

**Potential impacts of forest management on
streamflow in Melbourne's water supply
catchments**

Summary report

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EXECUTIVE SUMMARY

The aim of this report is to summarise the modelling work undertaken in the Wood and Water Project to estimate the impacts of different timber harvesting regimes, bushfire and climate change on water yield in Melbourne's water supply catchments. Its purpose is also to show how the timber harvesting regimes impact on timber yield from the associated Forest Management Areas (FMAs). This work was undertaken in response to Action 2.21 in the 2004 Victorian Government White Paper 'Securing our water future together'¹ aimed at improving water yield from State Forests supplying water to Melbourne.

Two hydrological modelling studies have been completed, followed by a body of work concerned with evaluating the impacts on both water and timber of different management regimes. The studies have also considered the possible impacts on water yield from bushfire and climate change. In the latter context, the current drought (1997 - 2006) was used as an indicator of what may lie ahead.

The hydrological studies used Macaque, a model capable of representing individual timber stands in a catchment, their water use (evapotranspiration) characteristics, the ground elevation, slope and aspect, and the spatial distribution of rainfall. The Macaque model was calibrated for each of the Thomson, Tarago, Bunyip, and Yarra Tributaries catchments, using observed rainfall and runoff data in each case. Some bushfire and climate change scenarios (based on CSIRO projections) were investigated.

To remove the effect of climate variations on water yield within the Macaque model, an average year from the available data was selected for each catchment as representing the long term average rainfall and seasonality, and used to produce a mean annual precipitation surface for each catchment. This, together with curves of age/evapotranspiration (one for each forest species on each catchment), was the data produced for input to the Woodstock timber management model.

The Woodstock model is capable of handling detailed spatial inputs of precipitation, elevation, slope, and forest species. For the Wood and Water Project, it was used to simulate twenty different forest management regimes for their impact on water and timber yield. Eleven of these, chosen to represent the range of response impacts, are included in this Summary Report.

Many assumptions are involved in the modelling of this kind. Some relate to the modelling of quite complex catchment systems and the simplifications that had to be made in the absence of data (eg. local temperature and soils data for the catchments, the prolonged impact on water yield of strip thinning and how climate change is modelled). Other assumptions concern the scenarios to be modelled (eg. occurrence and extent of bushfires and the severity of climate change).

Outcomes from the studies

There are differences between the water and timber yields under different management regimes, but the clear conclusion from these studies is that relatively little additional water is to be gained from changed timber management in the catchments (some four percent per annum by 2050 in comparison to the Status Quo). Under all regimes investigated, catchment water yield is increasing due to the maturing of the forests after the 1939 bushfires; it will be almost an average 40 GL more per annum in 2050 if historic conditions continue (assuming no bushfires). The maximum difference between management regimes investigated also

¹ The White Paper is also known as 'Our Water Our Future'

increases with time, growing to about 16 GL per annum in 2050. [While these figures may seem small in relation to Melbourne current usage (~480 GL per annum), it might be noted that Melbourne Water is currently spending \$100 million on the Tarago Treatment Plant to augment Melbourne's current water supply system by a comparable 16 GL per annum.]

The Study also makes it clear that, under changed forest management regimes, proportions of these water yield gains can be made without great impact on the timber industry.

On the other hand, climate change (which is expected to decrease rainfall and increase evapotranspiration) has a much greater potential for impact (than changed forest management regime) because it affects all of Melbourne's catchments, not just the logged areas. Continuation of the current drought conditions (ie 1997 – 2006) reduces potential flows for the combined catchment totals (not counting the Upper Yarra) by about 30% (or 136 GL per annum) for the best water regime (cease harvest 2009/10). The projected difference between the 'best' and 'worst' timber management regimes (as modelled) for water yield is 15 GL per annum in 2050, similar to that for historic rainfall.

Bushfires can be potentially severe, but rarely burn whole catchments, and almost certainly not all of them together. The Macaque modelling shows that fires like the 1939 bushfire (47% of the Thomson) will have several times more impact (on water yield) than changing timber management regimes. [Note: The impact of fires on timber yields was not considered in this Study.]

The next step envisaged by the White Paper is investigating '*the economic, social and environmental benefits and costs of these options*'. The regimes emerging for such evaluation are listed below.

Best regimes (from the DSE modelling)

For water yield

1. J. Cease timber harvesting by 2009/10
2. H1. 150 year rotation with one-off late age uniform thinning (Thomson only), and strip thinning at age 27
3. G4. 150 year rotation with uniform thinning at age 27
4. E. 150 year rotation with no thinning

For timber yield

1. G1. 80 year rotation with uniform thinning at age 27
2. A. Status Quo
3. B. 80 year rotation with no thinning

For both water and timber

1. G1. 80 year rotation with uniform thinning at age 27
2. G4 150 year rotation with uniform thinning at age 27
3. M. Phase down to 150 year rotation by 2030 with uniform thinning at age 27 and one off late age uniform thinning (Thomson only)
4. E. 150 year rotation

Additional Options

1. L. Existing catchment limits and cease timber harvesting in 2029/30
2. N. Existing catchment limits with uniform thinning at age 27 and one off late age thinning (Thomson only) then cease timber harvesting in 2029/30
3. D. 120 year rotation with no thinning.

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1. INTRODUCTION

The purpose of this report is to summarise the modelling work undertaken as part of the Wood and Water Project to estimate the impacts of different timber management regimes, bushfire, and climate change on water yield in Melbourne's water supply catchments. Its aim is also to show how these regimes impact on timber yield from the associated Forest Management Areas (FMAs).

The Victorian Government White Paper "Securing our Water Future Together"² (DSE, 2004; p36) reaffirmed the policy that Melbourne's original water catchments (eg Upper Yarra, Maroondah, Wallaby Creek, and O'Shannassy) '*are closed catchments and are managed as national parks. Logging will continue to be banned in those areas.*' However, recognising that significant water supplies to Melbourne (eg Thomson catchment) are sourced from State Forests, it states as policy the importance of improving the water yield from them to secure Melbourne's water supplies, and envisaged (Action 2.21):

- undertaking '*hydrological studies on the impact of logging on water yield of catchments in State Forests supplying water to Melbourne*'
- developing '*options aimed at improving the water yield, including potential changes to management practices, and phasing out logging in these areas*'
- assessing '*the feasibility of establishing plantations outside State forests to offset any reduction in timber availability*'
- investigating '*the economic, social and environmental benefits and costs of these options*'.

In response to Action 2.21, the Wood and Water Project was commenced, with significant studies now completed as follows:

- (i) *Hydrological studies into the impact of timber harvesting on water yield in state forests supplying water to Melbourne – Part 1 of Hydrological studies*, Feikema et al, eWater Cooperative Research Centre, October 2006
- (ii) *Hydrological studies into the impact of timber harvesting on water yield in state forests supplying water to Melbourne – Part 2 of Hydrological studies (Climate change and Bushfire)*, Feikema et al, eWater Cooperative Research Centre, April 2008
- (iii) *a number of DSE studies to assess the impacts on water and timber yield of different forest management regimes within Melbourne water supply catchments and associated Forest Management Areas. (DSE, 2008a; DSE, 2008b; Walker, 2008)*

This Summary Report gives an overview of the above studies and results obtained. To provide background context, Chapter 2 provides information on the catchments in question, and their current status with respect to harvested and timber resources. Chapter 3 then gives a brief review of previous research relating to water and timber trade-offs in forested catchments. The hydrological studies described in Studies (i) and (ii) above are summarised in Chapter 4. The modelling of water and timber yields from the catchments (and associated FMAs) is outlined in Chapter 5; the impacts, for a range of management regimes, are considered in Chapter 6. The conclusion (Chapter 7) presents the main findings, and some recommendations for further work.

² The White Paper is also known as 'Our Water Our Future'

2. THE CATCHMENTS IN QUESTION

Melbourne’s average water demand in 2001 was 480 GL per annum (Water Resources Strategy Committee for the Melbourne Area, 2001), with supplies for urban uses primarily from the Yarra catchments (average inflow of 450 GL per annum) and the Thomson (250 GL per annum). These average inflows do not reflect the drought of the last 11 years, or the consequences of long-term climate change.

As previously mentioned, the Upper Yarra, Maroondah, Wallaby, and O’Shannassy catchments were excluded from the Wood and Water Project as national park. However, other sources in the Yarra basin (McMahons, Starvation, Armstrong and Cement catchments, designated in this report as Yarra Tributaries) are included, along with the Thomson, Bunyip, and Tarago catchments. Figure 1 shows these catchments, which form part of the Central Gippsland and Dandenong Forest Management Areas (FMAs).

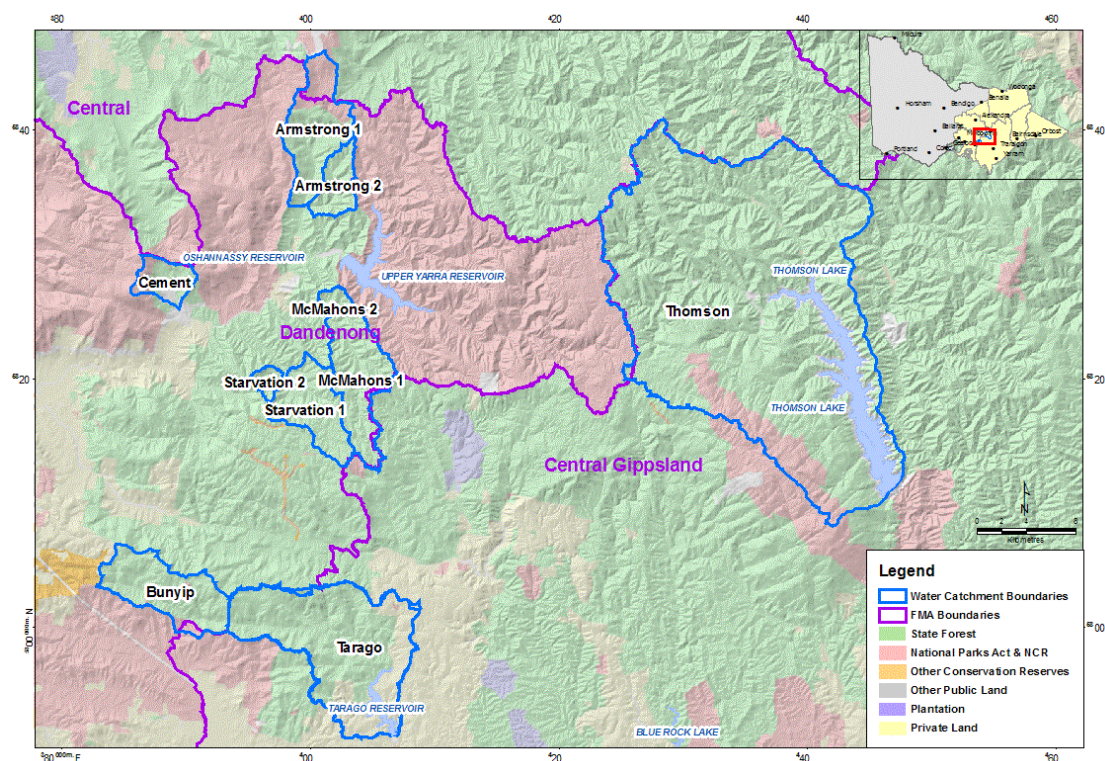


Figure 1: Water catchments in Central Gippsland and Dandenong FMAs. (DSE, 2008b)

Table 1 gives a listing of the current land use and management zones of the catchments, while Table 2 gives details of the timber available for harvest in the associated FMAs.

Table 1. Detailed area summary of water catchments where timber harvesting is permitted. (DSE, 2008a)

Catchment	Productivity	GMZ	SMZ	SPZ	CFP	Parks, Reserves & Other Public Land	Private	Water	Total Area (ha)
Yarra Tributaries	Productive	7,410	390	2,850	1,370				12,020
	Unproductive	460	20	250	80	1,970			2,780
	Total Area (ha)	7,870	410	3,100	1,450	1,970			14,800
Thomson	Productive	18,810	640	5,880	6,510				31,840
	Unproductive	3,370	50	3,420	1,070	5,440	70	2,430	15,850
	Total Area (ha)	22,180	690	9,300	7,580	5,440	70	2,430	47,690
Bunyip	Productive	1,900	330	680	500				3,410
	Unproductive	290	10	40	60	320	20		740
	Total Area (ha)	2,190	340	720	560	320	20		4,150
Tarago	Productive	5,060	1,020	540	900				7,520
	Unproductive	140	150	40	50	40	2,990	340	3,750
	Total Area (ha)	5,200	1,170	580	950	40	2,990	340	11,270

Note: The area of State forests comprises GMZ (General Management Zone), SMZ (Special Management Zone), SPZ (Special Protection Zone) and CFP (Code of Forest Practices exclusions). Timber harvesting is excluded from SPZs and permitted in SMZs and GMZs while considering the protection of other values within these zones.

Table 2. Area summary of available and merchantable stands for Central Gippsland and Dandenong FMAs, with Net Area Study* (NAS) factor adjustments. (DSE, 2008a)

Catchments	Ash species			Mixed species		
	Pre1940s	Post 1940s	Total	Pre1940s	Post 1940s	Total
A. Central Gippsland FMA						
Thomson	4,350	2,390	6,740	380	730	1,110
Tarago	1,360	810	2,170	830	1,020	1,850
Total in catchments	5,710	3,200	8,910	1,210	1,750	2,960
Outside of catchments	11,550	11,260	22,810	9,440	15,370	24,810
Total for FMA	17,260	14,460	31,720	10,650	17,120	27,770
B. Dandenong FMA						
Armstrong 1	470	70	540	310	10	320
Armstrong 2	110		110	100	10	110
Cement Creek	220		220			
McMahons 1	330	430	760	350	120	470
McMahons 2				10		10
Starvation 1	280	600	880	380	230	610
Starvation 2				90	20	110
Bunyip	540	300	840	630	30	660
Total in catchments	1,950	1,400	3,350	1,870	420	2,290
Outside of catchments	2,720	4,810	7,530	4,240	1,920	6,160
Total for FMA	4,670	6,210	10,880	6,110	2,340	8,450

Note: The Yarra Tributaries catchments consist of Armstrong 1 & 2, Cement Creek, McMahons 1 & 2, Starvation 1 & 2 catchments. [*NAS factor is a non-spatial adjustment factor which is the ratio of the coupe net area to the area modelled as available within the coupe gross area.].

The points to note from this information are:

- (i) that the Thomson catchment is dominant in size, water yield, and in timber inventory relative to the other three catchments considered in the Study (Bunyip, Tarago, and Yarra Tributaries).
- (ii) the area available for harvest is only a fraction of the total area, due to physical and planning limitations. In the Thomson, for example, some 83% is excluded from timber harvesting. In the Tarago, the figure is 64% exclusion.
- (iii) the two main commercial vegetation types are Ash species and Mixed Species. This has relevance when considering water yield (see later chapters).
- (iv) the dates (Table 2) of pre 1940s and post 1940s are relevant in the context of the 1939 bushfires which burnt large areas of forest. Thus, much of the regrowth timber is nearly 70 years old, and close to optimum harvest age.

It might also be noted here that bushfires are not limited to the areas of the Study catchments available for timber harvest, and consequently have the potential for much greater impact on water yield. Similarly, climate change and drought will affect all contributing areas, and hence have potentially large impacts on water production in Melbourne's water catchments.

3. PREVIOUS WORK

There have been many studies that relate to water use by trees. This chapter mentions only some pertinent for the Wood and Water Project.

3.1 Experimental studies

The Melbourne and Metropolitan Board of Works (now Melbourne Water) established a catchment hydrology research program in the 1950s, but greatly expanded it in 1968. The Department of Conservation and Natural Resources (now Department of Sustainability and Environment – DSE) was involved in the program from an early stage. Much of the empirical knowledge about tree/water behaviour in the species relevant to the current project stems from this program (eg. O'Shaughnessy and Jayasuriya, 1991; O'Shaughnessy et al, 1993).

One of the best known outcomes is the Kuczera curve (Kuczera, 1987), a plot of water yield versus tree age for *E. regnans* (mountain ash) shown in Figure 2. The relationship was deduced from observed streamflows on eight forested catchments following the 1939 bushfires. It shows the reduced yield during forest regeneration after an intense fire, a relation assumed to also apply for regeneration after timber harvesting of that species. There is considerable scatter in the data points, uncertainty due to extrapolation of the relation beyond the data record for advanced ages; Kuczera included 95% confidence limits to indicate this uncertainty.

[Note. Various forest treatments have been investigated in the Melbourne Water Hydrology Research Program. These included clear-felling, strip thinning (clearing of alternate 35m wide strips), and uniform thinning. Given the time scale of responses involved (as Figure 2 indicates), it takes many decades of measurement to determine the long-term effect of forest management options. Hence, early modelling studies have had to make assumptions based on observed early data, and anecdotal evidence. It is also worth noting the knowledge gap that exists in relation to the longevity of increased yield from thinning treatments.]

3.2 Research on processes

Research conducted by the CRC for Catchment Hydrology and other groups in the 1990s and later aimed at providing a physical explanation for the Kuczera curve. The upward flow

velocity of water in *E. regnans* sapwood was shown to be independent of tree age; a finding which, combined with the amount of sapwood per unit area of forest, explained much of the shape, i.e. younger stands have much higher volumes of sapwood per unit area of forest than older stands. Leaf-area index [LAI] (the ratio of leaf area to ground area) was shown to be important; high LAI values were associated with more active growth. The initial increase in water yield observed in the five years or so after clear-felling was not included by Kuczera, and has to be added. The theoretical picture was completed when the reduced evaporation from the under-storey (due to shading and higher air humidity) was factored in. Figure 2 shows a theoretical curve which results from applying this knowledge, and used to assist in extrapolating for other species. [Research on species other than *E. regnans* is not nearly so extensive. Nevertheless, several studies have shown a distinct, but smaller, response in mixed species forests (where mortality occurs), similar in characteristics to the Kuczera curve.]

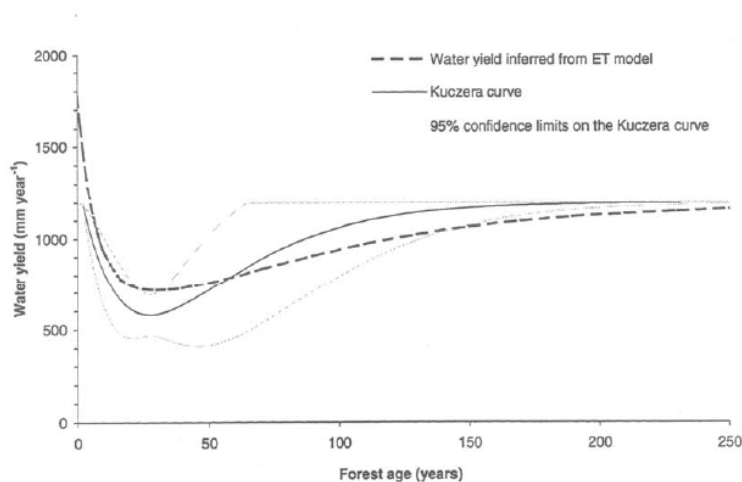


Figure 2. Generalised average annual water yield with *E. regnans* forest age shown by the Kuczera curve. Also shown is a similar relation inferred from evapotranspiration by Watson et al (1999). [Feikema et al, 2006]

3.3 Wood/water Modelling

One two-part study of relevance was that of Read Sturgess and Associates (1992, 1994) for the Thomson catchment. It used the average annual rainfall, and assumed that the Kuczera curve applied catchment wide for ash species. Further assumptions were made with respect to the water yield from other species. Read Sturgess considered twelve forest management regimes. Their studies indicated, *inter alia*, that a no-logging option would give an average yield of almost 290 GL per annum in 2050, compared with just under 260 GL per annum with the 'status quo' (the worst option), a difference of about 12%. Of note is that strip thinning at age 50 years with clear fell at age 200 years gave more water than no-logging in the first 30 years and an average yield of about 275 GL per annum at 2050.

[It should be noted that the area available for harvest in the Thomson is now about 40% of that used in the Read Sturgess study, the most significant point of difference with the Wood and Water Project.]

4. HYDROLOGICAL STUDIES

4.1 Introduction

The Kuczera curve (Chapter 3) is an average curve for *E. regnans* for Melbourne catchments; the Read Sturgess study similarly assumed average responses for each forest species catchment wide. Given the variations in altitude, rainfall, and (hence) vegetation that occur in the catchments considered here, it is very desirable to be able to take spatial variability into account when simulating timber harvesting regimes.

The Macaque hydrological model was developed as part of the research program of the CRC for Catchment Hydrology in the late 1990s. It has the capability to represent rainfall and different species spatially over the catchment, and makes use of the latest research in estimating water use by forest species. The model is widely recognised as being state-of-the-art, and hence was adopted for this study. [Simulations of harvesting, and subsequent impacts on both timber and water yield under different forest management regimes were conducted with the Woodstock model (Chap.5) using inputs from Macaque.]

This chapter has a brief description of Macaque and its capabilities (Sect. 4.2), its performance in calibration runs for the four catchments (Sect. 4.3), and (in Sect 4.4) some modelling scenarios considered in the eWater Cooperative Research Centre (CRC) reports (Feikema et al, 2006, 2008). In particular, it documents the hydrological information transferred to DSE for use in the Woodstock model (Sect. 4.5).

4.2 The Macaque Model

The core Macaque model was initially developed by Watson (1999), but visualisation and statistical tools have been added for its inclusion in the CRC for Catchment Hydrology Toolkit. For application to a catchment, Macaque:

- operates on a daily time-step and is calibrated on the total monthly flows.
- derives a spatially distributed rainfall surface from gauges on and adjacent to the catchment.
- breaks the catchment into a large number of elementary spatial units (ESUs).
- estimates the actual evapotranspiration (AET) for each ESU, based on the vegetation types (understorey and overstorey) and water use characteristics (linked to plant leaf area).
- calculates a water balance for each ESU, using input rainfall, output AET, and surface and subsurface water flows to/from the ESU from those upslope and downslope respectively.

The model has many parameters, most of which are assigned values based on measured data and knowledge of their function. Others (eg. soil parameters for which measured data are unavailable) are determined using trial and error fitting in calibration runs.

Inputs to Macaque comprise:

- topographic data: a digital elevation model (DEM) is used to delineate catchment and sub-catchment boundaries, ESUs, and their elevations, surface slopes and aspects. [A 10m DEM was supplied by DSE and re-sampled at 40m for this study.]
- vegetation type and age: the State Forest Resource Inventory (SFRI) was used for this purpose.
- precipitation: Macaque requires a daily estimate for each ESU, and uses a generated 'precipitation surface' derived from rain-gauge data for this. In operation, derived factors for each ESU are applied to recorded rain at key stations to estimate ESU rainfall.

- temperature: Macaque needs daily maximum and minimum (for each ESU). Such data are very limited, and a procedure to use data for the nearest climate stations (Sale and Melbourne) was devised. [Note: the lack of long-term temperature data is seen as a significant impediment to forest modelling in the Melbourne water supply catchments.]
- fixed values for a number of parameters (using typical values).

Other parameters are determined using calibration as discussed in the next section.

4.3 Calibration of Macaque

Calibration was performed on a portion of the streamflow record for each catchment; the remainder was used for independent validation. Typically, some thirty years or so of data were available for each catchment for this purpose (with less for two sub-catchments of the Yarra Tributaries). Values of only two parameters were determined in the calibration runs; a precipitation scalar, and a hydraulic gradient for groundwater relative to the surface.

A Leaf Area Index (LAI) was assigned to each vegetation type in Macaque based on experience in the nearby Maroondah catchments. A spatial mapping of LAI values over each catchment was compared with the remote sensed normalised difference vegetation index (NDVI) available for 23 December 1988, and found similar in spatial characteristics.

The key performance measure for the Macaque model was the goodness of fit measure **E**, the coefficient of efficiency (Nash and Sutcliffe, 1970). **E** values vary from minus infinity to plus 1.0. Chiew et al (1993) suggest that simulations for which **E** values were greater than 0.6 were satisfactory, greater than 0.8 were rated good. (A value of 1.0 indicates perfect simulation.)

For the Thomson catchment, 45 years of recorded data were available (1954-1998), and divided into three for calibration and validation data sets. Figure 3 shows predicted and observed flows for the whole period. For this catchment, **E** values ranged from 0.736 to 0.847 for three different sets of calibration and validation periods, which shows good simulation performance was achieved.

The other (smaller) catchments were, in the main, also modelled 'satisfactorily' and in most cases quite well.

In addition to the calibration/validation, sensitivity studies were performed to test for the changes in flow and evapotranspiration (ET) in response to changes in LAI and leaf conductance. Both flow and ET were found to be sensitive to these factors, highlighting the need for consistent/accurate values of LAI for each catchment for the Macaque model. [In later studies, input rainfall was shown to be an important determiner of yield, with a 10% decrease, for example, giving about 30% reduction in streamflow.]

The conclusion from the calibration studies is that the Macaque model suitably simulates the interactions between water use and vegetation (type and age) spatially over a catchment.

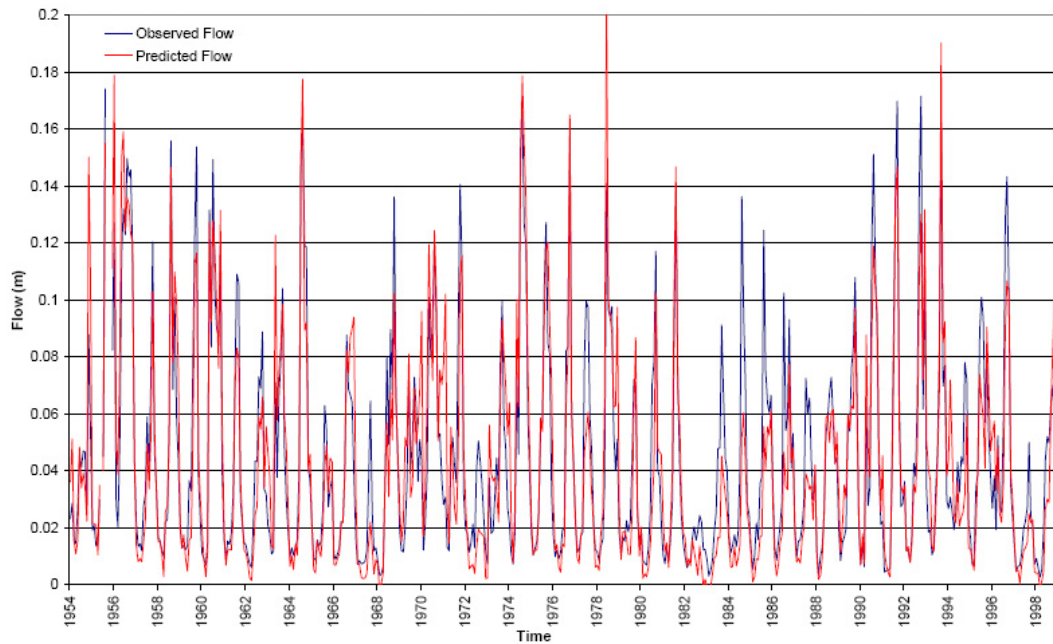


Figure 3. Predicted and observed total monthly flow in metres (m) for the Thomson catchment. [Feikema, 2006]

4.4 Modelling scenarios

4.4.1 Climate change

The Macaque models for three of the catchments (Thomson, Armstrong, and Starvation), chosen to represent a range of size and climatic condition, were run to determine the predicted changes in water yield and ET using CSIRO climate change scenarios for the year 2050 (Howe et al, 2005). Figure 4 shows the estimated rainfall changes under three postulated climate change scenarios. [Note: corresponding changes for were also made for ET and temperature.]

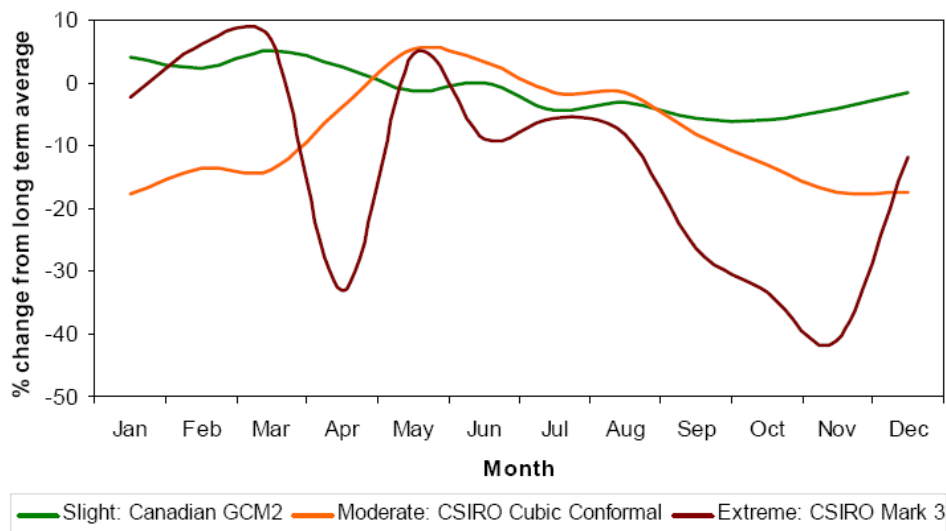


Figure 4. Estimated monthly percentage changes from long term rainfall for slight (least reduction), moderate and extreme (greatest reduction) projections under climate change conditions in 2050. On an annual basis, the slight, moderate and extreme projections represent a 1.6%, 7.1% and 13.8% reduction, respectively, in rainfall from the long term average. [Feikema et al, 2008]

An extreme case was considered, with a fully mature catchment (all trees 270 years old) undergoing a 100% mortality event during a period of climate change. This sets the upper bound of effect (a peak 80% reduction in streamflow on the Thomson) for the most extreme scenario.

Of more interest is the application of the climate change models to the three catchments with *current* vegetation. This was done by selecting an average year of climate for each catchment, and repeating it over and over to remove annual variability. Then the climate change scenarios were applied to the average year to determine their effect. Figure 5 shows the result, with major reductions in flow emanating from the reduced rainfall (Fig 4), and higher temperatures and ET, of the order of 30% less. This sets a context under which the relative impacts of timber harvesting on water yield can be considered.

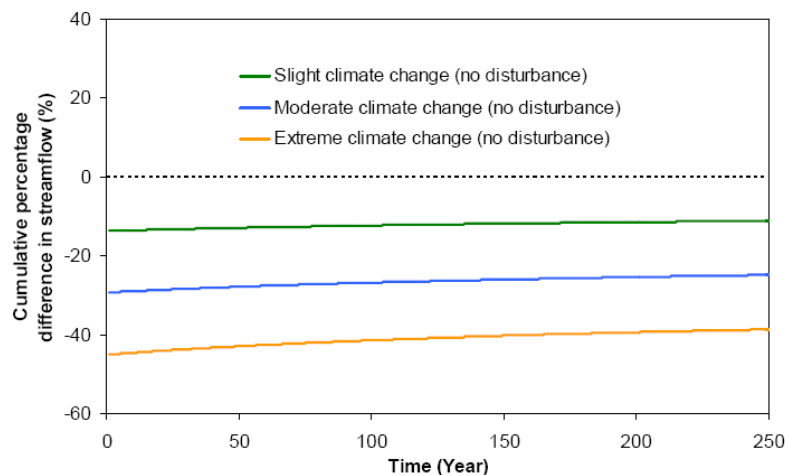


Figure 5. Annual streamflow for climate change projections for the Thomson catchment with current age structure and no disturbance. [Feikema et al, 2008]

4.4.2 Bushfire scenarios.

A range of fire mortality scenarios were examined, all related to different hypothetical proportions of the mortality extent of the 1939 bushfires. Table 3 gives details, and illustrates the spatial capabilities of the Macaque model.

Combined with these ranges were (i) a fully mature catchment (trees 270 years old) to begin with, and (ii) the current forest ages. Figure 6 gives a result for the Thomson for (ii), showing the impact for a repeat of the 1939 bushfires at 50, 100 and 250 year intervals. When compared to the no-fire case, it is clear that major reductions in catchment water yield (~ 15% less total flow over the next 50 years) would follow another '1939 fire'.

Table 3. Bushfire scenarios used for the Thomson catchment. Composition of the burnt area in terms of the main species are provided. The mortality is equivalent to the percentage of forest in the catchment killed. [Feikema et al, 2008]

Mortality	Description
0.08% mortality	Portion of the 1939 mortality extent in the northern part of the catchment (81% <i>E. regnans</i> ; 19% mixed spp.)
1.3% mortality	Portion of the 1939 mortality extent in the southern part of the catchment (53% <i>E. regnans</i> ; 44% mixed spp.)
8% mortality	Portion of the 1939 mortality across the catchment containing mixed species only (100% mixed spp.)
10% mortality	Portion of the 1939 mortality across the catchment containing <i>E. regnans</i> only (100% <i>E. regnans</i>)
14% mortality	Portion of the 1939 mortality extent in the north-western part of the catchment (67% <i>E. delegatensis</i> ; 24% mixed spp.; 9% <i>E. regnans</i>)
18% mortality	Portion of the 1939 mortality across the catchment containing <i>E. regnans</i> and mixed species only (57% <i>E. regnans</i> ; 43% mixed spp.)
33% mortality	Portion of the 1939 mortality extent in the western part of the catchment (60% <i>E. delegatensis</i> ; 18% <i>E. regnans</i> ; 17% mixed spp; 5% <i>E. nitens</i>)
47% mortality	The complete mortality extent for the 1939 bushfires, predominantly in the western half of the catchment (50% <i>E. delegatensis</i> ; 22% <i>E. regnans</i> ; 17% mixed spp)

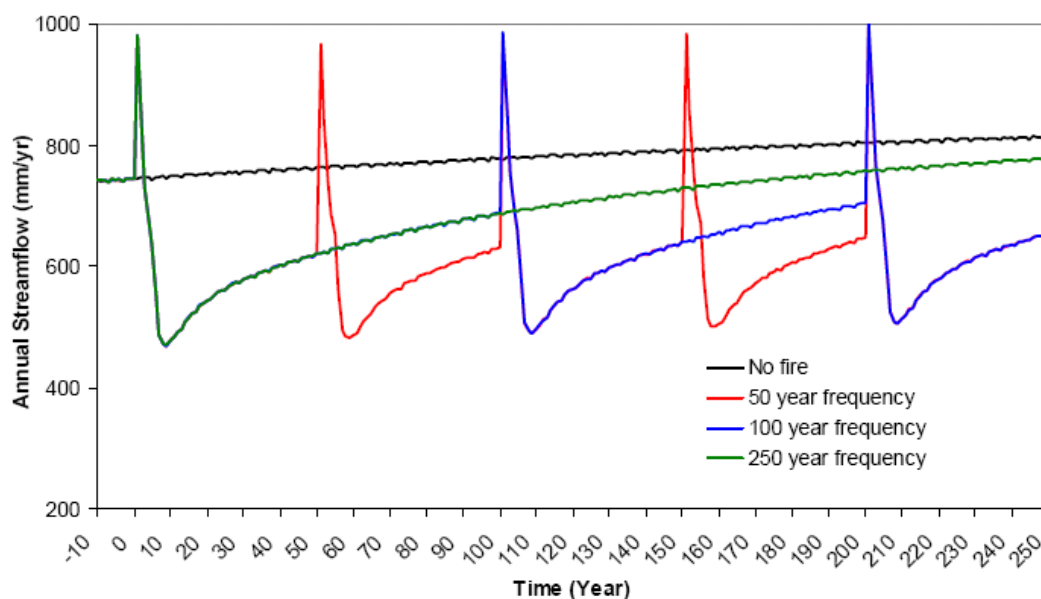


Figure 6. Predicted annual streamflow over time for a fire leading to 47% vegetation mortality, reoccurring at 50, 100 and 250 year intervals for the Thomson catchment. [Feikema et al, 2008]

4.5 Data transferred to the Woodstock model

To study the effect of timber harvesting on catchment water yield, the variation of flow due to climate variability needs to be removed. This is achieved by running two sets of scenarios:

- (i) choosing an average year based on available data, and assuming such a year is replicated each year for a long period.
- (ii) modelling the last ten years climate by scaling rainfall such that catchment yields match the average modelled for the last ten years.

Thus, for each catchment:

- an 'average year' (different for each catchment) was chosen to represent average rainfall/climate conditions
- a Mean Annual Precipitation (MAP) map was produced for that average year, and supplied in gridded form (40m intervals) for the Central Gippsland and Dandenong Forest FMAs
- average actual evapotranspiration (AET) curves were supplied for each vegetation type for each FMA. [The difference between the MAP and AET gives the water yield, as a function of vegetation age, a relationship akin to the Kuczera curve (Fig. 2) for each species.]

5. MODELLING THE IMPACT OF FOREST MANAGEMENT REGIMES ON WATER YIELD

The Woodstock model

The current management of timber harvesting in Victoria's State forests) is assisted by a computer model ('Woodstock', 2004) which:

- can accommodate a wide range of spatial data for the area modelled (eg species, age, slope, aspect, vegetation cover and rainfall)
- includes spatially based yields for both water and timber for all types (and ages) of vegetation in catchments within an FMA .
- allows for a wide variety of prescriptions (eg no logging, various rotation lengths and thinning) for any portion of the area
- uses a linear programming routine to optimise a selected output over the chosen planning period.[In this case, it was 40 steps of 5 years each, ie. 200 years.]
- implicitly assumes that the water generated on a sub-area of the catchment will reach the stream and count as catchment yield.

The Woodstock Model was recently adopted by DSE after an extensive review of the available alternatives. The model is recognised in the industry as being state-of-the-art.

Linking Woodstock to Macaque

One of the outputs from Macaque is the mean annual precipitation (MAP) gridded surface. As shown in Figure 7, this is just one of the sets of spatial data used as input to Woodstock.

The other hydrologic input is the AET curve (specified by a seven parameter equation) for each tree species, for each catchment.

To be able to use these hydrologic data in the format needed for Woodstock:

- the FMA was divided into polygons; each polygon has a specific vegetation type (species, age, etc), and MAP.
- polygons for the same species and age were grouped into rainfall intervals of 50mm bands to reduce the number (and make the problem more manageable for computation).
- a water yield code was assigned to each polygon (based on the MAP and the AET relation for that species). For the Dandenong FMA, for instance, there were about 500 different water yield codes.

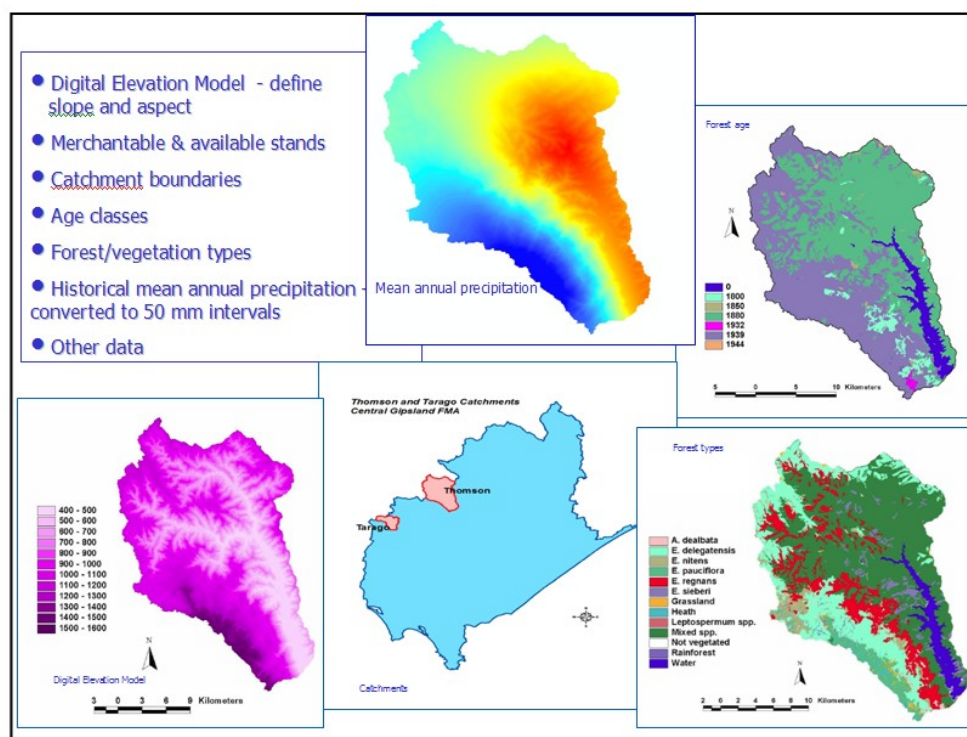


Figure 7. Some of the spatial data used as inputs to the Woodstock model. (DSE, 2008a)

It needs to be noted that a great deal of effort is required to implement the data transfer from Macaque to Woodstock. Hence, for the DSE studies, the data for the chosen average year was adopted as the basis for all the harvest regimes, and the MAP simply scaled (to match catchment yields) for consideration of the reduced rainfall scenarios.

5.3 Optimising Woodstock (constraints applied)

In normal use, the Woodstock model is programmed to optimise the timber output from an FMA. In the Wood and Water Project, the objective function was to optimise the production of D+ sawlogs. However, because of the tightness of the constraints applied, little difference was found when optimisation on water was investigated (Walker, 2008). The constraints applied in the modelling of harvesting regimes included:

- the standing volume of sawlogs and the sawlog volume harvested cannot decrease over time (across the FMA)
- the existing timber licences or supply agreements with VicForests (Table 4) must be met

Table 4. Annual timber licences or supply agreements from 2004/2005 – 2008/2009 (from DSE, 2008a).

Forest Area	Management	Ash (m ³)	Mixed Species (m ³)
Central Gippsland		87,420	9,780
Dandenong		30,580	5,700

- harvest rotation lengths, specified by a maximum area to be harvested
- areas suitable for uniform thinning or strip thinning
- excluding harvest within designated zones (eg designated for biodiversity and asset protection; Baw Baw Frog management envelope)

- excluding pre-1900 Ash stands from harvesting in accordance with Central Highlands Forest Management Plan.
- applying area harvest limits within the catchments apply (in accordance with the existing management guidelines and Melbourne Water agreements)

5.4 Timber harvesting regimes considered

Some twenty regimes were included in the DSE studies. Given the similarity of responses for many regimes, eleven regimes were selected to include those with the best yields for water and timber, as listed below. [Letters and numbers are used to designate each regime.]

A. Status Quo: The current management regime with prescribed area limits in the catchments. Rotation length (ie. the average age at harvesting) varies depending on site quality and species characteristics; however, the nominal rotation length is 80 years with a minimum of 60 years³.

B. 80 Year Rotation: An average 80 year rotation age is applied within the catchments only, with Status Quo applied outside of the catchments in the remainder of the FMA. [This regime represents what is the commonly understood rotation length for Victoria's higher productivity forests.]

D. 120 Year Rotation: As for Option B but with an average 120 year rotation length.

E. 150 Year Rotation: As for Option B but with an average 150 year rotation length.

G1. 80 year Rotation with Uniform Thinning age at 27. Thinning is of ash stands in the catchments at age 27. Thinned, stands can be harvested at/after rotation age.

G4. 150 year Rotation with Uniform Thinning at age 27. Same as Option E, but with thinning in ash stands within the catchments at age 27. Thinned stands harvested at/after rotation age.

HI. 150 year Rotation with Strip Thinning at age 27 and one off Late Age Thinning at age 72. The late age thinning applies to the Thomson.

J. Cease harvest in the catchments in 2009/10

L. Cease harvest in catchments in 2029/30. Status quo harvesting limits will apply until 2030

M. Phase down to 150 year rotation by 2030 with Uniform Thinning at age 27 and Late Thinning at 72. The late thinning applies to selected sites in the Thomson catchment occurring in the years 2009-2014.

N. Cease 2029/30 with Uniform Thinning at age 27 and Late Thinning at 72. Same as Option L but includes uniform thinning at age 27 in all catchments ceasing in 2030 and a one off late age thinning on selected sites in the Thomson catchment.

The modelling of these regimes uses yield and leaf area index data derived mostly from the catchment hydrology research program outlined in Chapter 3, and adopted for the Macaque modelling.

[It should be noted that (i) less information is available on the longevity of added water yield from thinning (uniform and strip) regimes than for other regimes due to the limited nature of available experimental data⁴, and (ii) due to operational considerations, not all of the harvestable ash area is suitable for thinning (hence limitations on thinning areas apply).]

5.5 Modelling variation in rainfall

³ The average rotation length expected for the next ten years is 76 years for ash and 105 years for mixed species.

⁴ plausible theoretical relations were derived to model the water yield from thinned forest stands

Section 4.4.1 described the modelling of climate change for three scenarios (slight, moderate, and extreme) without considering timber harvesting. For the Woodstock modelling of forest management regimes, a reduced rainfall scenario to simulate the drought from 1997-2006 was adopted. To implement this scenario for the management regimes, the MAP from Macaque was adjusted for each catchment until the streamflows matched the observed. Different adjustment factors of the rainfall were needed (5-12% reduction); the Thomson requiring the largest reduction to match observed flows. [Incidentally, the observed decrease over the long term average for rainfall for the Thomson for this period was 11.9%.]

6. MAGNITUDE OF IMPACTS ON WATER YIELD AND TIMBER YIELD

This chapter presents selected water and timber yield data from the extensive DSE studies. The water yield results are presented graphically and in tabular form for all catchments combined (the total picture). Timber yields are combined for the two FMAs. The scenarios considered are (i) mean annual precipitation, and (ii) reduced rainfall (to match the average drought flows). Results are discussed in Section 6.3.

Water and timber yields (using mean annual precipitation)

Water yield values in this section apply to all catchments combined, but it should be noted that the Thomson contributes nearly two-thirds of the amounts shown.

Figure 8 (upper curves) shows the expected water yields (all catchments) under historic rainfall for the management regimes outlined in Section 5.4. The figure shows that expected water yield increases under all regimes, and that the differences in water yield between timber management regimes are small.

Table 5 shows the expected water yields in 2050, an appropriate target year for water planning. These are shown and ranked by yield in 2050, and cumulative volumes 2005-2050.

Table 6 shows the timber yield produced under each harvest regime (both FMAs) for 2050. The figures may be compared with Table 4 totals, indicating a commitment of 133480 m³ per annum, or 6006 10³m³ in the 45 year period 2005-2050. It will be seen that most regimes meet the specified timber commitments, however regime E and J are less likely of meeting timber resource supply obligations.

[Tables for 2010, 2050, 2100, and 2150 are provided in the appendix.]

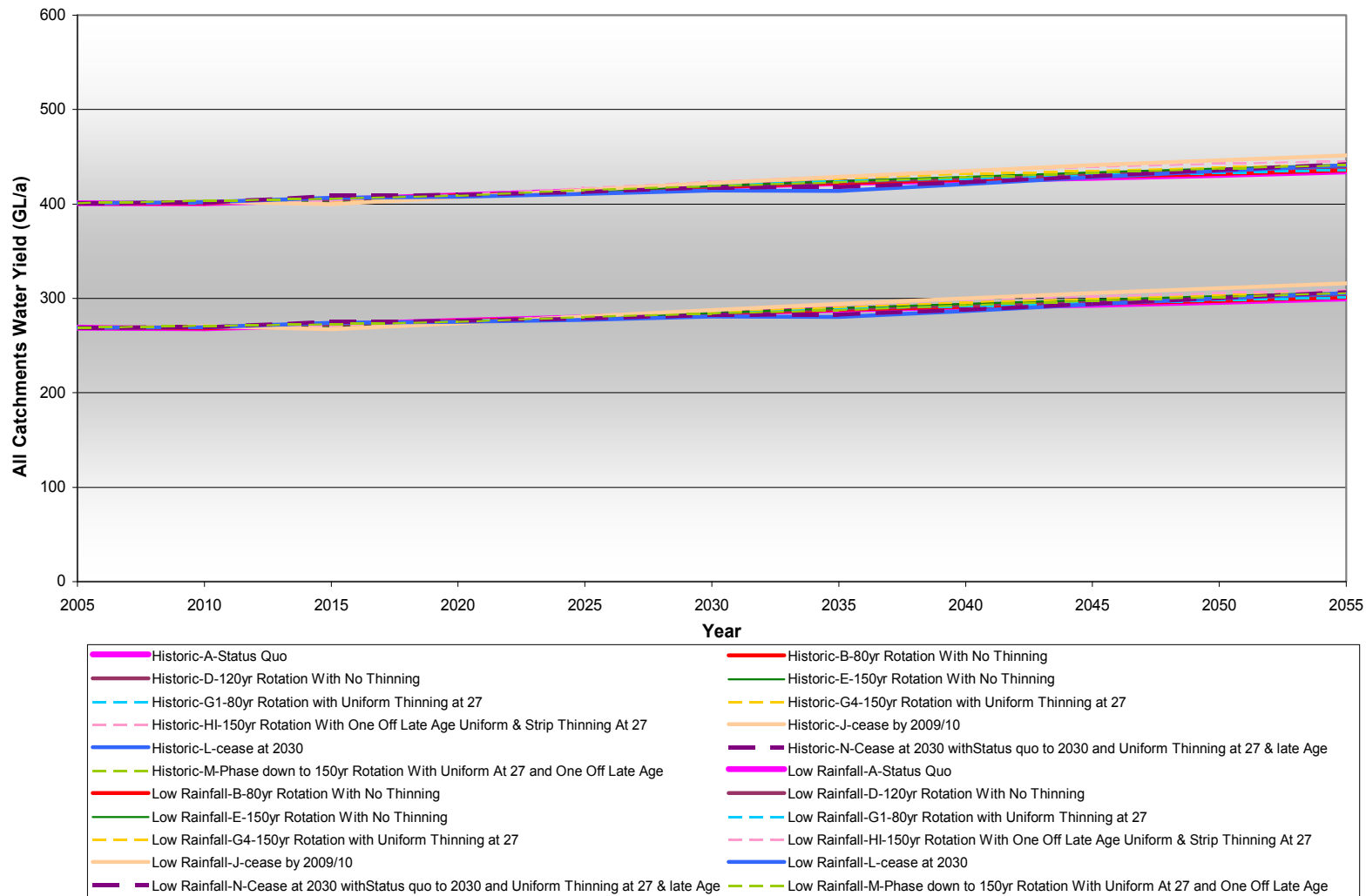


Figure 8 – Comparison of all management regimes and scenarios – Water Yield– Bunyip, Yarra Tributaries, Thomson and Tarago Catchments Combined 200 year outlook. The upper curve is for historic rainfall, the lower for reduced rainfall to match the 1997-2006 drought [after DSE, 2008b]

Table 5: Comparison and Ranking of Regimes and Scenarios – Historic rainfall –All Catchments combined [after DSE, 2008b]

	Water yield GL/a in 2050	Rank	Change relative to Scenario A	Cumulative Water yield GL for 2005-2050	Rank	Change relative to Scenario A
All-A-Status Quo	431	11	0.0%	18687	10	0.0%
All-B-80yr Rotation With No Thinning	432	10	0.2%	18691	9	0.0%
All-D-120yr Rotation With No Thinning	436	6	1.2%	18729	7	0.2%
All-E-150yr Rotation With No Thinning	438	4	0.2%	18748	6	0.3%
All-G1-80yr Rotation with Uniform Thinning at 27	433	9	0.5%	18751	5	0.3%
All-G4-150yr Rotation with Uniform Thinning at 27	439	3	1.9%	18812	3	0.7%
All-HI-150yr Rotation With One Off Late Age Uniform & Strip Thinning At 27	443	2	2.8%	18911	1	1.2%
All-J-cease by 2009/10	447	1	3.7%	18877	2	1.0%
All-L-cease at 2030	435	8	0.9%	18609	11	-0.4%
All-M-Phase down to 150yr Rotation With Uniform At 27 and One Off Late Age	437	5	1.4%	18773	4	0.5%
All-N-Cease at 2030 with Status quo to 2030 and Uniform Thinning at 27 & late Age	436	6	1.2%	18693	8	0.0%

Table 6: Comparison and Ranking of Regimes and Scenarios – Cumulative Sawlog Yields Central Gippsland and Dandenong FMA Combined [after DSE, 2008b]

	Cumulative sawlog yield 10^3 m^3 2005-2050	Ranking	Change relative to Scenario A %
All-A-Status Quo	6782	2	0.0%
All-B-80yr Rotation With No Thinning	6780	3	0.0%
All-D-120yr Rotation With No Thinning	6686	4	-1.4%
All-E-150yr Rotation With No Thinning	6513	7	-4.0%
All-G1-80yr Rotation with Uniform Thinning at 27	6916	1	2.0%
All-G4-150yr Rotation with Uniform Thinning at 27	6521	6	-3.9%
All-HI-150yr Rotation With One Off Late Age Uniform & Strip Thinning At 27	6436	8	-5.1%
All-J-cease by 2009/10	4890	11	-27.9%
All-L-cease at 2030	5912	9	-12.8%
All-M-Phase down to 150yr Rotation With Uniform At 27 and One Off Late Age	6671	5	-1.6%
All-N-Cease at 2030 with Status quo to 2030 and Uniform Thinning at 27 & late Age	5910	10	-12.9%

Reduced rainfall

As explained in Section 5.5, the reduced rainfall option matches the low stream flows of the current drought (1997-2006). Figure 8 (lower curves) illustrates the results obtained for the different harvest regimes. Table 7 is directly comparable with Table 5. Both the figure and table show (i) the massive reduction in yield if such a climate scenario were to persist, and (ii) the effect of the drought on water yield relative to forest management regimes. [Timber production was assumed to be unchanged for the reduced rainfall scenario.]

Table 7: Comparison and Ranking of Options and Scenarios – Reduced rainfall –All Catchments combined [after DSE, 2008b]

	Water yield GL/a in 2050	Change relative to Scenario A	Ranking	Cumulative Water yield GL for 2005-2050	Ranking	Change relative to Scenario A
All-A-Status Quo	296	0.0%	11	12679	9	0.0%
All-B-80yr Rotation With No Thinning	297	0.3%	10	12684	8	0.0%
All-D-120yr Rotation With No Thinning	301	1.7%	7	12714	7	0.3%
All-E-150yr Rotation With No Thinning	302	2.0%	4	12732	4	0.4%
All-G1-80yr Rotation with Uniform Thinning at 27	298	0.7%	9	12716	6	0.3%
All-G4-150yr Rotation with Uniform Thinning at 27	303	2.4%	3	12767	3	0.7%
All-HI-150yr Rotation With One Off Late Age Uniform & Strip Thinning At 27	306	3.4%	2	12832	2	1.2%
All-J-cease by 2009/10	311	5.1%	1	12848	1	1.3%
All-L-cease at 2030	300	1.4%	8	12607	11	-0.6%
All-M-Phase down to 150yr Rotation With Uniform At 27 and One Off Late Age	302	2.0%	5	12728	5	0.4%
All-N-Cease at 2030 with Status quo to 2030 and Uniform Thinning at 27 & late Age	301	1.7%	6	12660	10	-0.1%

6.3 Discussion of relative impacts, and best regimes.

The clear conclusion from these studies is that the additional water to be gained from changed timber management is relatively small in the totality of Melbourne's water needs. Under all regimes (as modelled), catchment water yield is increasing; it will be an average 40 GL per annum more in year 2050 than in 2005. The difference in water yield between the eleven timber regimes (as modelled) is about 16 GL per annum in that year. In cumulative terms (2005-2050), the difference between the best and worst options is just over 320 GL (or 1.4% in comparison to the Status Quo). The differences due to management regime are small in relation to Melbourne current usage (~480 GL per annum), although it is also clear that, for some scenarios, these minor water yield gains can be made without great impact on the timber industry.

As Figure 8 shows, climate change (and drought) has the potential for far greater impacts. Continuation of the current drought conditions (ie as modelled under reduced rainfall) reduces potential flows for the combined catchment totals by about 30% (or 135 GL/a) in 2050. The difference between the 'best' and 'worst' timber management regimes (as modelled) for water yield is 15 GL per annum; in cumulative terms (2005-2050) this is only 270 GL (or 2% in comparison to the Status Quo).

Bushfires can be potentially severe, but rarely burn whole catchments. The modelling shown in Section 4.4.2 above indicates that fires like the 1939 bushfire (which burnt 47% of the Thomson) will have several times the impact (on water yield) of possible timber management scenarios (20% reduction relative to 1.4% in cumulative yield to 2050 terms). [The impact on timber was not considered in this study, nor the likely impact of climate change on an increase both the intensity and frequency of bushfires.]

From the modelling work, the apparent best options are:

For water yield

1. J. Cease timber harvesting by 2009/10
2. H1. 150 year rotation with one-off late age uniform thinning (Thomson only), and strip thinning at age 27
3. G4. 150 year rotation with uniform thinning at age 27
4. E. 150 year rotation with no thinning

For timber yield

1. G1. 80 year rotation with uniform thinning at age 27
2. A. Status Quo
3. B. 80 year rotation with no thinning

For both water and timber

1. G1. 80 year rotation with uniform thinning at age 27
2. G4 150 year rotation with uniform thinning at age 27
3. M. Phase down to 150 year rotation by 2030 with uniform thinning at age 27 and one off late age uniform thinning (Thomson only)
4. E. 150 year rotation

Additional Options (to be further assessed)

1. L. Existing catchment limits and cease timber harvesting in 2029/30
2. N. Existing catchment limits with uniform thinning at age 27 and one off late age thinning (Thomson only) then cease timber harvesting in 2029/30
3. D. 120 year rotation with no thinning.

6.4 Robustness of the results

All modelling studies of this kind necessarily involve a simplification of reality, so it is pertinent to consider the degree of confidence one can have in the results obtained.

Starting with the hydrological component, the Macaque model has incorporated the results of some excellent scientific studies, and is capable of simulating the high degree of variability of rainfall, slope, aspect, and vegetation over each catchment. With optimisation on only two major parameters it has been shown to reproduce historic flows in the several catchments, an aspect of key importance. Sensitivity tests on key parameters have been done to show the importance of vegetation leaf area (obtained from remote sensing) to generated water yield.

The Woodstock modelling uses the mean annual precipitation surface and evapotranspiration versus age relationships for individual species generated by Macaque. Together with remote sensed data on tree species (and checks of modelled timber yield estimates against actual for logged sites), a good deal of confidence applies to the modelled output. The further test of matching the drought flows in the Thomson by decreasing the rainfall by the observed amount gives further confidence in the results.

There are two aspects to consider with respect to accuracy. The first is the *relative* accuracy of the differences between management regimes for the same input climate; the second is the *absolute* accuracy of the actual streamflow predictions. In modelling, the relative accuracy is dependent on the extent to which the causative processes are specifically included in the model. Macaque certainly includes the best knowledge of hydrologic process (although it doesn't model tree growth), so its estimates of changes due to tree disturbance (harvest and bushfire) are considered reliable. The relative accuracy of such estimates is likely to be of the order of +/- 5-10%.

The absolute accuracy of streamflow estimates is less than the relative accuracy, but can be expected (for the unchanging climate conditions used for each regime and climate/bushfire scenario) to be of the order of +/- 10-15 %.

7. CONCLUSION

Summary of work done for the Wood and Water Project to date

The Macaque model was calibrated for each of the Thomson, Tarago, Bunyip, and Yarra Tributaries catchments, using observed rainfall and runoff data in each case. Some bushfire and climate change scenarios (based on CSIRO projections) were investigated together with reduced rainfall scenarios representing a continuation of current drought conditions.

To remove the effect of climate variations on water yield, an average year was selected for each catchment as representing the long term average rainfall and seasonality, and used to produce a mean annual precipitation surface for each catchment. This, together with curves of actual evapotranspiration (one for each forest species on each catchment), was the data produced for input to the Woodstock model.

The Woodstock model is capable of handling detailed spatial inputs of precipitation, elevation, slope, and forest species. In operation, much effort is required to prepare the data files for it to simulate individual forest coupes. For the Wood and Water Project, once this was done, it was used to simulate a large number (20) of different forest management regimes. It was optimised on timber yield, with water yield calculated from the yield curves transferred from Macaque.

A number of assumptions were involved in the modelling output. Some relate to the modelling of quite complex catchment systems, and the simplifications that had to be made in the absence of data (eg local temperature and soils data for the catchments, the prolonged impact on yield of strip and uniform thinning, how climate change is modelled). Other assumptions were made as to the scenarios to be modelled (eg extent of bushfires, extent of climate change).

Many model runs were involved, with detailed results presented in comprehensive reports (listed in Chapter 1). A selection of these is given in this summary document.

Conclusions

A number of broad conclusions emerge from the studies:

- (i) The expected yield⁵ of the water supply catchments is increasing, due to the continued aging of the forest after the 1939 bushfires.
- (ii) The impacts of changing timber management regimes on cumulative water yield are relatively small, modelled here as being all within -1.5% of the cease-logging regime.
- (iii) The impact of climate change on water yield can be large. For every 1% decrease in long-term average rainfall, water yield is reduced by 2-3% in all catchments. [For the last 10 years the reduction in flows has been of the order of 30%]
- (iv) The potential impact of bushfires is also major. A repeat of the 1939 bushfires would see a decrease of 15% of the inflow to the Thomson Dam over the following 50 years.

Recommendations

1. This project has not considered the combined effects of bushfires and climate change on water yield to Melbourne's reservoirs in a probabilistic way (eg Figure 6 is for bushfires of fixed size and duration). A Monte Carlo approach would be the best way to determine the risk of not meeting various levels on inflow in the next say 50 years due to these highly influential factors. Such an analysis could be done using (i) an historic climate sequence, (ii) a sequence adapted for slight climate change, (iii) moderate climate change, and (iv) severe. In say 50-100 realisations, a random sampling approach would determine whether bushfires occurs in the next time period and, if so where and how large. A link between climate change and bushfire occurrence and severity would need to be part of the input.
2. The next step envisaged by the White Paper is investigating '*the economic, social and environmental benefits and costs of these options*'. It is recommended that the eleven options considered in this Summary report be evaluated in terms of these additional factors.
3. For the forest management scenarios, there remains significant uncertainty about the sustainability of increased yield from thinning treatments. Experimental areas were established under the Melbourne Water research program provided invaluable data on forest treatments, including the early data on the effect of thinning. It is recommended that hydrological measurements on these areas be recommenced to establish the extent to which the increased yields may have changed (relative to the control catchments).

⁵ ie. water yield under a continuation of the average historic climate and forest management, without bushfires

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APPENDIX. SUMMARY OF MODEL RESULTS FOR SELECTED DATES.

(Water figures are totals for all catchments. Timber figures are for sawlog for both FMAs.)

Item	For Period Ending	ALL- A- Status Quo	ALL-B- 80yr Rotation With No Thinning	ALL-D- 120yr Rotation With No Thinning	ALL-E- 150yr Rotation With No Thinning	ALL- G1-80yr Rotation with Uniform Thinning at 27	ALL- G4- 150yr Rotation with Uniform Thinning at 27	ALL-HI- 150yr Rotation With One Off Late Age Uniform & Strip Thinning At 27	ALL-J- cease by 2009/10	ALL- L-cease at 2030	ALL-M- Phase down to 150yr Rotation With Uniform At 27 and One Off Late Age	ALL-N- Cease at 2030 with Status quo to 2030 and Uniform Thinning at 27 & late Age
Water (Historic rainfall) GL/a	2010	401	401	402	403	401	403	403	403	402	403	402
	2050	431	432	436	438	433	439	443	447	435	437	436
	2100	461	461	465	470	460	471	473	489	483	471	484
	2150	477	477	483	489	478	491	492	515	512	490	512
Cumulative Water (Historic rainfall) GL	2010	2004	2004	2007	2010	2004	2011	2009	2009	2006	2010	2006
	2050	18687	18691	18729	18748	18751	18812	18911	18877	18609	18773	18693
	2100	41044	41044	41303	41490	41142	41622	41787	42348	41665	41497	41784
	2150	64544	64557	65075	65533	64658	65758	65964	67532	66608	65577	66748
Sawlog 10 ³ m ³ /a	2010	131	131	131	131	131	131	131	131	131	131	131
	2050	174	174	171	165	180	166	159	124	126	166	126
	2100	179	179	175	170	184	171	164	129	131	171	131
	2150	180	180	177	171	185	172	165	131	132	172	132

Item	For Period Ending	ALL-A-Status Quo	ALL-B-80yr Rotation With No Thinning	ALL-D-120yr Rotation With No Thinning	ALL-E-150yr Rotation With No Thinning	ALL-G1-80yr Rotation with Uniform Thinning at 27	ALL-G4-150yr Rotation with Uniform Thinning at 27	ALL-HI-150yr Rotation With One Off Late Age Uniform & Strip Thinning At 27	ALL-J-cease by 2009/10	ALL-L-cease at 2030	ALL-M-Phase down to 150yr Rotation With Uniform At 27 and One Off Late Age	ALL-N-Cease at 2030 with Status quo to 2030 and Uniform Thinning at 27 & late Age
Cumulative Sawlog 10 ³ m ³	2010	653	653	653	653	653	653	653	653	653	653	653
	2050	6782	6780	6686	6513	6916	6521	6436	4890	5912	6671	5910
	2100	15594	15592	15346	14902	15982	14934	14533	11200	12346	15097	12340
	2150	24587	24584	24158	23448	25212	23505	22787	17736	18940	23686	18930
Water (low rainfall) GL/a	2010	269	269	269	269	269	269	269	269	269	269	269
	2050	296	297	301	302	298	303	306	311	300	302	301
	2100	325	325	330	334	324	335	336	353	347	334	347
	2150	341	341	347	352	341	354	354	379	375	353	375
Cumulative Water (low rainfall) GL	2010	1343	1343	1346	1349	1343	1350	1348	1348	1345	1349	1345
	2050	12679	12684	12714	12732	12716	12767	12832	12848	12607	12728	12660
	2100	28282	28282	28520	28694	28314	28774	28884	29515	28870	28652	28955
	2150	44982	44995	45483	45922	45006	46064	46196	47858	46975	45887	47080