

Effects of plantation forest harvesting on water quality and quantity: Canobolas State forest, NSW

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Abstract

Protection of streams and riparian zone functions is a key objective of sustainable forest- and aquatic-ecosystem management. Forest managers utilise best management practices (BMPs) for timber harvesting, log extraction and soil conservation, including the use of riparian buffer strips, sensitive stream crossing and road drainage design. In NSW the efficacy of these BMPs has not been fully tested, nor has their cumulative effect in protecting stream systems at the catchment scale. This paper presents findings of a small catchment experiment conducted in a native forest control catchment and two 1962 age-class *Pinus radiata* plantation catchments within Canobolas State forest. The plantation catchments were harvested in 2002/3 using legislated BMPs. Streamflows and water quality (turbidity and suspended sediment concentration) were measured between 1999 and 2006 allowing assessments of the impacts of harvesting activities using the BMPs. Results indicate that no significant differences were observed in event mean concentrations of suspended sediment, mean turbidity, or low-flow turbidity or TSS. In these catchments the BMPs used were adequate for protecting streams from the potential effects of forestry activities. These results and monitoring of the effects of BMPs in other catchments provide valuable feedback for the review of practices and policies. Analyses of water yields and evapotranspiration have confirmed that annual streamflows in pine plantations vary with respect to annual rainfall and plantation age; the majority of changes being attributable to changes in the baseflow component of total streamflows. Predictions of the likely interception of rainfall by plantations need to take account of these factors.

Keywords

Adaptive management, forest hydrology, water quality, water quantity, plantation water use

Introduction

Between 1950 and 1980 the area of pine plantations expanded rapidly in Australia as a result of government investment to establish a domestic softwood industry. Since 1990, due mainly to private investment, the plantation estate has expanded further and according to the Commonwealth, State and Territory Governments' 2020 Vision strategy the plantation forest estate in Australia should treble between 1997 and 2020 to a total of 3 million ha (Roberts, 2005). This will contribute to growth in the forest industry, enhancement of rural and regional economies and potentially help in solving natural resource management issues including salinity and climate change. There are concerns, however, that reforestation could have detrimental effects on catchment runoff due to increased evapotranspiration in comparison to pastures or grassland (e.g. Zhang *et al.*, 2001; Keenan *et al.*, 2004). Furthermore, forestry activities including timber harvesting and road construction have the potential to increase soil erosion and contribute to increased stream sediment loads to the detriment of aquatic ecosystems and also downstream water users (Webb & Haywood, 2005).

The State of NSW has over 330,000 ha of forest plantations, approximately 245,000 ha of which is owned by the NSW Government (Parsons *et al.*, 2006). Forests NSW is the trading name of the Forestry Commission of NSW and is responsible for managing both native State forests and government-owned plantations, many of which are located in the headwaters of catchments that are used for domestic and agricultural water supplies. Forests NSW is legislated to implement Best Management Practices (BMPs) that aim to protect the aquatic environment and domestic water supplies from the potential impacts of forestry activities. The main State instruments relevant to plantation forestry are the *Plantations & Reforestation Act, 1999* and the *Protection of the Environment Operations Act, 1997*. Forests NSW is required to comply with the

Plantations and Reafforestation (Code) Regulation, 2001 regulated by the NSW Department of Natural Resources (DNR) and has been issued with five Environment Protection Licences (EPLs) by the NSW Department of Environment and Conservation (DEC) for the carrying out of forestry activities on State forests and Crown timber lands. The object of each licence is to require practical measures to be taken to protect the aquatic environment from water pollution. The conditions and practical measures contained within the EPLs and the Code include soil conservation measures for the design of bridges, culverts and causeways; appropriate drainage spacings on roads and skid tracks; seasonal harvesting restrictions; slope restrictions for harvesting and road construction activities; wet weather restrictions on the use of roads and log landings; mass movement hazard conditions; soil dispersibility conditions; and protection of drainage features by the use of filter strips and/or buffer strips (Webb & Haywood, 2005).

To provide some feedback on the effectiveness of the EPL and Code conditions, Forests NSW is implementing a water quality monitoring (WQM) program in over 30 small catchments in native forests and pine plantations. The objective of the WQM program is to determine if there is an identifiable impact on water quality from licensed forestry activities and if so, to quantify the level of that impact. The aim of this paper is to present the findings of a 7 year study to determine the effects of pine plantation harvesting on water quality and quantity using prescribed BMPs.

Study sites

Canobolas State forest, located near the township of Orange in the Central West of NSW comprises >3800 ha of *P. radiata* plantations that are situated on the Middle Miocene Canobolas Volcanic Complex comprising basaltic intrusions and flows, alkali rhyolite, and trachyte intrusions, flows and volcanics (Pogson & Watkins, 1998; Erskine, 2005). Great soil groups present include lithosols, kraznozems, yellow solodics and occasional yellow podzolics (Kovac *et al.*, 1990; Erskine, 2005). Mean annual rainfall is ~1080 mm (Erskine, 2005). Forests NSW has undertaken WQM in a number of small catchments in Canobolas State forest. Results from three of these are presented in this paper (Table 1). All three streams are tributaries of Cadiangullong Creek which flows to the Belubula River. Another small catchment, CNBL06 was instrumented between 1999 and 2000 but was destroyed by a landslide and debris flow in November 2000 (Erskine, 2005). The CNBL07 catchment was instrumented in 2001 to replace CNBL06. Canobolas State forest was chosen for inclusion in the WQM program because it is situated on steep slopes in an area of comparatively high rainfall and therefore represents a higher potential for soil erosion than the majority of the plantation estate.

Table 1. Catchment characteristics in Canobolas State forest

Catchment	Treatment type	Vegetation type	Area (ha)	Period of Monitoring
CNBL01	Control	Native forest	170	1999-2006
CNBL05	Impact	1962 age-class <i>P. radiata</i>	55.3	1999-2006
CNBL07	Impact	1962 age-class <i>P. radiata</i>	55.4	2001-2006

Methods

Stream gauging stations consisting of a flat-v weir were installed at the outlet of each catchment, while a tipping bucket rain gauge (pluviometer) and manual rain gauge were installed and maintained within each catchment. Gauges were located upstream of tributary junctions on each stream and in similar geomorphic settings. Each station was instrumented with an automatic pump water sampler, a datalogger, pressure transducer, turbidity probe and staff gauge, powered by 12V batteries charged by a solar panel. Stream height and in-stream turbidity were logged at six-minute intervals. Routine water samples were collected weekly during periods of baseflow, while stage-activated samples were automatically pumped from each stream throughout flood events. At each data download visit water samples were collected from the automatic samplers, refrigerated and couriered to the laboratory where they were analysed for turbidity and total suspended sediment (TSS) concentration according to the appropriate methods (APHA, 1998).

Forest harvesting and soil disturbance

Harvesting of the two water quality monitoring catchments in Canobolas State Forest (CNBL05 and CNBL07) was conducted between December 2002 and October 2003. A post-harvest audit of soil

disturbance revealed that 23.9 ha (43.2%) and 22.3 ha (40.3%) of the CNBL05 and CNBL07 treatment catchments were clearfall harvested, respectively. It is estimated that cable harvesting accounted for ~35% and 65% of the harvested area in each catchment, respectively. In both catchments the general harvest area (GHA) accounted for the majority of the harvested area, with forwarder tracks having the next greatest areal extent. Quadrat surveys along transects indicated that total vegetated groundcover over the harvested area was in excess of 80% in both catchments. The vegetated groundcover was dominated by small litter (<0.2m diameter) with lesser amounts of large litter (>0.2 m diameter) and living vegetation (Figure 1). The degree of soil disturbance was comparatively minor in both catchments but where evident it comprised mainly ruts and to a lesser degree log furrows, while the extent of rills was insignificant.



Figure 1. Groundcover within General Harvest Area of catchment CNBL07 post-harvest, showing the high degree of cover dominated by small litter and to a lesser extent large litter and living vegetation.

Of all surface types recorded in the catchments roads had the lowest amount of vegetated groundcover, as expected. However, the roads cover a minor area, were recorded on low gradient slopes in both catchments (up to 6° and 8° in CNBL05 and CNBL07, respectively) and had a predominantly gravel surface. Mean vegetated groundcover on cable log furrows was >64% in CNBL05 catchment and >55% in CNBL07 catchment while mean vegetated groundcover on forwarder tracks was >70% in CNBL05 and >80% in CNBL07. Mean vegetated groundcover on log dumps and chipper dumps was >70% in CNBL05, while mean vegetated groundcover on log dumps was >90% in CNBL07 catchment. In both catchments mean vegetated groundcover in the GHA was greater than 90%. A bivariate analysis of vegetated groundcover and slope data from both catchments indicated that in very few quadrat locations was vegetated groundcover less than 70% in combination with slopes greater than 20°. Such situations only occurred on cable log-furrows and the GHA in upper catchment locations away from drainage features.

Results

Impacts on water quality

Streamflow data for each site were separated into baseflows and stormflows (runoff) using the digital filtering method of Lyne & Hollick (1979) with parameter values for an interpolation interval of 1 hour, with 3 passes and a filter factor of 0.9, after Cornish & Vertessy (2001). Stormflow data were then used to calculate Event Mean Concentrations (EMC) of suspended sediment and Event Mean Turbidity (EMT) values for each flood “event” using the methods of US EPA (1999). Events were included only when three or more samples had been taken and only when the samples had been collected at sufficient intervals to represent the rising and falling limbs of the hydrograph. Where data were available, events and low-flow samples were paired between the Control (CNBL01) and Impact (CNBL05 and CNBL07) sites for the pre- and post-harvest periods. Control site values were subtracted from Impact site values (to give IMC or Impact Minus Control values) and differences between pre- and post-harvest values were then tested for statistical significance using a 2-tailed *t*-test. If data did not conform to a normal distribution, they were log-transformed to meet the assumptions of a *t*-test. Where F-tests revealed heterogeneity in the datasets, *t*-tests for unequal variance were used. Where the variances were not significantly different, *t*-tests for equal variance were used. A total of 467, 449 and 342 samples were analysed respectively from the CNBL01, CNBL05 and CNBL07 stations.

At CNBL05 no statistically significant differences were observed between the pre- and post-harvest periods for EMC, EMT, or for low-flow turbidity or TSS values (Table 2). This is exemplified in Figure 2 which shows trends in EMT for the CNBL05 site with respect to the CNBL01 control. Similarly at CNBL07 no statistically significant differences were observed between the pre- and post-harvest periods for EMC, EMT, or for low-flow turbidity or TSS values (Table 3). However, the power of the experiment to detect differences was compromised due to the short pre-harvest period but was unavoidable as an earlier station (CNBL06) was destroyed by a landslide and debris flow (Erksine, 2005).

Table 2. Results of analysis undertaken on all variables for the CNBL05 catchment (v CNBL01)

Variable	No. samples, Pre & post	IMC Variance, Pre & post	IMC Mean, Pre & post	F value (df)	p-value (for F-test)	T value	Df	p-value
EMC (mg/L)	12 16	2228 448	29.34 8.61	4.98 (11&15)	0.01	1.42	14.33	0.178
EMT (NTU)	13 16	121.9 174.1	15.67 12.68	1.43 (12&16)	0.54	0.65	27	0.52
Low-flow NTU	18 32	3.85 16.76	7.401 6.132	4.35 (31&17)	<0.001	1.48	47.15	0.146
Low-flow TSS (mg/L)	18 32	116.9 84.3	4.617 3.525	1.39 (17&31)	0.42	0.38	48	0.707

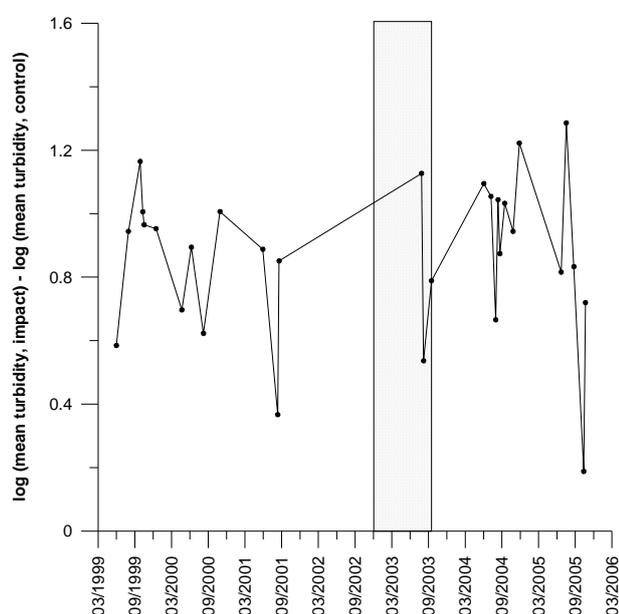


Figure 2. Log event mean turbidity values for CNBL05 minus CNBL01. The shaded area represents the period of harvesting.

Table 3. Results of analysis undertaken on all variables for the CNBL07 catchment (v CNBL01)

Variable	No. samples, Pre & post	IMC Variance, Pre & post	IMC Mean, Pre & post	F value (df)	p-value (for F-test)	T value	Df	p-value
EMC (mg/L)	6 12	163.9 310.9	-6.350 9.000	1.90 (11&5)	0.50	-1.89	16	0.078
EMT (NTU)	6 12	20.03 16.32	7.609 7.980	1.23 (5&11)	0.72	-0.18	16	0.861
Low-flow NTU	5 15	31.79 3.30	9.280 3.438	9.63 (4&14)	<0.001	2.28	4.28	0.081
Low-flow TSS (mg/L)	5 15	9.86 16.02	2.182 1.826	1.63 (14&4)	0.68	0.18	18	0.859

It is well established that forests, including plantations, intercept more rainfall than grasslands or pastures and that the absolute amount of forest evapotranspiration (ET) increases as rainfall increases (e.g. Zhang *et al.*, 2001). Furthermore, it is accepted that plantation water use (or ET) varies with plantation age and can be affected by silvicultural interventions such as thinning (Bren *et al.*, 2006). Annual water yields in the CNBL01 native forest control catchment conform to the global average for forested catchments with respect

to annual rainfall (Figure 3) as per Zhang *et al.* (2001). It was possible to assess the effects of forest harvesting on streamflows in the two impact catchments. In each case ET from the mature 40 year old pine plantations prior to harvesting was equivalent to ET in the native forest catchment. Double mass curves, as illustrated in Figure 4 for CNBL07, indicate that following harvesting streamflows were increased in the impact catchments. Annual ET values in the catchments post-harvest were, on average, mid-way between annual ET predicted by the Zhang *et al.* (2001) curves for forests and grasslands. Given that the catchments were only 40-43% harvested, these results are entirely plausible. Both pre- and post-harvest ET in the impact catchments were well predicted by the empirical equations of Bren *et al.* (2006), thereby validating their model at these sites. When stormflows and baseflows were separated and a similar analysis conducted between impact and control sites, it was evident that the majority of the increase in post-harvest water yields was attributable to an increase in the baseflow component of total streamflow.

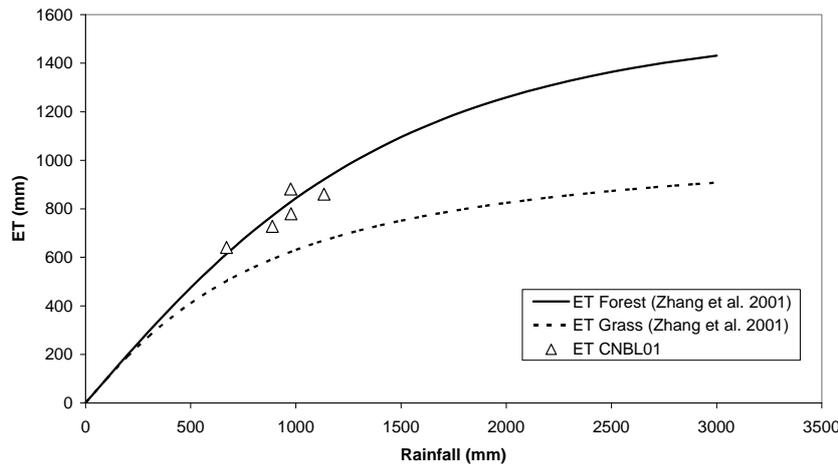


Figure 3. Control catchment annual rainfall and evapotranspiration (ET) with respect to the Zhang *et al.* (2001) curves.

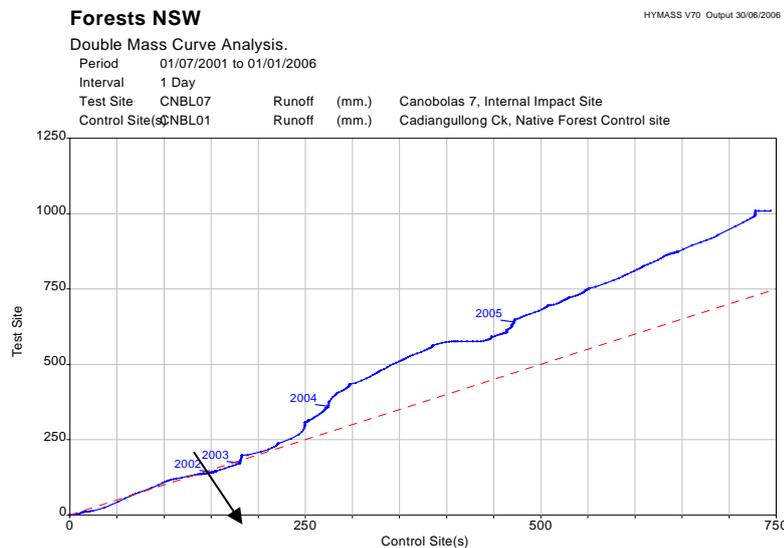


Figure 4. Double mass curve of total runoff (mm) at the CNBL07 impact site versus the CNBL01 control site. The arrow corresponds with the commencement of harvesting activities.

Discussion and conclusion

The National Water Initiative has identified large-scale plantation development as a land-use activity that has the potential to intercept significant volumes of surface and/or ground water now and in the future. This study has illustrated that evapotranspiration by mature pine plantations at Canobolas is approximately the same as for a native forest and greater than for pastures or grassland. It has also provided confirmation that plantation water use will vary with age and rainfall characteristics. When modelling the potential effects of plantations on streamflows it is essential that the additional factors of stand age and silvicultural

interventions (e.g. thinning, harvesting) be considered as the simplistic models of Zhang *et al.* (2001) tend to overestimate water used by plantations over the course of a full rotation. The models of Bren *et al.* (2006) are more useful for this purpose but there is a need for further research into the effects of silvicultural interventions, field-based studies of the effects of topographic location (e.g. planting in upper catchment locations versus floodplains) and the problems of scaling up from small catchment studies to very large catchments. The results of the Canobolas study presented here have important implications for the sustainable management of planted forests and provide a critical evaluation of best management practices (BMPs) used in the forestry industry with respect to stream function. In this study it was evident that a high degree of groundcover remains following clearfall harvesting of pine plantations in the form of small and large litter and regenerating vegetation. This, combined with minimised soil disturbance and the utilisation of a raft of BMPs designed to conserve soil and protect streams, has resulted in non-significant changes in high- and low-flow turbidity and suspended sediment concentrations post-harvest. Further research is required to determine if these results are applicable in other localities and to identify the effects of forestry activities on other aspects of aquatic ecosystem health. In this context Forests NSW is committed to continue monitoring the efficacy of BMPs at the catchment level and to seek up-to-date information as it becomes available to further refine individual conditions, where appropriate to ensure adequate protection of water resources and aquatic ecosystems.

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