources Management Act 2004*

[6] Lower Limestone Coast Prescribed Wells Area comprises 59 groundwater management areas or zones

7 The 46 includes part of Border Designated Zone 5A

[8] A conversion process is currently being finalised for converting existing area based allocations to volumetric allocations for inclusion in a revised water allocation plan

- unsuitable soil or topography
- distance to key forest infrastructure, such as milling, or Portland for wood chip export
- proximity to existing plantations, for management efficiency, or risk management
- rainfall considered marginal
- land is tightly held by grazing interests
- land price is too high due to competing land uses (e.g. dairy, viticulture)

In total, approximately 100 000 ML of groundwater remains unallocated in the Lower Limestone Coast Prescribed Wells Area. Approximately half of this volume is reserved by the Minister for Environment and Conservation and is only available for lease, subject to the criterion established by regulation (at the time of preparing this report, criterion was yet to be made). Some of this unallocated water is likely to remain in low demand, as it is considered marginal for irrigation and industrial use, or the soil and topography is unsuitable for irrigation and or plantation forests.

In terms of the forest water policy position being addressed by the Intergovernmental Agreement on a National Water Initiative (NWI) (particularly paragraphs 55-57), the lower South East can be considered at a position of full water allocation or approaching full allocation, with some management areas considered over allocated. In some cases, the over allocation is historical and requires addressing in the next water allocation plan. Some over allocation has been brought about by the first time accounting in the water budget for the direct extraction by about 60 000 ha of plantation forest overlaying shallow water tables (six metres or less from ground level).[9]

[9] Source is data from SERIC and DWLBC, Mount Gambier, 14 November 2008

ACCOUNTING FOR PLANTATION FOREST IMPACTS ON LOWER SOUTH EAST GROUNDWATER

10. Need for forest water accounting

Plantation forests are an extensive land use in the lower South East, covering nearly 16 per cent of the available landscape. As plantation forests impact directly on groundwater recharge and can extract groundwater where the water table is shallow, it is important there is an accounting system particularly where there are threats to the water resources or its existing users. This accounting need has led to the development and adoption of the forest water accounting systems discussed in this report.

11. Plantation forest biophysical issues

Plantation species are selected for the productivity and qualities of useable wood. The high dry matter productivity of plantation species results in a greater evapotranspiration potential than the replaced dryland agricultural landscape.[10] To meet the increased plant water use, plantation forest species generally extract soil moisture through a deep and extensive root zone, with the soil water replacement being provided by local rainfall events. In addition, where the water table is shallow, it has been established by the CSIRO that plantation forests can directly extract groundwater in an endeavour to meet the evapotranspiration potential of the forest species.[11]

Although not regarded to be a significant issue in the South East, in addition to the impacts mentioned above, plantation forests can also reduce surface water yields.[12] Whether the higher water use characteristics of plantation forest are manifested as impacts in reducing surface water runoff, reduced groundwater recharge, or the direct extraction from shallow water tables, the impact

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10 Zhang L, Dawes WR, and Walker GR, 2001. *The response of mean annual evapotranspiration to vegetation changes at catchment scale*, Water Resources Research 37, 701-708

11 Benyon RG, Theiveyanathan S, and Doody TM, 2006. *Impacts of tree plantations on groundwater in south-eastern Australia*, Australian Journal of Botany, 54, 181-192

12 While external to South Australia management, there is a potential for a reduction in surface water flows from Victoria into Bool Lagoon caused by plantation forest expansion in the Mosquito Creek catchment.

on the local water resource is largely determined by the underlying geology, topography and soil type.

12. Forest impact accounting for current water allocation plans

At the time of developing the water budgets for the current water allocation plans,[13] the policy of no groundwater recharge under plantation forests (and lakes and native vegetation) was taken. In the absence of detailed scientific information relating to hydrological impacts of plantation forest and given the anticipated rapid forest expansion, an initial 'no recharge under plantation forest' was the only responsible accounting approach to account for forest recharge interception. This management approach was applied to the area of known proposed plantation expansion as well as the existing estate at the time.

Having employed the 'no recharge' accounting approach, it was considered necessary to develop an accounting and management approach for plantation forest impacts on groundwater resources for future management, particularly if plantation impacts were to involve transferable water allocations.

13. Deemed accounting values

It is impractical to commercially measure actual forest water consumption, whether in terms of impacts on surface water yield reduction, reduced groundwater recharge, or by direct extraction from shallow water tables. Apart from the technical difficulties of achieving continuous point measurements, there can be site differences brought about by seasonal variability, differing biophysical characteristics within the plantation tree (or the stage within the plantation rotation cycle) and silvicultural practices. The significant differences between the water uses of a seedling plantation tree, a tree approaching canopy closure, or a tree just prior to clear felling, all add to accounting complexities if accounting is to be accurate and accumulative for each point in time, for each plantation management compartment, or water resource management unit.

Due to these technical and practical limitations, the use of deemed values for plantation forest impacts appeared to be a practical way of accounting for the variable plantation impacts on water resources. Deemed values are considered to reflect a reasonable characterisation of biophysical reality in plantation forests of the same type in the same groundwater management area. They are

[13] Naracoorte Ranges PWA, Comaum-Caroline PWA, and Lacepede Kongorong PWA

not point measurements of impact, but are considered appropriate estimations of groundwater impacts and suitable for accounting and management purposes.

14. Annualised deemed values

A further practical consideration is the temporal scale to which deemed values for forest impacts on water resources are applied; should values reflect the annual impact, the forest growth stage, seasonal conditions, and plantation site variability? In considering the use of deemed values in a temporal context, the issue of spatial distribution of any assigned value also requires consideration for each form of hydrological impact.

Significant factors in considering spatial and temporal issues include administrative practicality and the ability of the aquifer to 'buffer' any inherent variability. Variability can be caused by different stages of the plantation life cycle, seasonal variability, plantation site variability (productivity), or plantation management variability. The causes for variability may be for multiple reasons and consideration should be given to whether any accounting system, or systems, should be common to both water accounting and water management policies.

While the annualised approach was developed specifically for the robust lower South East unconfined aquifer, it may also be a useful concept for accounting and allocation purposes in surface water systems and fragile aquifers. However, it may not be the appropriate mechanism for management in these systems. In fragile and endangered water systems, the management approach may need to include site management of peak annual water impacts, with consideration to plantation design for optimal water sustainability outcomes for other water users and the forest owner.[14]

This report discusses the rationale and approaches taken in establishing the adopted deemed annualised values for accounting and managing the impacts of plantation forest on South East groundwater resources.

[14] Plantation design criteria may include buffer widths, maintenance of open drainage lines to prevent interception of overland flows of water, the orientation of planting rows in relation to natural contours, or breaks in planting mounds to allow the passage of water.

15. Softwood plantation industry

At the time of considering the options for accounting and management of plantation forest water issues,[15] the South East plantation forest estate was about 100 000 ha of softwood long rotation plantation, mostly comprising *Pinus radiata.* The softwood industry has well-established infrastructure in place, for both plantation management and value adding to the harvested product. In general, there are well-established industry programs of plantation felling, thinning and replanting operations to provide a steady flow of wood products to various markets. This implies a relatively consistent and constant impact on regional water resources from the aggregated plantation biophysical processes. Furthermore, the aggregate softwood forest area expansion rate remains at less than one per cent per year.

16. Hardwood plantation industry

While the softwood industry can be considered as a 'mature' industry, the hardwood short rotation plantation industry has not settled to a regular work and replanting routine. Most of the existing hardwood (Tasmanian blue gum) plantation forest area was planted in the four-year period from1999 to 2002.[16] Due to the investment nature of the South East hardwood industry, it is anticipated that harvesting will generally occur in plantations 9-12 years of age, depending on productivity, management obligations to investors, and logistics such as harvesting capacity, transport, and wood chip contract conditions.

The existing hardwood plantations were largely established to supply the export wood chip market for paper pulp production. If the proposed Penola Pulp Mill proceeds to construction, it is anticipated that the local hardwood industry will need to manage future harvests to provide a steady product flow to the local mill when operational. This will require a plantation replanting strategy that will support the contractual commitments for a consistent product flow to the pulp mill.

The area of Tasmanian blue gum plantations in the lower South East at the end of 2008 was estimated to be 43 000 ha.

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[15] These issues were being considered in the period 1999-2000, when the water allocation plan for the Lacepede-Kongorong Prescribed Wells Area was being considered

[16] During the period 1999-2000, development applications for land use change were approved, or proposed for about 35 000 ha of blue gum plantations. At 2002, about 25 000 ha of the 35 000 ha had been planted.

17. Annualised impact of plantation forest on groundwater resources

Using biophysical principles and a plantation forest management calendar to characterise forest water use, a simple numeric model was developed in 2001 to represent plantation water requirements, or conversely, to express how much groundwater recharge occurred under plantation forests in the lower South East.[17] This was considered to be an important need as there was a likelihood of further extensive plantation forest expansion with a species that was relatively unknown to the region, with respect to impacts on water resources.

Since the mid 1970s, most forest development has occurred on land previously utilised as dryland pasture. It is this agricultural landscape that is largely responsible for groundwater recharge and influences the quantity of water allocated to licensed beneficial uses. Therefore, any significant reduction in groundwater recharge from anthropogenic induced causes requires accounting and management, particularly where the water resource is fully allocated, approaching full allocation, or valued water dependant environments are placed at risk.

While lower South East agricultural land use and management is in 'constant change', responding to market demands, seasonal variability and technology advances, recharge impacts vary at a point scale. However, in terms of broad management area scale, the observed water table trends have generally remained within the historic range of variability until the early 2000s when the accumulative effect of a number of recent years of below average rainfall started to take effect.[18]

The historic data indicates that while there may be differences in recharge in the agricultural landscape, the fluctuations have not been of a magnitude to warrant hydrologic management of the agricultural landscape changes at this time.

This also provides a reinforcement of the view that the proposed annualised approach to forest accounting is suitable for a mature and relatively stable industry with a continuous program of felling

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[17] At the time, as it was considered there was no significant relevant technical advice regarding direct extraction of groundwater by plantation species, it was decided that this possibility would not be included in a plantation forest water budget until further investigated.

[18] The long-term (100 year) mean annual rainfall for Naracoorte is 565 mm and the median value is 570 mm. For eleven of the last 15 years, the annual rainfall has been below the long term mean, with the cumulative deviation below the mean annual rainfall for the four years 2005-2008 being 688 mm. For the previous 15 years (1978 to 1992), only 6 years had an annual rainfall less than the long term mean.

and re planting, as practiced by the current softwood industry. With the prospect of the development of a regional pulp mill, it is expected that the hardwood industry will 'mature' quickly because of the relatively short time from planting to harvest and the need to establish a stable and constant flow of raw material into the future for local pulp processing.

18. Hydrologic response by plantation forest

Different hydrological responses are expected from a forest plantation at each site or development stage. In the accounting model, the hydraulic responses are summarised as an expression of what would normally occur in the dryland agricultural landscape that the forest has replaced, or could be substituted for. The responses are treated as assumptions that are generally accepted by forest and water resource scientists and the forest industry. The base hydrological assumptions were adopted in 2001.[19] The impact phases are separated into the following forest development stage descriptors:

- Pre-planting period of one year before the planting of seedling trees. Based on the assumption of some weed control, recharge occurred at the same rate as the management area rate (that of the dryland agricultural landscape).
- From canopy closure, or full site occupancy, until the site was clear felled, there was no aquifer recharge from rainfall (100% interception of groundwater recharge by plantation forests).
- Transition from the recharge phase in the pre planting period to the no recharge condition in the post canopy closure phase is considered linear.

19. The adopted annualised forest water recharge model

The adopted forest water model 'smoothes' hydrologic impacts over the full forest rotation period and expresses impacts as an annualised value for the full rotation of all plantations of the same species in the same groundwater management area. An important model aspect is the annualised impact of commercial plantation forests on groundwater recharge is expressed as a percentage of recharge that occurs in a dryland agricultural landscape in each individual groundwater management area.

The forest water model minimises administrative complexity for water accounting by not having to assess and track forest water use at different stages of forest growth throughout the forest rotation.

19 At a meeting late in 2001, CSIRO forest scientists and hydrogeologists, state hydrogeologists, water resource managers and forest owners agreed with the base hydrological assumptions associated with the forest stage.

The model is considered relatively robust and reliable for a 'mature' plantation forest industry, such as in the South East where there is a constant activity of planting, thinning and clear felling. This activity is generally distributed throughout the region, rather than being concentrated at any one point in the general landscape. This is largely an historic consequence of land acquisitions combined with a deliberate risk management approach by the industry. It is considered any model limitations, compared to actual physical reality, are insignificant when compared to the natural recharge variability of annual rainfall and its incidence.[20]

The recharge model indicates hardwood plantations use more water than the replaced or alternative dryland agricultural landscape. The impact of hardwood plantations on groundwater recharge is that they intercept 78 per cent of the average annual groundwater recharge that would normally occur under the agricultural landscape.[21] Conversely, the annualised groundwater recharge under a hardwood plantation is 22 per cent of that occurring under a dryland agricultural landscape.

For softwood plantations, the corresponding values are an annual water use equivalent to 83 per cent of the recharge under an agricultural landscape. Alternatively, the annualised forest impact on groundwater recharge can be expressed as the forest allowing 17 per cent of the recharge that occurred under the previous, or alternative, agricultural landscape.

Applying the model outputs to the most recent assessments of groundwater recharge in the main forested groundwater management zones, in comparison to the dryland agricultural landscape, hardwood plantations reduce recharge of the local groundwater system by between 94 mm and 117 mm per year.[22] In the case of softwood plantations, the relative reduction is between 100 mm and 125 mm per year.[23]

If the *forest threshold area*[24] was fully developed, plantation forest would reduce recharge to the lower South East unconfined aquifer by about 205 000 ML per year, under mean rainfall conditions.

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[20] In 2006 key stakeholders reviewed and reaffirmed the model concept, during a consultation process convened by the South East Natural Resources Management Board.

[21] Agricultural landscape consists of pastures and annual cropping. It is a mixed and variable landscape reflective of traditional agriculture and is the main source of groundwater recharge.

[22] For the management areas of Coles and Short, annual groundwater recharge on the agricultural landscape is assessed at 120 mm and 150 mm /yr respectively- ref DWLBC 2007/11

[23] For the management areas of Hindmarsh, 2A and 3A, annual groundwater recharge on the agricultural landscape is assessed at 150 mm, 140mm and 120 mm /yr respectively- ref DWLBC 2007/11

[24] Threshold area is a term used in the National Water Initiative. It is the sum of the existing plantation forest estate plus any allowance for plantation expansion that has been accounted for within the water budget. In the

20. Annualised groundwater extraction impact models

In addition to the annualised recharge impact values for softwood and hardwood, plantations, annualised groundwater extraction impact models have also been developed for both plantation types overlying shallow water tables.

The adopted annualised groundwater extraction model indicates that where the median water table is six metres or less below ground level, hardwood plantation forests extract 1.82 ML/ha/year and softwood plantation forests extract 1.66 ML/ha/year.[25]

The extraction model is based on biophysical principles and information provided by the CSIRO technical report *Water use by Tree Plantations in South East South Australia.*[26]

Based on the latest data and the depth to water table determined by the recent LIDAR survey and digital elevation modelling (DEM), there is approximately 60 000 ha of plantation forest extracting about 106 000 ML per year from the groundwater system.[27]

A previous extraction estimate, prior to the availability of the DEM, was 80 000 ML/year and this was presented in the DWLBC 2007/11 report.[28] Based on recharge data reported in DWLBC 2007/11, the combined impact of plantation forests on the total water budget is about 32 per cent of the total water available for allocation and that assigned to forest impacts.

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case of the lower South East, threshold tables were developed by summing the forest estate, as at 2002, and approximately 59 000 ha of recharge allowed for expansion potential.

[25] These figures are annualised values derived from a model that was refined by a technical working group convened by the SENRMB during the key stakeholder consultation process of September - November 2006

[26] CSIRO Report 148, Benyon, R and T Doody; September 2004; and also presented in Australian Journal of Botany, 2006, **54**, 181-192; *Impacts of tree plantations on groundwater in south-eastern Australia;* Richard G. Benyon, S Theiveyanathan and Tanya M. Doody

[27] Base data from SERIC and calculations by DWLBC Mt Gambier; per coms, Jeff Lawson, 14 November 2008

[28] DWLBC 2007/11. *A New Understanding on the Level of Development of Groundwater Resources in the South East*. Latchem B, R Carruthers, G Harrington and D Harvey

21. Plantation forest descriptions for accounting and management

To manage both forest types (hardwood or softwood), as separate but single classes, has administrative benefit for both forest owners and the water resource manager. It minimises the need to account for the various plantation growth stages or for individual years. This is achieved by treating each forest type as a single accounting class, regardless of age. In reality there is, and expected to be, significant point variability of impacts on the groundwater resource at each growth stage, or site, in the same management area, but an acceptance of the 'unders' and 'overs' and aquifer resilience to short term fluctuations, it is considered the annualised models are suitable in the current context.

In consultation with the forest industry, the two forest types have been described in terms of forest life (years) from planting to clear felling. In the case of softwood plantations, the number of thinning operations is also included. To assist in 'visualising' the characterised plantation, each industry has estimated the productivity, or site quality, of its 'standard plantation'.

The hardwood plantation industry has advised that second rotations will be established by replanting and not by the coppice method.[29] Industry has acknowledged if coppicing were to be practiced, there is an expectation the forest manager would be responsible for the additional water impact associated with a coppiced plantation. This additional impact would likely be accounted for by quarantining an appropriate water allocation for the plantation life for the additional deemed annualised impact.

In the case of softwood plantations, there is considerable variation in how the three main South East forest companies manage and harvest their plantations. During the 2006 review, it was generally agreed plantation rotation length varied from about 28 years to 45 years, with some compartments being harvested at a greater age, however, industry agreed on a single description that takes account of different plantation management strategies through a 'weighting' approach.

In the development of future water allocation plans, a review of silvicultural practices or forest management changes is anticipated to be undertaken, including a review of the current description of the typical plantation and hence, the annualised water accounting model.

While it is a policy issue to be confirmed, through the relevant water allocation plan, the impact of changing annualised deemed values for recharge impacts should only impact on the transfer water

[29] Current view of the hardwood industry is higher forest productivity will be gained from improved genetic material that is associated with replanting with seedling stock, rather than continuing by coppicing the existing tree stock. There are also management cost issues in establishing a second rotation by coppicing.

accounting, that is, for a business enterprises entering and exiting the industry, or changing the forest type. In the case of a stable mature forest industry, a change to the deemed recharge values should have no consequence for ongoing forest water rights if the accounting approach remains a function (a percentage) of management area recharge.

In 2006, the respective plantation industries supported the following basic descriptors for the 'standard plantation' forest: [30]

21.1 Hardwood (short rotation) plantation forest

- Planting to harvest, the time period is ten years;
- Expectation of a site index of 14 with an aggregated productivity of 220 cubic metres by year ten; and
- Establishment of next rotation is one year after clear felling and by planting new seedlings (no coppicing).

21.2 Softwood (long rotation) plantation forest

- Planting to harvest, the time period is 35 years;
- Four thinning operations, where the object is to approximately halve the tree stocking existing at the time of commencing the thinning;
- Plantations expected to be site quality three; and
- Establishment of next rotation is one year after clear felling.

Table 1 presents a summary of current (2006) assigned deemed annualised values for South East plantation forests. Details on the assumptions, rationale, construct and mathematics of the models are presented in the section titled *Development of the plantation forest annualised recharge impact model*, later in this report.

[30] Determined and agreed by industry representatives in consultation with the South East Natural Resources Management Board in October 2006.

22. Summary

- The impact of plantation forest on water resources in the lower South East is determined by the deemed annualised impact per hectare of forested land, relative to the agricultural landscape replaced or substituted for. In the case of hardwood plantations, groundwater recharge for the forested area is reduced by 78 per cent of that of the agricultural landscape and softwood plantations reduce recharge by 83 per cent.
- Where the median water table is six metres, or less, from ground level, hardwood plantations are deemed to extract 1.82 ML/ha/year, on an annualised basis, and softwood plantations are considered to extract 1.66 ML/ha/year.
- Dryland agricultural uses are constantly changing, but at a management area scale the outcome on the groundwater system remains relatively constant. It is recognised that if any significant hydrological changes were brought about by agricultural land-use change, or by land management change, they would need to be assessed on merit at the time of identification.
- The overall impact of plantation forest on water resources is estimated to be equivalent to about 32 per cent of the volume of water potentially available for allocation in the lower South East.

ANNUALISED PLANTATION FOREST GROUNDWATER IMPACT MODELS

23. Forest water accounting concepts

The following discussion describes the two initial conceptual numeric recharge models developed in 2001. These characterised the hardwood and softwood plantation impacts on groundwater recharge and currently underpin the accounting and administrative processes in South East water resource management.

The area of a plantation forest that impacts on the groundwater resource was agreed with the plantation industry as being the effective or productive plantation forest area that lay between the outer stump lines of a plantation compartment. This area may incorporate 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 generally reports for fire information surveys.

In 2006, the two initial recharge models were revised and the revisions are expected to underpin forest water management in the next water allocation plan. In addition, groundwater extraction models were developed for both forest types in 2006. These currently apply to new plantation forests established over shallow water tables.[31]

Each model version and the underpinning applied assumptions are described in this section.

24. Hardwood recharge model: version 2001 (11-year rotation)

The assumptions applied to the conceptual numeric models were based on descriptions of plantation forest industry management at the time (2001) and agreed by a meeting of CSIRO forest scientists and hydrogeologists, State hydrogeologists and water managers, Catchment Water Management Board representatives and South East plantation forest owners.

Within the models, the particular hydrological responses are related to the plantation biophysical stage and management assumptions for the forest site.

[31] Introduced by regulation on 31 July 2007

24.1 Forest management assumptions:

- One year of weed control prior to planting seedling trees.
- Canopy closure occurs three years after planting.
- Clear felling occurs 11 years after planting.
- One year clean up following clear felling.

24.2 Hydrological impact assumptions based on forest biophysical stage:

- Recharge occurs for one year prior to planting at the management area recharge rate (MARR).
- No recharge under a closed canopy forest.
- Reduction in recharge from planting to canopy closure is linear.
- Recharge resumption after clear felling back to the MARR is linear.

24.3 Calculation of annualised recharge impact (refer to Figure 3) :

- Recharge impacts expressed as a percentage of MARR.[32]
- Recharge credit for the one year prior to planting is 100% MARR
- Recharge credit for three years from planting to canopy closure is [3/2]*100% MARR
- Recharge credit for final year of rotation, for clean up, is [½]*100% MARR
- Sum of all credits divided by 13 years is the annualised recharge impact of hardwood plantations, expressed as a percentage of MARR:

[100 + (300/2) + (100/2)] /13 % MARR

= 23% MARR

25. Softwood recharge model: version 2001 (30-year rotation)

The assumptions were based on descriptions of plantation forest industry management at the time and developed using similar principles as applied to the hardwood model.

[32] For offset accounting, recharge can be expressed as an annual volume, or irrigation area based equivalent. The units of licensed water allocations at the time were area based Irrigation Equivalents (IE) with a designated exchange rate in ML.

25.1 Forest management assumptions:

- One year of weed control prior to planting of seedling tree.
- Canopy closure occurs six years after planting.
- Clear felling occurs, on average at 30 years after planting.
- Two thinning operations occurring before clear felling.
- One year 'clean-up' following clear felling.

25.2 Hydrological impact assumptions based on forest biophysical stage:

- Recharge occurs for one year prior to planting at the MARR.
- No recharge under a closed canopy forest.
- Reduction in recharge from planting to canopy closure is linear.
- Recharge resumption after clear felling back to MARR is linear.
- A recharge, equivalent to 50% MARR, occurs in the year immediately following each thinning operation.

25.2 Calculation of annualised recharge impact (refer to Figure 4):

- Recharge impacts expressed as a percentage of MARR.
- Recharge credit for the one year prior to planting is100% MARR
- Recharge credit for six years from planting to canopy closure is [6/2]*100% MARR
- Recharge credit for each year following the thinning is [2*1/2]*100% MARR
- Recharge credit for final year of rotation, for 'clean-up' is [½]*100% MARR
- Sum of all credits divided by 32 years is the annualised recharge impact of softwood plantations, expressed as a percentage of MARR:

[100 + (600/2) + (200/2) + (100/2)] /32 % MARR

=**17% MARR**

A graphic expression of the two annualised recharge models are presented in Figures 3 (hardwood) and 4 (softwood).

26. Revision of the 2001 annualised recharge impact models

As an input to the report DWLBC 2006/02,[33] based on the same plantation forest calendar, a groundwater extraction model was developed. The plantation forest industry later indicated that the forest calendar required revision to better reflect its management practices and the estate at the time (2006). This request was addressed during an industry consultation process conducted by the South East Natural Resources Management Board (SENRMB) in 2006.[34] Consequently, the hardwood and softwood recharge models were revised to reflect a more considered description of a typical plantation forest estate, its management, and the related biophysical characteristics. These discussions led to refined models being developed for the Lower Limestone Coast Prescribed Wells Area Water Allocation Plan.

In the 2001 model, the decreasing recharge benefit from planting to canopy closure was presented linearly. The plantation industry expressed a view that it preferred the recharge representation (while still essentially linear) as a specified percentage of the management area recharge rate in each consecutive and relevant year.

The revised 2006 recharge models are summarised below.

27. Hardwood recharge model: version 2006 (10-year rotation)

27.1 Forest management assumptions:

- Weed control (mid row between seedling rows strip sprayed, representing 50% of area) is practiced at time of planting seedling trees, and generally considered as persisting 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.

[33] *Review of groundwater resource condition and management principles for the Tertiary Limestone Aquifer in the South East of South Australia*, Brown KG, Harrington GA and Lawson J, DWLBC 2006/02

[34] SENRMB Technical sub- committee meeting 4 October 2006

27.2 Hydrological impact assumptions based on forest biophysical stage:

- Recharge credit of 120% of MARR for 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 clean up year, but recommences in following year, which is the planting year of the next rotation.

27.3 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 impact of hardwood plantations, expressed as a percentage of MARR.

[120% + 80% + 40%] /11 MARR

= 22% MARR

28. Softwood recharge model: version 2006 (35-year rotation)

The assumptions are based on descriptions of plantation forest industry management at the time (2006) and developed using similar principles as the hardwood model.

28.1 Forest management assumptions:

- Full weed control at time of planting seedling trees (usually follows clear felling and clean up year of a previous rotation).
- Canopy closure occurs six years after planting.
- Clear felling occurs at 35 years.
- Four thinning operations occurring before clear fell.
- One year clean up following clear felling.

28.2 Hydrological impact assumptions based on forest biophysical stage:

- Recharge occurs at 120% of MARR for 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.

28.3 Calculation of annualised recharge impact:

- Recharge impacts 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 32 (years) is the annualised recharge impact of softwood plantations:

{[120%+100%+80%+60%+40%+20%] + [50%+50%+50%+50%]} /36 MARR

= 17% MARR

A graphic expression of the two revised annualised recharge models are presented in Figures 5 (hardwood) and 6 (softwood).

29. Direct extraction annualised models

From 2002 to 2004, CSIRO observed and sampled a number of sites situated in commercial hardwood plantation forests in the area known as Wattle Range, west of Penola. Following this study and combined with observations at other sites, CSIRO released a technical report and other technical papers on the issue of direct extraction of groundwater by plantation forest species from shallow water tables.

Essentially, the value attributed to groundwater extraction by the plantations is the difference between the annual evapotranspiration of the observed trees and the rainfall observed at the respective sites. The CSIRO report includes adjustments for changes in soil moisture storage. The methodology is described in the CSIRO papers, *Water use by Tree Plantations in South East South Australia*[35] and *Impacts of tree plantations on groundwater in south-eastern Australia*[36]. In order to develop a numerical model that characterised the direct extraction of groundwater by plantation forests, the following findings of the CSIRO documents were noted:

- Hardwood and softwood species in the lower South East can extract groundwater where the water table is shallow (a six metre median depth, or less, from ground level to the water table) and there is no root impedance between the ground surface and the water table.
- All observations were taken in closed canopy forests.
- Eight of the nine research plots used groundwater, while at the ninth site a shallow hardpan layer is believed to have prevented *Pinus radiata* trees accessing groundwater.[37]
- A mean annual extraction rate of 4.35 ML/ha was observed for the eight water extraction sites, with lower and upper 90% confidence limits of 3.22 ML/ha and 5.48 ML/ha.
- Annual extraction values for the observations ranged from 1.08 ML/ha to 6.70 ML/ha.

To develop an accounting numeric model for direct extraction by plantation forest, the following principles and preferences were assumed:

- For management purposes, the groundwater extraction impacts should be based on the principle that hydrogeological impacts are averaged over the forest life cycle. This is the same approach adopted in estimating plantation impacts on groundwater recharge and could be considered complementary to the existing annualised recharge models.
- While CSIRO observations did indicate extraction from depths greater than six metres, there was (and is) no obvious justification or policy reasons at this time to depart from the CSIRO specified median depth of six metres, or less.

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[35] CSIRO Report 148, Benyon, R and T Doody; September 2004.

[36] ***Australian Journal of Botany***, 2006, **54**, 181-192; Richard G. Benyon, S Theiveyanathan and Tanya M. Doody

[37] A shallow hardpan layer condition has occurred at some commercial forest sites, resulting in lower forest productivity. The industry now uses extensive soil analysis in selecting plantation sites; with many land purchase agreements being subject to a full soil analysis. The land selection process now minimises the likelihood of significant future impact of this condition on forest production.

- CSIRO have presented no evidence to suggest that either pine or blue gum have any greater propensity to extract groundwater than the other. Consequently, CSIRO has assumed that the mean annual impact of the two species is identical.
- Observed values are representative of closed canopy plantations at peak productivity.
- To ensure a fair and reasonable baseline value was established, it was considered important to only use data that was collected:
    - during the same time sequence; and
    - from plantations recognised by the industry as being commercially managed sites.

The outcome was the peak annual mean baseline extraction value of 3.64 ML/ha for plantation forests overlying a shallow water table of six metre median depth, or less, from ground level. This is compared to the CSIRO reported value of 4.35 ML/ha/year.

Five observation sites contribute to the value of 3.64 ML/ha/year, while eight sites provided data to give the CSIRO value of 4.35 ML/ha/year. A hardpan site is believed to exist at one site of the five sites used in the above DWLBC calculation, essentially discounting the potential impact down to the adopted management value of 3.64 ML/ha/year. Abbreviated data used to establish the 3.64 ML/ha/year value is presented in Table 2.

30. Assumptions for the direct extraction annualised accounting models

The assumptions for the direct extraction models are based on the plantation forest management practices and associated biophysical assumptions applied to the 2006 revision of the recharge models. These were established in consultation with the plantation forest industry technical representatives.

During these discussions, the hardwood industry expressed a view that coppicing to establish a second tree harvest was unlikely. This was contrary to an earlier position of the industry in not dismissing the use of coppicing. As a result, a precautionary approach was taken in the technical report DWLBC 2006/02 in applying the principle that all hardwood plantations would be coppiced to establish a second wood chip harvest. [38]

[38] It is unclear how a restructured blue gum plantation industry (due to the failure of the main MIS forest managers in early 2009), will approach the issue of establishing the next forest rotation.

31. Hardwood direct extraction model

31.1 Forest management assumptions:

- Canopy closure occurs three years after planting.
- Clear felling occurs 10 years after planting.
- An 11-year management cycle for a 10-year forest rotation.

31.2 Hydrological impact assumptions based on forest biophysical stage:

- Where there is a shallow water table, no direct extraction commences before canopy closure.
- Extraction commences at canopy closure and gradually increases until peak productivity in the 7th year after planting, when extraction plateaus at 3.64 ML/ha.
- Increased extraction from the 4th year to 7th year is considered to be linear, but expressed as a discrete volume for each year.
- Extraction ceases with clear felling.

31.3 Calculation of annualised extraction impact:

- Annualised extraction is expressed as ML/ha/year.
- Extraction is calculated to be 0.91 ML/ha in the year following canopy closure. Extraction for each consecutive year is 1.82, 2.73 and 3.64 ML/ha respectively after canopy closure:

$$[0.91 + 1.82 + 2.73 + 3.64] \text{ ML/ha}$$

- Extraction continues at the peak rate of 3.64 ML /ha for the remaining three years, until clear felling in the 10th year after planting:

$$[3.64 + 3.64 + 3.64] \text{ ML/ha}$$

- The sum of all extraction debits divided by 11 (years) is the annualised recharge impact of hardwood plantations:

$$\{[0.91 + 1.82 + 2.73 + 3.64] + [3.64 + 3.64 + 3.64]\} /11$$

= 1.82 ML/ha/year

31.4 Coppiced hardwood direct extraction model

As there is a possibility that some hardwood plantations may generate a second tree harvest by coppicing, a model with the following key characteristics was adopted:

- A coppiced plantation has the same assumptions as the above single rotation model, but with the following additions for the second tree harvest:
    - From felling to coppicing, there is no recharge of groundwater or direct extraction of groundwater during this one-year period. This year is already incorporated into the initial rotation calculation.
    - From the first year of the coppiced regeneration to peak extraction of the second cropping phase, there is a time lapse of three years. Extraction in this period advances from zero to the adopted peak rate of 3.64 ML /ha. This is apportioned at the rates of 0.91, 1.82 and 2.73 ML/ha respectively for the consecutive years.
    - There are four years of peak extraction of 3.64 ML/ha to clear felling.
    - After clear felling there is one year of site recovery with no groundwater extraction.
    - The aggregated groundwater extraction described in the above assumptions is divided by 19 (years), based on a 10-year standard rotation (an 11-year time lapse) and an eight-year continuation for the coppiced crop, to provide an annualised extraction impact for the hardwood plantation.
- The coppiced plantation extraction can be expressed as:
    - an increase from 1.82 ML/ha/yr to 2.50 ML/ha/yr for the 8 years of the coppiced period, or alternatively;
    - As an average annualised rate of 2.11 ML/ha/yr for the full 19 year plantation period.

32. Softwood direct extraction model

32.1 Forest management assumptions:

- Canopy closure occurs six years after planting.
- Clear felling occurs 35 years after planting.
- A 36-year management cycle for a 35-year forest rotation.

32.2 Hydrological impact assumptions based on forest biophysical stage:

- Where there is a shallow water table, no direct extraction commences before canopy closure.
- Extraction commences in the 7th year after planting.
- Extraction increases from canopy closure until peak productivity in the 11th year after planting when extraction reaches 3.64 ML/ha.
- Increasing extraction from the 7th year to 11th year is considered to be linear, but expressed as a discrete volume for each year.
- Direct extraction is considered to assume a generalised linear taper from the peak of 3.64ML/ha to 1.0 ML/ha towards the end of the rotation. The general decline in extraction reflects the impact of the reducing stem density associated with thinning. The trend is interrupted with each of the four thinning operations, with extractions recommencing at 1 ML/ha, following each thinning, and increasing to offset the increased production until next thinning. This results in a 'ratchet' effect, but within the general overall declining trend.
- Extraction ceases with clear felling.

32.3 Calculation of annualised extraction impact:

- Extraction is expressed as ML/ha /year.
- Sum of all extraction debits divided by 36 (years) is the annualised recharge impact of softwood plantations.
- The individual adopted values contributing to the aggregated extraction of 59.9 ML is presented in Table 3.
- The outcome is an **annualised value of 1.66 ML/ha/year**

A graphic expression of the two-groundwater extraction models is presented in Figures 7 (*Hardwood)* and 8 (*Softwood*), but Figure 8 must be considered with accompaniment of Table 3.

33. Summary

The deemed annualised accounting approach for plantation forest impacts on South East groundwater resources appears to provides a simple administrative accounting tool with the recharge impacts expressed as a percentage of that recharge that would normally occur in the dryland agricultural landscape. The approach is suitable for a mature plantation forest industry in a region with a relatively robust groundwater resource. The system requires little administrative input by the forest or water resource managers, but it should be subject to a regular review to ensure that it is reflective of silvicultural practices for the forest estate being accounted for. Similarly, any new relevant technical knowledge gains, with respect to forest biophysical characteristics or hydrogeology, need to be considered in any revision.

FIGURES AND TABLES

Table 1

Summary of current assigned deemed annualised values for South East plantation forests 2006

Plantation forest type	Forest rotation length – planting to clear felling	**Recharge** under forest relevant to MARR	**Extraction rate per hectare**, where water table is 6 metres, or less, at time of planting	Refer to notes
	Years	**%**	**ML/ha/yr**	1 and 2
Hardwood	10	**22**	**1.82**	3
Softwood	35	**17**	**1.66**	4
Hardwood coppice	10 standard + 8 coppiced = 19	**22**	**2.11** Or, 2.5 for the 8 yr coppiced rotation	5

Note 1: The recharge impact is expressed as a percentage of the management area recharge rate (MARR); it is not expressed as a discrete depth of water as the MARR may be adjusted as technical knowledge for a groundwater management area is refined.

Note 2: It is assumed the policy to be recommended by the South East Natural Resources Management Board in its draft water allocation plan will specify that the extraction assessment is to be based on the depth to water table at the time of planting, or that referred to by the water allocation plan relevant at the time of assessment.

Note 3: Both annualised extraction and recharge rates are based on a rotation length of 10 years from planting to clear felling and the following rotation is established by the full clearance of the initial rotation and a full replant with new seedlings for the subsequent rotation.

Note 4: Both annualised extraction and recharge rates are based on a rotation length of 35 years from planting to clear felling. Recharge and extraction calculations are based on four 'thinnings' within the 35-year plantation rotation.

Note 5: The hardwood industry during the 2006 review, while not ruling out the use of coppicing to generate the next productive rotation, believed it be an unlikely outcome, however an amended deemed annualised extraction rate was established for any coppiced rotation following clear felling. Any minor recharge impact associated with coppicing is ignored.

Table 2

Blue gum groundwater extraction data

CSIRO observations in South East blue gum plantations						
Site ID	Median depth to water table	Plantation age range	Observed rainfall	Mean ET	Net change in soil water	Net water balance
	metre	years	mm/year	mm/year	mm/year	mm/year
BG1	1.7	4 - 6	662	1059	16	-413
BG2	1.7	6 - 9	641	847	-99	-107
BG3	1.9	6 - 9	675	1158	-43	-440
BG4	3.0	5 - 10	545	1193	-12	-636
BG5	3.2	4 - 7	669	904	-9	-226
Mean value for all sites						-364
Derived from Benyon and Doody, (CSIRO) 2004						

Table 3

Annual assignment of groundwater extraction for South East softwood plantations - 2006

Softwood groundwater extraction of standard mean 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**				

Figure 1

Distribution of plantation forest in relation to groundwater management areas

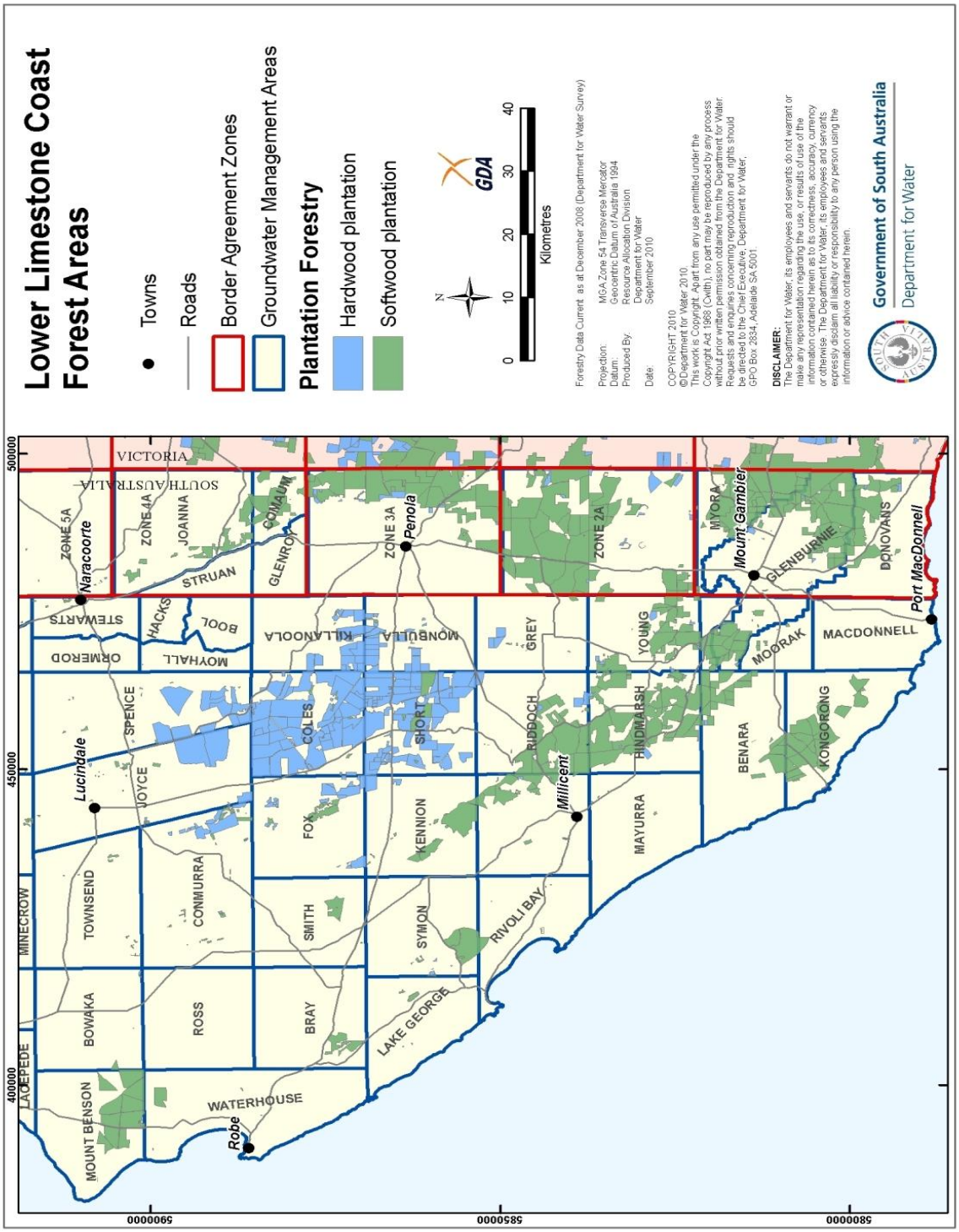


Figure 2

Location of cross sections of Lower South East aquifer system

Figure 2a

Cross section of Lower South East aquifer system: west-east

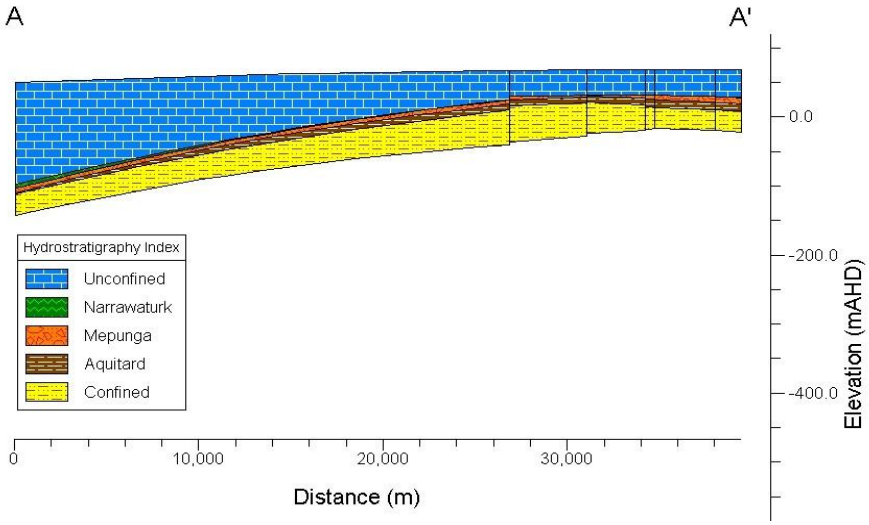


Figure 2b

Cross section of Lower South East aquifer system: north-south

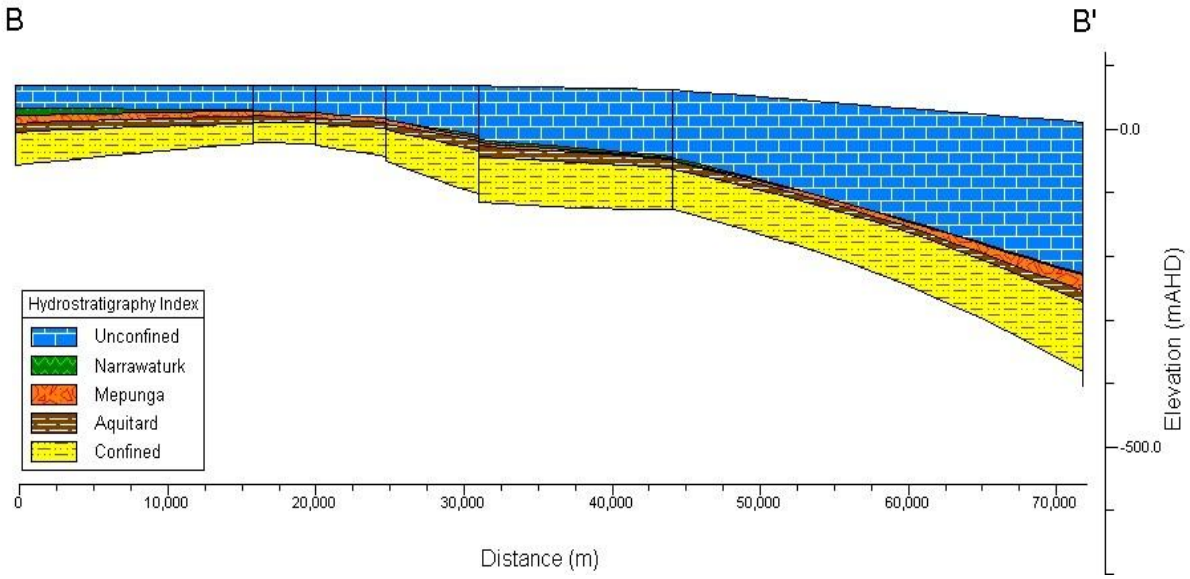


Figure 3

Hardwood annualised recharge impact model: 2001

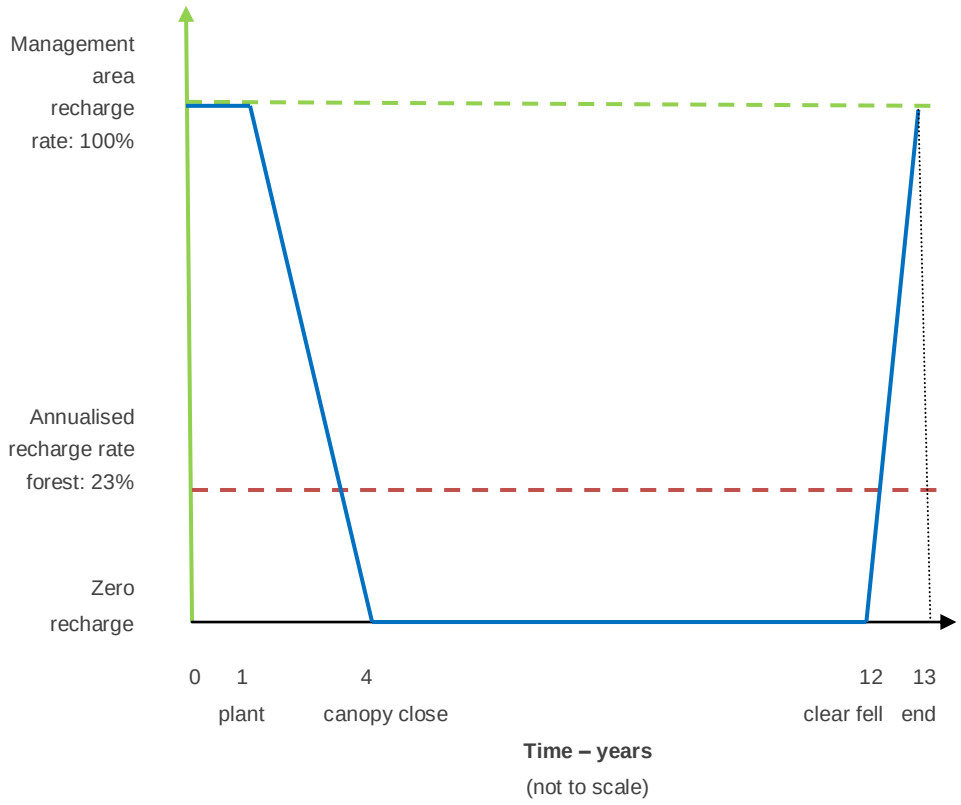


Figure 4

Softwood annualised recharge impact model: 2001

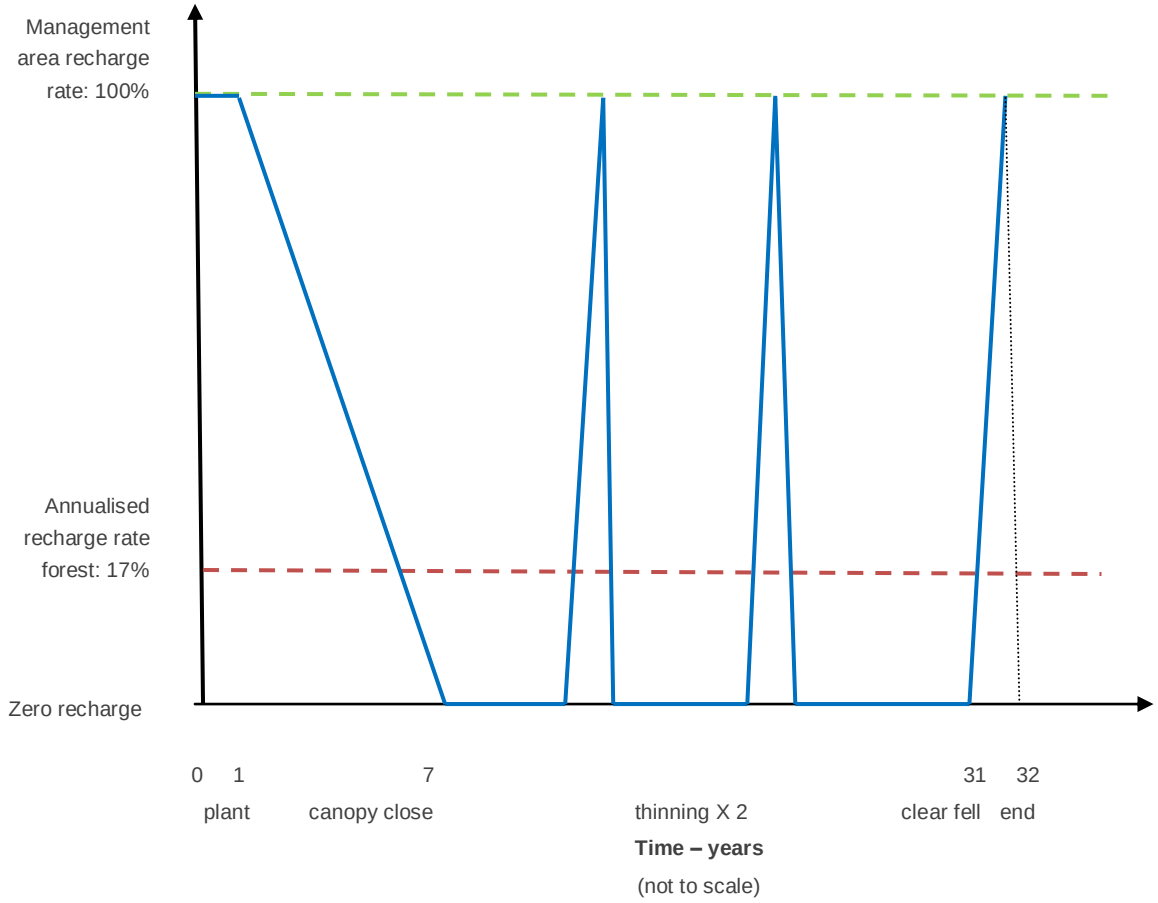


Figure 5

Conceptual model for hardwood plantation forest impacts upon groundwater recharge
Version 2006 - not to scale

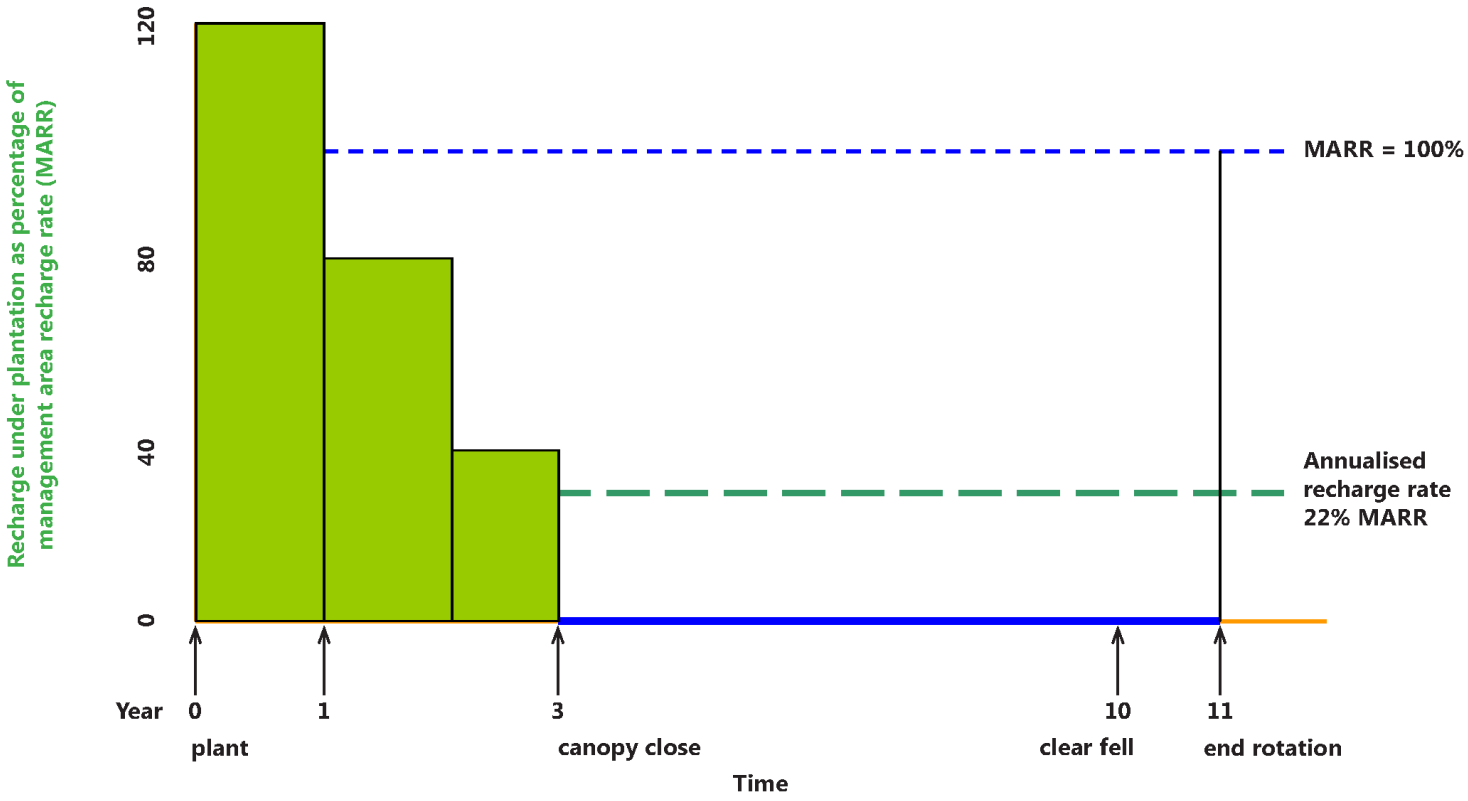


Figure 6

Conceptual model for softwood plantation forest groundwater recharge impacts
Version 2006 - not to scale

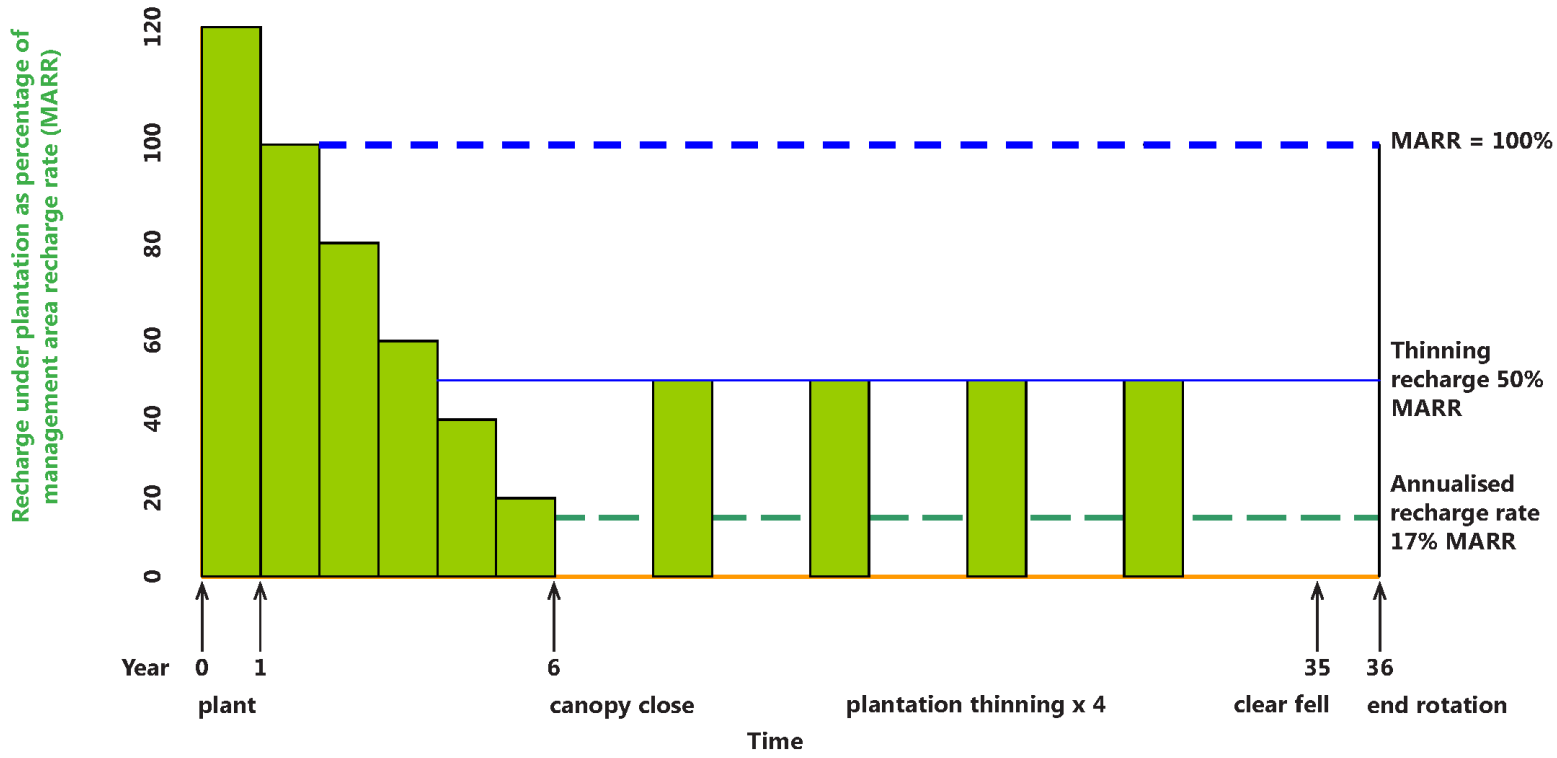


Figure 7

Conceptual model for hardwood plantation forest groundwater extraction impacts
Version 2006 - not to scale

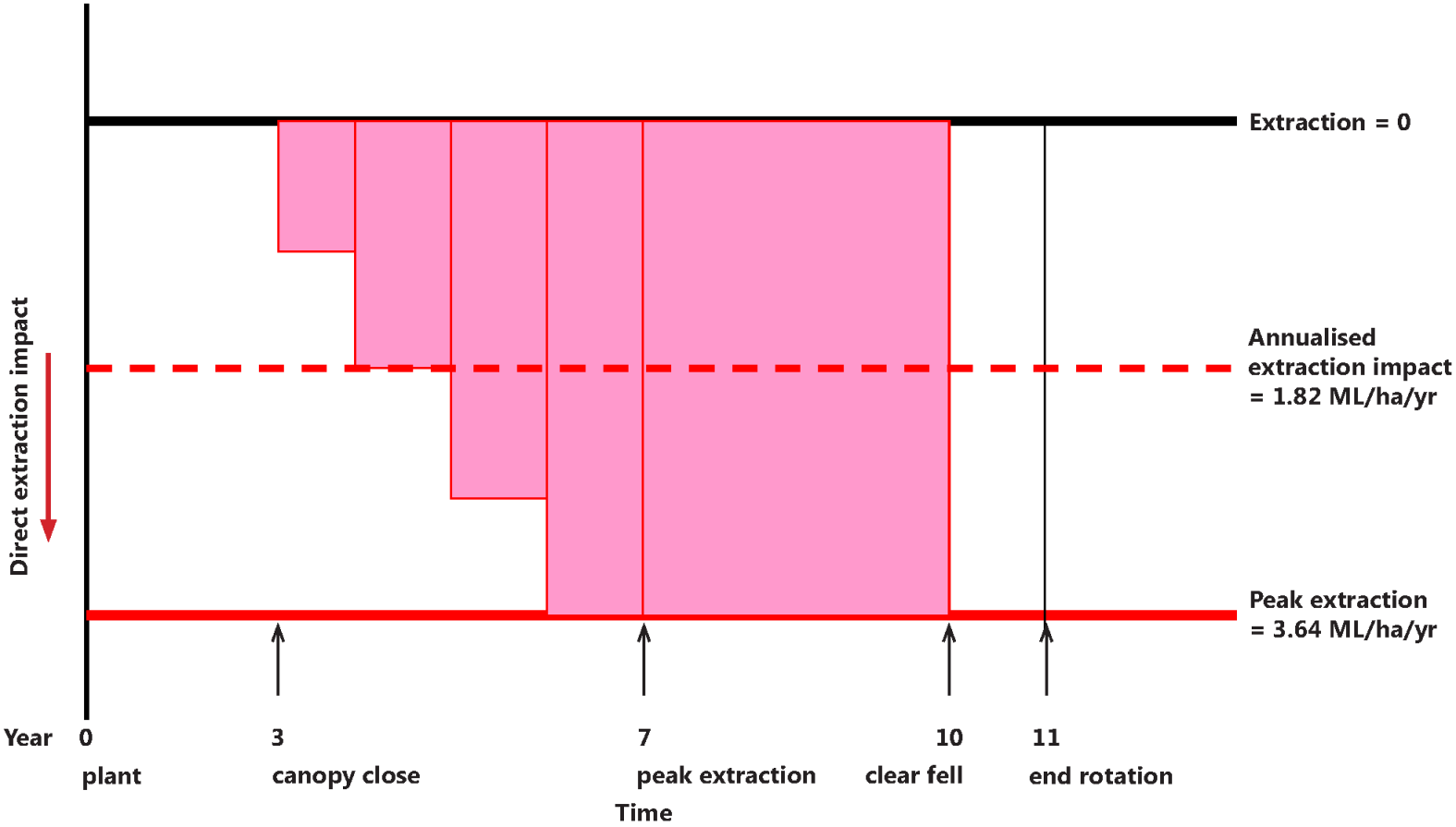
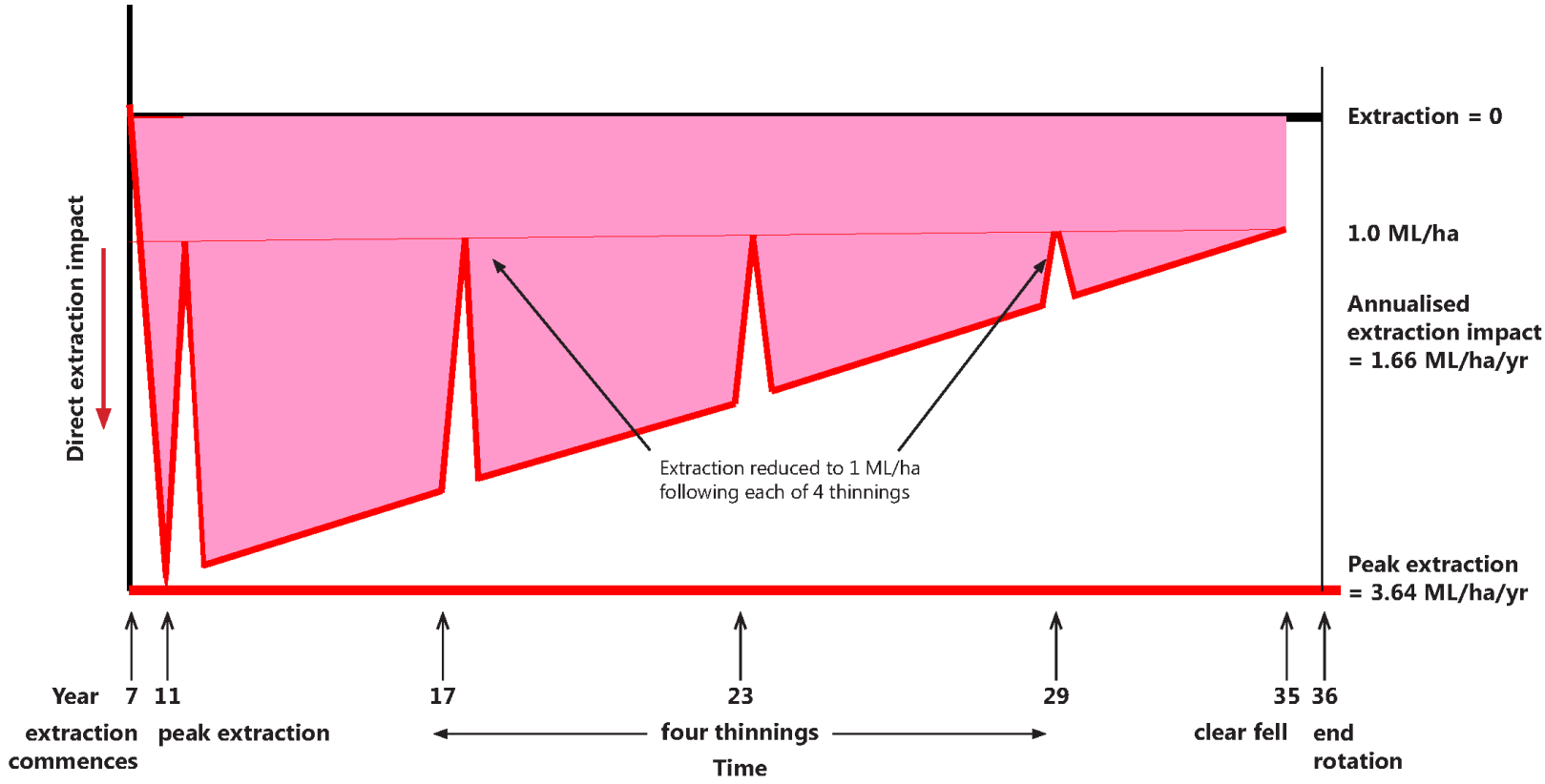


Figure 8

Conceptual model for softwood plantation forest groundwater extraction impacts

Version 2006 - not to scale

The below simplified diagram is presented without annual values:
assigned annual impacts are presented in Table 2



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

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

Catchment Water Management Board — statutory body established under the Act whose prime function is to implement a catchment water management plan for its area

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

Coppicing — the term applied to allowing another eucalyptus plantation tree crop to establish after the clear felling of the original plantation forest. Regrowth occurs from the cut stump of the clear felled trees. While coppicing obviates the need to replant new seedlings, it requires a change to forest management practices due to the numerous new shoots (and potential stems) from the parent stump. There are differing views about the cost effectiveness of the aggregate plantation outcomes, but it is an accepted alternative management strategy to single harvest plantings.

CSIRO — Commonwealth Scientific and Industrial Research Organisation

CWMB — Catchment Water Management Board

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

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

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

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

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

Interception — term used in the *Intergovernmental Agreement on a National Water Initiativ*e (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 water tables

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

Licence system — would record plantation forest impacts as offsets through the water allocation system. Under a licensed allocation system a transferable property right is assigned to the plantation owner/manager/landowner for the deemed impact on the water resource

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

Natural recharge — the infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc). See also recharge area, artificial recharge

Plantation forest — for the purpose of this document, the term is used to describe a commercial plantation forest activity carried out at an industrial scale by companies, or private individuals,

recognised as commercial forest operators. It excludes small-scale commercial forest integrated into a farming operation

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

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

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

PWA — Prescribed Wells Area

Recharge area — the area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer

Significant (or significance) — term used in the NWI (paragraphs 55-57) When the aggregated impact of plantation forests represents a noteworthy portion of the total water budget in the relevant water allocation plan and has considerable impact, the impacts are considered significant

Silviculture — dealing with the development and care of forests

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

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

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

Threshold area — a term used in the NWI. 39 It is the sum of the existing plantation forest estate plus any allowance for plantation expansion for which the impact on groundwater recharge has been accounted for within the water budget

In the case of the lower South East, threshold tables were developed by summing the forest estate, as at 2002, and approximately 59 000 ha of expansion potential. Within the threshold area, the impacts of the plantation forest on groundwater recharge are fully accounted for within the relevant groundwater management areas

It should be noted that no allowance has been made for the impacts of direct extraction of groundwater by plantation forest within water budget of the threshold areas that were developed on 2002 data and implemented in 2004

Transmissivity — a parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m2/d

Water affecting activities — Activities referred to in Part 4, Division 1, s. 9 of the Act

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

[39] NWI paragraph 57

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