Assessment of the Impact of Forest Logging on Water Quantity in the Otway Ranges

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Abstract: The West Victorian Regional Forest Agreement, signed in March 2000, promotes long term sustainable management of forests in western Victoria of which the Otway forests are the most notable. In response to community concerns, research into the hydrology of the Otway forests was commissioned to evaluate the impact of timber harvesting on stream flow and water quality. This paper describes a part of the research undertaken, specifically the modelling framework used to estimate stream flow. A numerical model is developed and applied to three key catchments using data from geographic information systems as input. The model relies on functions relating forest age and stream flow for the two most dominant forest types; mountain ash (*Eucalyptus regnans*) and eucalypt mixed species. These functions are developed from a large body of research carried out in the Melbourne water supply catchments and elsewhere. Using the functions and applying logging schedules proposed for the next 100 years, demonstrates that only minimal changes to the current mean annual stream flow of test catchments are likely. By comparison, a large wildfire causes a brief increase in stream flow in test catchments, followed by a significant decrease with reduced flows being sustained for up to 60 years. The stream flow from forests undisturbed for the next 100 years is estimated to be about 50 mm greater than that generated when logging schedules are applied. The approach described provides objective estimates of stream flow under different forest management scenarios and provides a basis from which to develop appropriate management policy.

Keywords: Forest hydrology; Logging; Stream flow; Otway Ranges.

1. INTRODUCTION

The Commonwealth Government and State Government of Victoria signed the West Victorian Regional Forest Agreement in March 2000 [Commonwealth of Australia, 2000]. This agreement provides for the long term sustainable management of forests in western Victoria, of which the Otway forests are the most notable. In response to community concerns, the Victorian Minister for Environment and Conservation facilitated research into the potential impacts posed by timber harvesting on stream flow and stream water quality in the Otway forests. This paper describes the modelling framework used to estimate stream flow.

The major limitation in this type of study, and particularly in the Otway Ranges, is the lack of controlled experimental data for stream flow. This necessitates the use of process-based models that can be adapted to the environment under investigation and draw on existing data sets from other locations. Studies contributing to development of the modelling approach are briefly discussed below.

The seminal study by Kuczera [1985 and 1987] evaluated stream flow measurements from Mountain Ash forest in the Melbourne water supply catchments. This study described the response of stream flow to the fires that destroyed mature forest in 1939 and to the forest regeneration over the following 40 years. In Kuczera's study catchments, average annual stream flow from a mature Mountain Ash forest was estimated to be 1195 mm. During forest regeneration after fire, stream flow decreased to a minimum of 580 mm after about 27 years. Thereafter stream flow rose slowly and it was estimated that it would return to the mature forest value after about 150 years. The stream flow response to forest disturbance was described by a function with two parameters. Kuczera's analysis did not show an initial increase in stream flow that was expected in the 2 or 3 years after forest disturbance.

Nathan et al. [2000] describe an approach to estimating the effects of logging on stream flow in mixed eucalypt State Forest in New South Wales. The function of Kuczera [1985] was changed to allow for an initial increase in stream flow immediately after forest disturbance that has been well documented [e.g. Langford and O'Shaughnessy, 1977; Nandakumar and Mein, 1993]. The resulting three parameter stream flow response function was used with two sets of parameter values developed for Northern and Southern regions respectively. The approach was applied to many catchments by adjusting the response function using catchment annual rainfall.

Watson et al. [1999] built on Kuczera's work in the Melbourne water supply catchments but modelled the forest leaf area and water use to estimate the stream flow response to forest disturbance and regeneration. A seven parameter function was presented allowing a lot of flexibility in the description of the stream flow response. Following on from this work, Vertessy et al. [2001] discussed the factors influencing the change in water use of Mountain Ash forest with age.

Recently, Roberts et al. [2001] reported a decrease in forest water use with age for forest ages of 14, 45 and 160 years in a *Eucalyptus sieberi* forest. Following logging Cornish and Vertessy [2001] reported an increase and then a decrease in stream flow relative to flow from mature forest with dominant species *Eucalyptus saligna* and *Eucalyptus laevopinea*. Lane and Mackay [2001] recorded an increase in average annual stream flow immediately after forest clearance relative to flow from a mature mixed eucalypt forest and later a decrease in flow relative to mature forest. These findings confirm that Kuczera's observations of average annual stream flow during forest regeneration are relevant to eucalypt forests other than Mountain Ash.

In this study the approach of Nathan et al. [2000] is adapted and applied to catchments in the Otway Ranges State Forests. Adaptation of the approach is required because catchments in the Otway Ranges typically have more than one forest type due in part to steep gradients in rainfall.

2. MODELLING APPROACH

2.1 Inputs and Site Description

The inputs required to apply this modelling approach to a particular catchment are:

- catchment average annual rainfall;
- stream flow response functions for forest types in the catchment;
- land uses and forest types by area ;
- current forest age distributions;
- proposed future logging management .

A stream flow response function allows calculation of changes in annual stream flow as a function of forest age, catchment rainfall, and forest type.

The Otway Ranges are approximately 200 km South West of Melbourne and just inland from coastal towns of Lorne and Apollo Bay. Two forest types dominate in the Otway Ranges, Mountain Ash forest, and Mixed Species Eucalypt forest. Table 1 provides the distribution of land use in catchments investigated in this study. The derivation of stream flow response functions for these two forest types is described in Section 2.2.

Data availability is such that it is not possible to reliably assess the impacts of logging on low flows or flow seasonality. The approach is restricted to characterising the impacts on average annual stream flow only.

Information regarding forest type and forest age was extracted from the State-wide Forest Resource Inventory (SFRI) of the Dept. of Natural Resources and Environment. Tree age information was not available for land use types other than Mixed Species forest and Mountain Ash forest. Over the period of simulation it was assumed that stream flow did not change from land uses in the 'Other' category of Table 1.

Table 1. Land Use distribution by area in catchments of the Otway Ranges.

Catchment	Area (ha)	Percentage of Forest Type (%)		
		Mountain Ash	Mixed Species	Other
West Barwon	5121	9	65	26
East Barwon	1643	1	91	8
St. George	1278	14	55	31
Arkins	1100	33	57	10

2.2 Stream Flow Response Functions

The stream flow response function for Mountain Ash forest in the Otway Ranges was fitted by eye to functions presented by Kuczera [1985] and Watson et al. [1999] (Figure 1).

Both Kuczera and Watson et al. developed functions for Mountain Ash forest in the Melbourne water supply catchments. The function for the Otway Ranges uses the seven parameter functional form proposed by Watson et al. [1999] and has an initial increase in stream flow that is absent in Kuczera's analysis. The function also compared well with another used by Moran [1988] to estimate the stream flow response for Mountain Ash forest in the Otway Ranges.

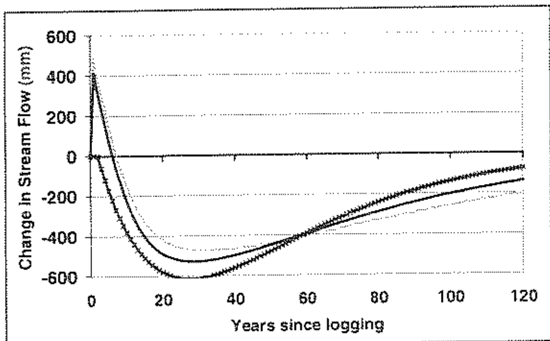

Figure 1. The stream flow response function for Mountain Ash forest for an annual rainfall of 2000 mm. The change in stream flow relative to flow from a mature forest is shown versus years since forest disturbance by logging or fire. The line with markers is from Kuczera [1985], the grey line from Watson et al. [1999] and the black line the function adopted in the Otway Ranges.

The East Barwon catchment was used to test stream flow response functions for Mixed Species forest in the Otway Ranges. This catchment had a good stream flow record from 1958 to 1998 and was classified as 91 % Mixed Species forest (Table 1). A GAM analysis [Generalised Additive Model, Nathan et al., 1999] of the stream flow data in the East Barwon catchment was used to remove the effects of annual variation in rainfall and showed no significant change in flow between 1958 and 1998.

The stream flow response function used by Nathan et al. [2000] for Mixed Eucalypt forest in Southern New South Wales was adapted for conditions in the Otways. A sensitivity test of the chosen parameter values (± 20 %) showed all combinations of parameters performed similarly with a maximum difference of 30 mm in predicted change in stream flow at the end of the measurement period. All parameter combinations also showed good agreement with the trend in stream flow over the measurement period. This test supported the use of the function for Mixed Species Forest shown in Figure 2, although it did not allow separation of the most representative set of parameter values.

2.3 Modelling Procedure

The stream flow response functions for the two forest types are used in the following way. Firstly the forest age distribution is calculated independently for both forest types over the period of modelling, in this case 100 years. Forest age is equivalent to the number of years since logging or fire. At the start of a model run the input initial forest age distribution is used to initialise the ages of a large number of elementary unit areas of forest. These unit areas are homogeneous in forest type and forest age. During a model period the age of a unit area of forest is increased year by year until a logging event or a fire occurs. A logging event is described by: (a) the decade in which it occurs; (b) the proportion of the forest canopy cleared; and (c) the target tree age for harvesting. Logging resets the appropriate fraction of the forest to age 0 years.

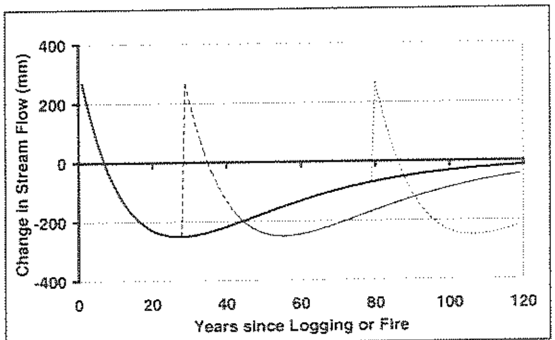

Figure 2. Stream flow response function for Mixed Species forest in the Otway Ranges for a catchment rainfall of 1240 mm. The change in stream flow relative to a mature forest is shown (solid line). The dotted lines indicate the predicted response if a second logging event occurred either after 30 or 80 years.

Once the forest age distribution is known over the 100 year period the change in stream flow relative to mature forest is calculated. This is demonstrated in Figure 2. A unit area of mature Mixed Species forest logged in its first year will show a change in stream flow delineated by the solid line. If this forest area is logged a second time in year 30 the first dotted line shows the resulting stream flow changes over the following years. If the second logging event occurs in year 80 the change in stream flow is shown by the second dotted line.

Within a region the stream flow response function is adjusted for catchment rainfall by multiplying the change in stream flow by the ratio of catchment rainfall to rainfall associated with the stream flow response function. The implicit assumptions are that the increase in stream flow immediately following forest disturbance and the reduction in stream flow during regeneration are both proportional to rainfall [Nathan et al., 2000]. The arguments supporting these two assumptions are that: (1) the initial increase in stream flow is a rainfall excess above forest water use and thus will be strongly dependent on average rainfall; and (2) that forest water use is optimised to suit average rainfall conditions (this argument is supported by the change in the mix of forest species with land surface elevation). Nevertheless, other similar adjustments have been considered [e.g. Munday et al., 2001] but were not used here.

Finally, the net change in stream flow within the whole catchment is calculated by summing over all unit areas of forest and both forest types for the modelled period.

3. MODEL APPLICATION

3.1 Forest Management Scenarios

Catchment stream flow was simulated for 100 years under the following forest management scenarios:

I. No disturbance. No logging, fire or other disturbance occurs and the forest is allowed to age from the year 2000.

II. Logging Only. Logging is the only disturbance to the forest over the 100 year period.

III. Wildfire Only. Complete mortality of 50% of the catchment at the beginning of the 100 year period with no other forest disturbance.

Scenarios II and III are described further below.

In the Otway Ranges, the West Victorian Regional Forest Agreement and the Otway Forest Management Plan [DCE, 1992] provide firm guidelines controlling forest logging. The Dept. of Natural Resources and Environment in Victoria has developed a timber harvesting model that complies with these guidelines and aims to maintain a timber yield that varies as little as possible from year to year within the Otway Ranges. This model was used to forecast timber harvesting in the study catchments over the period from 2000 to 2100 as shown in Figure 3.

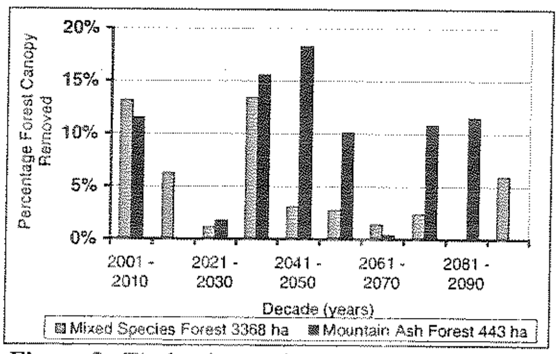

Figure 3. Timber harvesting schedule in the West Barwon catchment for both forest types.

The effects of a major wildfire were modelled by assuming that half of the catchment area was reset to age zero in the second year of simulation. The proportional loss of forest required to represent a major fire was chosen in consultation with the Otway forest managers from the Dept. of Natural Resources and Environment. Major fires caused large scale destruction in the Otway forests in 1918 and 1939, and minor fires occur much more frequently.

In the wildfire scenario more than half of the Mixed Species forest and Mountain Ash forest were reset to age zero because the catchment area included other land use types (Table 1) with no change in water use. The same fraction of both forest types and all forest age groups was reset to age zero to simulate the effect of fire. While it is recognised that Mountain Ash forest and Mixed Species forest may be affected in different ways by fire, these differences are not considered in this study.

3.2 Application to West Barwon

The application of the model is demonstrated here using the West Barwon catchment. Information regarding forest age was extracted from the State-wide Forest Resource Inventory, Figure 4 shows the initial forest age distribution in the West Barwon catchment. All forest ages over 120 years were considered to be mature forest when estimating the contribution to stream flow.

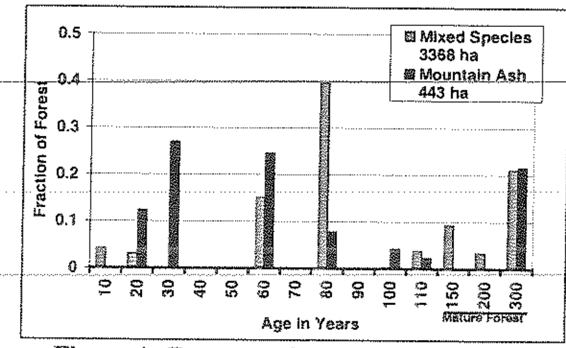

Figure 4. Forest age distribution in the West Barwon catchment for the year 2000.

In the logging-only management scenario, information about the area logged (Figure 3) and tree age targeted for harvesting was used to calculate the forest age distribution in 2100 (Figure 5).

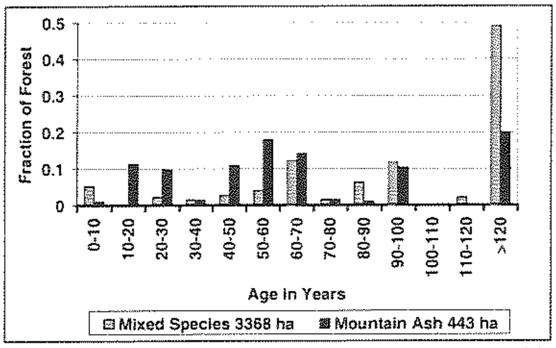

Figure 5. Predicted forest age distribution in 2100 for the West Barwon catchment under the logging only management scenario.

The forest age distribution in 2100 is less complex in Scenarios I and III. In Scenario I it was assumed that there was no forest disturbance at all so that the youngest forest age would be 110 years in 2100. In Scenario III the only forest disturbance was the fire occurring in the second year of simulation so the youngest forest age in 2100 would be 99 years.

Figure 6 shows the change in stream flow relative to stream flow in the year 2000 estimated over the 100 year period under the three management scenarios.

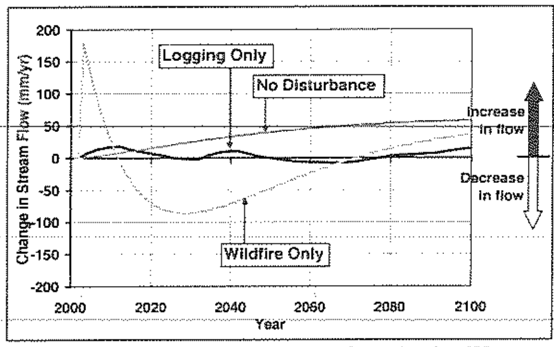

Figure 6. Change in stream flow in the West Barwon catchment relative to stream flow in the year 2000 under 3 forest management scenarios.

3.3 St.George and Arkins Catchments

Results for the St. George and Arkins catchments are given in Figures 7 and 8.

Differences between Figures 6, 7 and 8 reflect the current forest age distribution and the estimated logging scenarios. The timber harvesting model aims to provide a constant supply of timber from the Otway Ranges as a whole and takes account of many factors. For example, low rates of logging are estimated in the Arkins catchment between 2000 and 2100 and this is reflected in Figure 8.

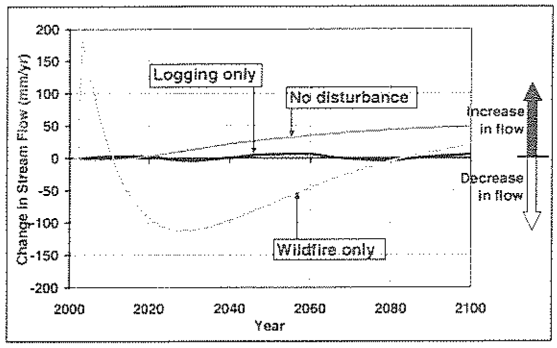

Figure 7. Change in stream flow in the St. George catchment relative to stream flow in the year 2000 under 3 forest management scenarios.

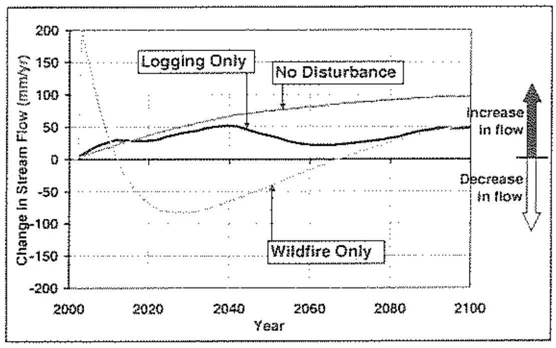

Figure 8. Change in stream flow in the Arkins catchment relative to stream flow in the year 2000 under 3 forest management scenarios.

4. DISCUSSION AND CONCLUSIONS

The results for the West Barwon catchment (Figure 6) can be summarised as follows. Under the prescribed logging scenario, there is little change in current stream flow. Allowing the forest to age causes a 60 mm increase in average stream flow over the 100 year period; this equates to approximately 10 % of mean annual flow. The wildfire scenario has the most significant effect on stream flow. In this scenario a large initial increase in flow is followed by 60 years with stream flow decreased from its current value.

The West Barwon, St. George and Arkins catchments show a similar response to the three forest management scenarios. Clearly the wildfire scenario has the largest effect. Low rates of forest disturbance by logging in the Arkins catchment have resulted in an increase in flow over the simulation period.

It is likely that disturbance by fire, logging and possibly insect or disease damage will all affect catchment stream flow in the Otways in some way over the next 100 years. The scenarios demonstrate how one factor acting alone is likely to influence future stream flow. Because many factors influence forest hydrology simultaneously, all three scenarios are relevant to estimation of future changes in stream flow. It must be remembered that in the Otway Ranges there is a large annual variation in stream flow driven by climatic variation and the influence of the factors considered here is of a considerably smaller magnitude.

The appropriate use of water resources is a topic of increasing importance in Australia. The impact of logging on forest water use in the Otways is no exception as indicated by community interest in the issue. The modelling approach demonstrated above is an objective analysis that applies the best available methods to estimate changes in stream flow in a region with incomplete data sets. This type of analysis facilitates discussion between stakeholder groups with different perspectives and provides a basis from which to develop appropriate forest management policies.

The modelling approach described here can be developed for use in different regions and on a range of different issues concerning forest hydrology. Stream flow response functions can be fitted directly where data are available and otherwise estimates can be derived from existing functions. Munday et al. [2001] develop and apply the approach to a catchment with changing land use and calculate new response functions for both eucalypt and pine forest. The modelling approach is a valuable tool to aid the management of forest water resources.

5. ACKNOWLEDGMENTS

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