Modelling the Effects of Large-Scale Plantation on Streamflow and Water Allocation: A Case Study for the Goulburn-Broken Catchments

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Abstract: Large-scale plantation development will have significant impact on mean annual water yield and hence affect water allocation. In the Goulburn-Broken catchments there are plans to convert large areas of pastures to forestry plantations in the coming decades. There is a range of commercial and environmental considerations that motivate these plans. About 20% of the area above Goulburn Weir has been identified as suitable for blue gum plantations (*Eucalyptus globulus*). An attempt was made in this study to evaluate the impact of blue gum plantation on mean annual water yield in the Goulburn-Broken catchment. A simple water balance model has been implemented into a GIS framework to facilitate spatial analysis of rainfall and land-use information. The results showed that the maximum reduction in mean annual flow is 8% for Lake Eildon and 14% for Goulburn Weir. However, under a scenario where both social and economic factors are considered, the area of the blue gum plantation will be significantly smaller. As a result, reduction in mean annual flow is 2% at Lake Eildon and 4% at Goulburn Weir. When combined with the system simulation model for Goulburn, it was predicted that the fraction of time water allocations are less than 100% increases from current 3% to 7% under the maximum plantation scenario. The results from this study provide catchment and resource managers with useful insights into the hydrologic impacts of land-use change.

Keywords: *plantations, water yield, mean annual water balance*

1. INTRODUCTION

It is now generally established that large-scale plantation development can significantly alter catchment water balance and thus affect water allocation. The Goulburn-Broken Catchment covers 17% of Victoria and supports a population of 250,000 people. It generates over 15% of the total state stream flow. As a major water supplier to the Goulburn-Murray Irrigation District, stream flow along the Goulburn River has been highly regulated. Water is also diverted from the catchment to service western Victoria for irrigation, stock and domestic water supplies. The region generates about $1.5 billion of food products annually. A catchment management strategy has been developed by the Goulburn-Broken Catchment & Land Protection Board to improve the region's productivity while maintaining social well being, and environmental quality. Key issues that concern catchment managers, irrigators and the local community are water quantity, allocation, quality and river restoration. To address these issues in the catchments, a number of land-use options have been proposed including the establishment of southern blue gum plantations (CLPR, 2000).

The major aim of this study was to predict the changes in water yield as a result of blue gum plantations in the upper part of the Goulburn-Broken catchment. The model used in the analysis was developed by Zhang *et al*. (1999, 2001) and implemented into a GIS framework by Bradford *et al.* (2001), but was substantially modified during this work.

2. METHOD AND DATA

2.1. Mean annual water balance model and inputs

The water balance model used in this study was developed by Zhang *et al.* (1999, 2001). It calculates mean annual evapotranspiration from mean annual rainfall and potential evapotranspiration with only two parameters. The average relationships are shown in Figure 1 for grassland and forest with 95% confidence intervals. In estimating catchment average water yield, it is assumed that there is no net change in catchment water storage over a long period of time. As a result, catchment water yield can be calculated as the difference between long-term average rainfall and estimated evapotranspiration.

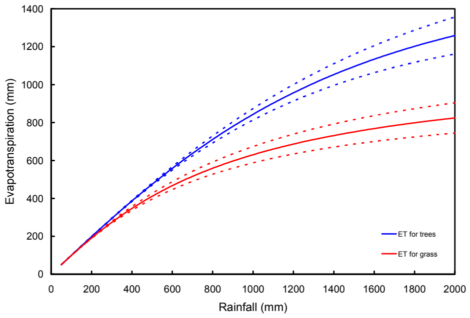

Figure 1. Relationships between mean annual evapotranspiration and rainfall. Solid lines indicate average annual evapotranspiration and dotted lines represent ±2STD, where STD is standard deviation.

The water balance model was implemented in ArcInfo based on the characteristics of each cell to account for spatial variability in the vegetation and rainfall. The method also considers the effect of tree growth or leaf area index on evapotranspiration. Three key datasets are required to calculate evapotranspiration: catchment boundaries, long term mean annual rainfall and percent forest-cover. To investigate the change in water yield, each scenario required a different forest-cover input, while the catchment boundaries and rainfall surfaces remained constant.

2.2. Catchment description and data

The Goulburn River catchment covers an area of 16,191 km^2 with a mean annual flow of 3,000 GL at Goulburn Weir. Rainfall varies significantly from greater than 1,600 mm per year in the south-eastern high country to less than 450 mm per year in the far north of the catchment (Figure 2). The Broken River catchment has an area of 7,723 km^2 and it joins the Goulburn River south of Shepparton. The mean annual flow is 325 GL and average annual rainfall is about 1,200 mm in the south of the catchment and decreases to less than 500 mm in the north west (Figure 2). Major land-use units in the Goulburn catchment include native vegetation (34%), dryland agriculture (58%) and irrigated agriculture (7%). Major land-use units in the Broken catchment are similar, but with a lower percentage of native vegetation and a higher percentage of plantations.

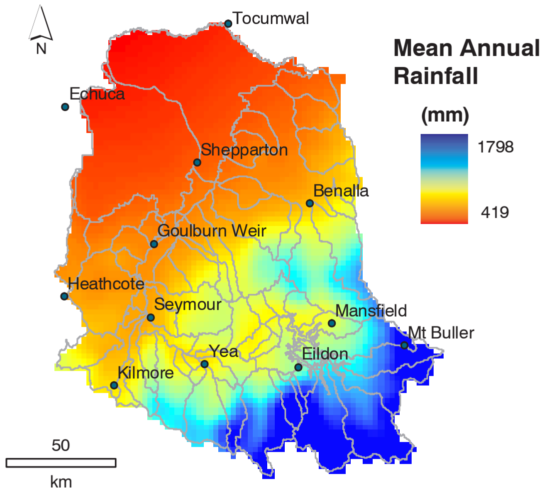

Figure 2. Long term mean annual rainfall distribution for the Goulburn-Broken catchment.

The catchment boundaries (Figure 3) were determined from a 25m grid resolution digital elevation model (DEM) provided by the Department of Natural Resources and Environment, Victoria (NRE). Long-term average annual rainfall for the period of 1961 – 1990 was used in the study. The rainfall data was calculated from mean monthly rainfall surfaces obtained from the Bureau of Meteorology at 2.5 km spatial resolution (Figure 3).

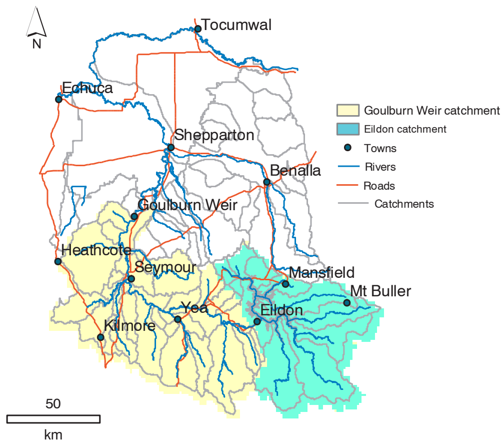

Figure 3. Location map of the Goulburn-Broken catchments.

A generalized tree cover map was provided by the Murray-Darling Basin Commission (MDBC)

(Ritman, 1995) and is shown in Figure 4. All the spatial inputs were resampled to 100m grid resolution for analysis. Measured stream flows at 16 gauged sub-catchments were used to validate the water balance model. These sub-catchments are defined by their contributing areas upstream of selected gauging stations (see Figure 5). Monthly stream flow data for a number of selected gauging stations were provided by Thiess Environmental Services.

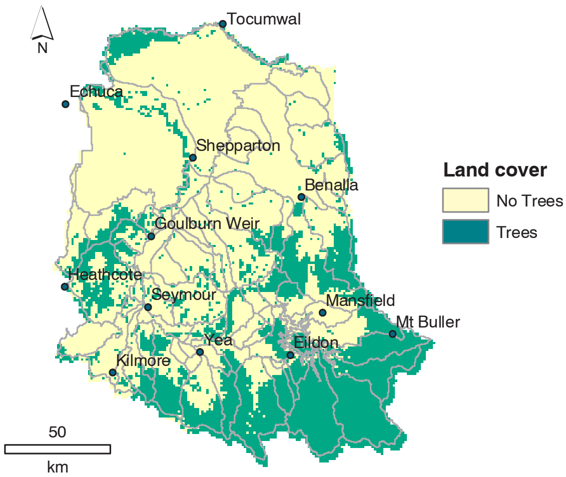

Figure 4. Map of current tree cover in the Goulburn-Broken catchments (Ritman, 1995)

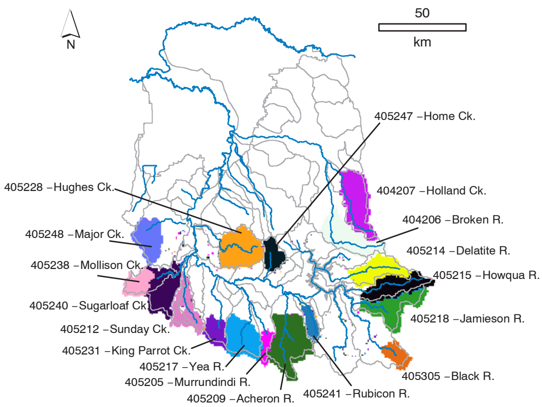

Figure 5. Location of the 16 gauged catchments used in this study for model validation.

3. MODELLING IMPACT OF BLUE GUM PLANTATIONS ON WATER YIELD

The ultimate goal of this study was to predict the impact of blue gum plantations on catchment water yield and water allocation. Two scenarios were considered for the catchment and the impact on water yield was evaluated for Lake Eildon and Goulburn Weir.

3.1 Maximum Scenario: Blue gum plantation establishment on all suitable land currently not forested

To investigate the impact of possible future land-use changes on catchment water yield, scenarios were derived from plantation suitability data developed by the Centre for Land Protection Research (2000). These datasets were generated from land suitable for sustaining plant growth based on the most limiting factor (MLF) method. The biophysical criteria used to generate these data included rainfall, temperature, slope and soil characteristics. In our study, we considered specifically the impact of a southern blue gum (*E. globulus* spp *globulus*) plantation on catchment water yield because it is the most economically attractive species for the region (Trapnell pers. com.). Areas identified as suitable for blue gum plantations are shown in Figure 6. Classes 1 and 2 were considered suitable and assigned 100% adoption rate. It should be noted that the areas shown in Figure 6 represent the maximum likely extent of plantations and is thus likely to be a significant overestimation of the actual adoption rate.

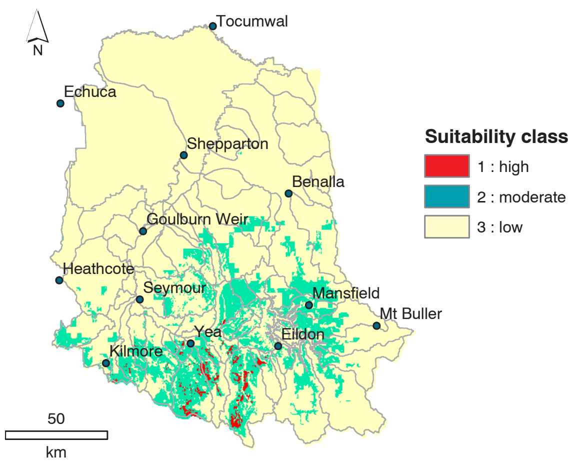

Figure 6. Southern Blue gum suitability map using the most limiting factor (MLF) method (source: CLPR, NRE, 2000). Class 1 and 2 are considered as suitable and Class 3 is not.

3.2. Moderate Scenario: Blue gum plantation establishment at variable adoption rates

Plantation development is not only influenced by biophysical but also social and economic factors. Hence, the areas that will be planted with trees will be far less than the area deemed suitable for plantation in Figure 6 above. In this scenario, the effect of those other factors was estimated as a consensus of expert opinion. The maximum plantation area is scaled down based on the likelihood of adoption rate. Under this scenario, adoption rates for suitability classes 1, 2 and 3 are 50%, 25% and 0% respectively. It assigns the proportion of each of the 'suitable' cells that will become plantation under the scenario.

4. RESULTS

4.1.Model validation

The performance of the model under current vegetation conditions was evaluated by comparing model estimates of mean annual water yield against measured stream flow. This is a necessary step in predicting the effects of future afforestation on water yield and it provides a measure of confidence in how well the water balance model holds for the catchment.

Figure 7 shows a comparison between modeled and measured mean annual water yields for these catchments. The slope of the regression through the origin is 1.04 with a correlation coefficient of 0.8. Since the main interest is in flow to Lake Eildon and Goulburn Weir, model estimates were compared with measured flow at these locations. It is encouraging that the difference between modelled and measured flow is only 7% and 3 % at these two sites, respectively.

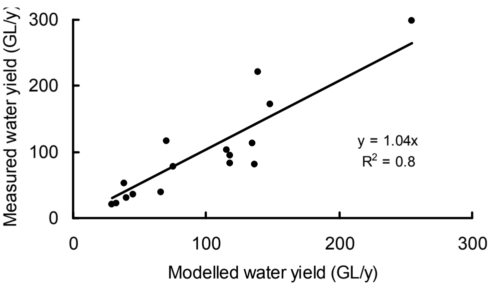

Figure 7. Comparison between modelled and measured mean annual water yield for 16 gauged catchments in the Goulburn-Broken region.

4.2.The impact of blue gum plantation establishment on water yield under the maximum scenario

In this scenario, it was assumed that 100% of the areas suitable for blue gum become plantations (Figure 6). This represents an increase in forest cover of 618 km^2 or 16% of the total catchment area above Lake Eildon and 2246 km^2 or 21% of the total area above Goulburn Weir (including Lake Eildon). It is clear that water yield reduction shows large spatial variation (Figure 8). The unit reduction in mean annual water yield varied between 0 and 150 ML/km^2. The greatest reduction occurs in catchments with the most suitable land between Seymour and Eildon. The least change in water yield occurs in catchments around Goulburn Weir and in the wettest catchments above Lake Eildon that have snowfall complications.

The maximum impact of southern blue gum plantation on inflow to Lake Eildon was investigated by aggregating the effects of the plantation on water yield in the catchments above Lake Eildon. As a result of the *maximum* scenario, the predicted mean annual flow to Lake Eildon will be reduced by 113 GL per year, which is about 8% of the current mean flow to the lake. For catchments above Goulburn Weir (including Eildon catchments), the predicted reduction in mean annual flow is 400 GL per year or 14%.

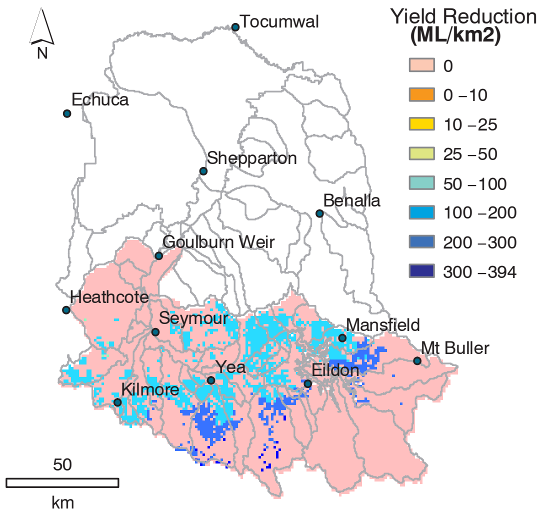

Figure 8. *Maximum* reduction in water yield or stream flow if all suitable areas became blue gum plantations

It should be noted that these reduction estimates represent the worst case scenario from a water yield point of view. There are economic and social factors that will limit the adoption rates of blue gum plantations. It is unlikely that all areas suitable for blue gums will be planted at any one time.

4.3.The impact of blue gum plantation establishment on water yield under the moderate scenario

In the *moderate* scenario, a more realistic adoption rate determined by other factors was considered. For this *moderate* adoption scenario, it represents an increase of 154 km^2 or 4% of the total area above Lake Eildon and 612 km^2 or

5.8% of the total area above Goulburn Weir. Reductions in catchment water yield predicted to occur in this scenario are shown in Figure 9. The overall reduction is much less than predicted for the worst case (*maximum*) scenario. The estimated mean annual reduction in flow is 27 GL per year or 2% for Lake Eildon and 105 GL per year or less than 4% for Goulburn Weir.

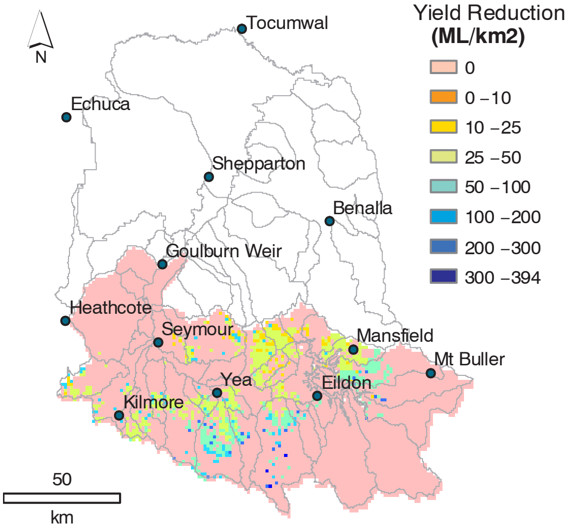

Figure 9. Reduction in water yield or stream flow based on *moderate* adoption rates

4.4 Impact of blue gum plantation establishment on water supply

The system simulation model of the Goulburn water supply system (GSM), which is used in defining the Goulburn Bulk Water Entitlement (Water Bureau, 1995), was used to estimate the impacts of afforestation identified in this study on water supply in the Goulburn system. Use of the GSM allows the complex interactions between inflow rates and volumes, harvesting in both on-stream and off-stream storages, and water supply to be assessed. The model simulates operation of the Goulburn/Broken/Loddon and Campaspe water supply systems using inflow and climatic data for the period 1891 – 1993. Model outputs include time series of irrigation deliveries, water available for use, and streamflow.

Goulburn System gravity irrigation customers hold a "Water Right", which effectively provides access to two separate water products. The first is referred as the water right. The system is managed to provide this with a high reliability, that is, in almost all years. The second is the sales component, which is made available in varying quantities when there are sufficient resources to provide the water right in the following season under minimum inflow conditions. Throughout each season, water available for use is progressively declared by way of the "seasonal allocation", which expresses in terms of percentage how much of the water right is available for delivery. A seasonal allocation of 100% corresponds to all the water right being available, but no sales. A seasonal allocation of 200% is equivalent to 100% of the water right being available, plus the maximum of 100% sales.

Figure 10 shows the predicted impact of the afforestation scenarios on Goulburn system irrigation security (where security is the reliability of the seasonal allocation). This shows that the percentage of time final seasonal water allocations to irrigators are less than 100% of the water right would increase from 3% under current conditions to 7% in the *maximum* plantation scenario.

The GSM also predicts that average deliveries of irrigation water in the irrigation districts would decrease by 1.5% in *moderate* plantation scenario, and 4.9% in the *maximum* plantation scenario. Any alteration of the bulk water entitlement to reduce environmental impacts of afforestation would further reduce average deliveries and security.

5. DISCUSSION AND SUMMARY

This study has focused on the impact of blue gum plantation on mean annual water yield. The maximum area identified as suitable for blue gum plantation represents 16% and 21% of the total catchment area above Lake Eildon and Goulburn Weir (including Lake Eildon), respectively. The estimated reductions in mean annual flow to Lake Eildon and Goulburn Weir are 113 and 400 GL per year. These reductions are significant, representing 8% and 14% of current mean annual flow. However, it should be noted that this is a worst case scenario based on the unlikely assumption that the whole area suitable will become plantations. There are other factors, such as infrastructure, social and economic, that can significantly limit plantation expansion.

Under the *moderate* scenario, reduction in mean annual flow of only 2% and 4% for Lake Eildon and Goulburn Weir is still likely to be an overestimation. In all scenarios, the greatest yield reduction occurs in the catchments with most suitable land and therefore a greater percentage of new tree plantations. The least affected areas coincide with the least suitable land, therefore the least conversion to plantations.

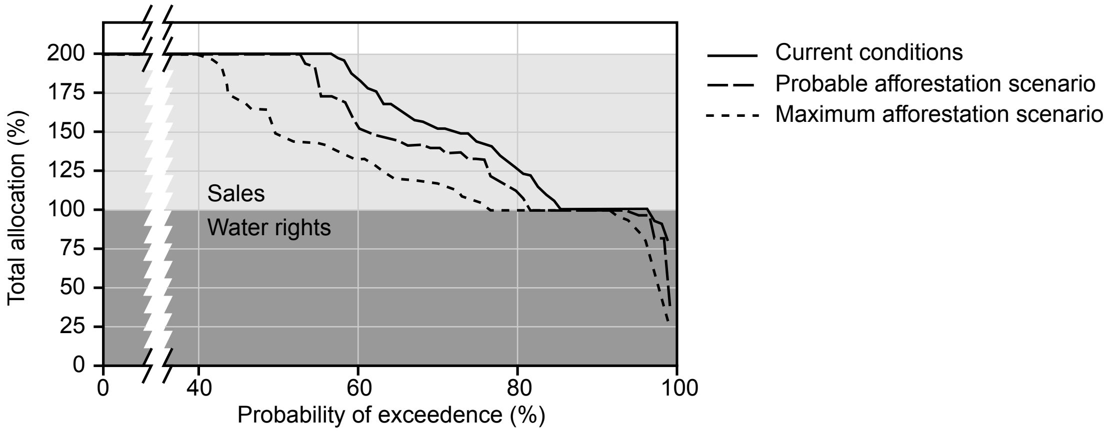

Figure 10. The predicted effect of two bluegum afforestation scenarios on the reliability of water allocations in the Goulburn-Broken system. Note that allocations are committed to a 200% level under the Victorian system, with the first 100% representing allocations against water rights, and the remainder against sales.

In the vicinity of Goulburn Weir, land, although cleared, is generally too dry to be suitable for blue gum plantations, while above Lake Eildon, it is mostly tree covered. Where these high catchments are cleared, there are limiting factors relating to low temperature and snow conditions.

It is clear that while the predicted reduction in stream flow is affected by rainfall, current land-use, and the underlying assumptions of the model, adoption scenarios influence the results even more significantly. Irrespective of the adoption rate chosen, there will be an establishment and harvesting cycle which will keep the actual plantation area below the assumed adoption rate. Evaluating the current land-use and developing more realistic scenarios will make the model predictions more relevant for catchment management.

Afforestation has been suggested as a major future land-use change in Australia. There are plans to convert large areas that are currently under pasture to tree plantations in the Goulburn-Broken catchments. While there are many sound reasons for the expansion of plantations, catchment managers should also consider the impact of plantation on water yield.

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References

Bradford, A., L. Zhang, P. Hairsine, Implementation of a mean annual water balance model within a GIS framework and application to the Murray-Darling Basin. Technical Report 01/8. Coop. Res. Cent. For Catch. Hydrol., Canberra, ACT, 2001

Centre for Land Protection Research, Goulburn Broken Dryland Regional Development Projects, Land and Climatic Suitability Criteria, 2000

Ritman K.T, Structural Vegetation Data: a specification manual for the Murray Darling Basin Project M305, 1995

Water Bureau, Department of Conservation and Natural Resources Victoria, Goulburn Simulation Model – Base Run 0600 Specification. Bulk Water Entitlements Report Series. Report No. 3, 1995

Zhang L., W.R. Dawes and G.R. Walker, Predicting the Effect of Vegetation Changes on Catchment Average Water Balance. CRC for Catchment Hydrology Technical Report 99/12, 1999

Zhang, L., W.R. Dawes and G.R. Walker, Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research*, 37, 701-708, 2001.