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Longer-term changes in streamflow following logging and mixed species eucalypt forest regeneration: The Karuah experiment

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SUMMARY

The Karuah replicated paired catchment experiment was initiated in the 1970s to examine the hydrological effects of eucalypt-to-eucalypt forest succession in New South Wales, Australia. Treatments were conducted on 25.4–78.8% of the area of six small catchments in 1983. Five of the treated catchments experienced a significant increase in streamflow following forest disturbance, equivalent to annual water yield changes ranging from 120 mm to 319.6 mm which varied in proportion to the percentage of each catchment logged. This initial increase lasted for greater than 5 years in the logged and unburnt Bollygum (L−) catchment, but had returned to pre-treatment levels within 2.5 years in the logged and burnt (L+) Corkwood and Jackwood catchments, and within 2 years in the Kokata and Coachwood plantation catchments (P). A significant reduction in streamflow then occurred in three catchments – Corkwood (113.5 mm a^{-1}), Bollygum (72.7 mm a^{-1}) and Kokata (68.9 mm a^{-1}) – but had returned to the pre-treatment level within 7 years post-harvest in the Corkwood catchment. A continuing suppression of streamflow after 27 years is evident in two of the catchments, Bollygum and Kokata, with Kokata experiencing a further decline from 2005 onwards to a mean annual reduction of 172.4 mm. By contrast a significant increase in streamflow relative to the pre-treatment level has been recorded in the Jackwood catchment after 23 years (157.6 mm a^{-1}).

Relative changes in streamflow measured in this experiment can be explained largely by changes in forest species composition, basal area and stocking rates. The eucalypt stands have variously self-thinned and in some cases forest growth appears to have been slowed by insect attack and bell miner associated dieback. Contrary to earlier published findings, while this study confirms that Mountain ash type water yield reductions can occur in other forest types, this response appears to be the exception rather than the rule. These findings have implications for the modelling and management of water yield impacts of mixed species eucalypt forest disturbance.

1. Introduction

Some of the most frequently cited forest hydrology studies in Australian native forests have been conducted in the Melbourne water supply catchments, Victoria. These catchments are largely forested by *Eucalyptus regnans* (Mountain ash), which is one of the world's tallest trees and often grows in pure stands (Langford, 1976). In a review of catchment experiments Bosch and Hewlett (1982) noted that Langford's (1976) results contradicted other studies from around the world by reporting a reduction in streamflow 3–5 years following a wildfire. The hydrological response of these forests to disturbance is somewhat unusual and such streamflow reductions have not been recorded in other forest types, such as those of North America (Stednick, 1996), the Mediterranean (Cosandey et al., 2005) or indeed the eucalypt forests of southwestern Australia (Bari et al., 1996). The streamflow effect following disturbance of Mountain ash forest is often referred to as the Kuczera (1987) response or "Kuczera curves" (Bren and McGuire, 2012). Due to removal of the mature forest there is a marked reduction in evapotranspiration which results in an initial increase in water yield. The increase in water yield persists for a period of between 4 and 7 years. If the forest is left to regenerate, water yield then declines logarithmically to the pre-disturbance level. If a significant proportion of the catchment is disturbed and the forest regenerates water yield is then reduced to below the

Abbreviations: BIC, Bayesian information criterion; CUSUM, Cumulative sum; DBHOB, Diameter at breast height over bark; NSW, New South Wales; RSS, Residual sum of squares.

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pre-disturbance level. The maximum suppression of water yield reported is 50% and this typically occurs at around 28 years after disturbance. Mean annual water yield then slowly returns to pre-disturbance levels as the forest ages (Kuczera, 1987). Subsequent work has confirmed the streamflow response as resulting from prolific regeneration by seed and subsequent high rates of evapotranspiration (e.g. Haydon et al., 1996; Watson et al., 1999; Vertessy et al., 2001), though the magnitude and timing of water yield suppression due to forest disturbance may not be uniformly experienced (Bren et al., 2010).

The Karuah hydrology project is the longest running native forest paired catchment study in the state of New South Wales (NSW), where different eucalypt species occur. Following logging in 1983, Cornish (1993) reported that water yields increased significantly by about 150–250 mm per year in five of the six treated catchments and the magnitude was related to the percentage of basin harvested. Both base flows and storm flows increased after harvesting then declined as the forest regenerated, falling below pre-harvest levels after 7 years (Cornish and Vertessy, 2001). This trend, though of different magnitude, led Cornish and Vertessy (2001) to conclude that the study extended the findings from the Mountain ash studies to other eucalypt species in a somewhat different environment. In the Tantawangalo study, also in mixed eucalypts, Lane and Mackay (2001) reported that in a catchment that was patch-cut, streamflow initially increased but then declined to below the pre-harvest level after 4 years. Subsequently, the Kuczera-curves or derivatives of them, have been used in modelling to assess the potential effects of eucalypt harvesting in NSW on water resources (e.g. Webb, 2012), despite uncertain evidence confirming the response in the longer term.

The aim of this paper is to revisit the Karuah hydrology project results by analysing a longer data set covering 27 years post-logging. We aim to critically analyse streamflow response to disturbance and regeneration in these paired catchments, with a view to examining the appropriateness of using Kuczera-type models in mixed species eucalypt forests in NSW.

2. Material and methods

2.1. The Karuah catchments

The Karuah hydrology research project was established in 1975 to investigate the effects of various forest management and operational practices on water yield and water quality (Cornish, 2001). The project consists of eight 'paired' catchments, 12.5–97.4 ha in area (Table 1), located approximately 200 km north of Sydney near the town of Dungog in Chichester State forest (Fig. 1). Each catchment is a tributary of the Telegherry River, itself a tributary of the Karuah River. The climate is warm temperate and precipitation occurs almost exclusively as rainfall. Mean annual rainfall at the highest elevation No. 1 rain gauge (Fig. 1) for the period 1975–2009 was 1743 mm with a coefficient of variation of 0.21. Across the catchments there is an orographic effect, with mean annual rainfall at the lowest elevation No. 4 rain gauge being 1350 mm (1975–2009) in comparison. Rainfall is summer dominant with the highest monthly means recorded between November and May (Fig. 2).

All catchments are situated on the eastern slope of a ridge running south from the Barrington Tops. The elevation extends from 450 m at the lower sites to 950 m on the ridge. Catchment aspects are generally easterly and range from ESE to ENE. Although some slopes exceed 30°, the majority of slopes fall within the range 5–25° (Cornish, 1993). Underlying geology comprises a folded Carboniferous sequence of sedimentary rocks of the Ararat Formation, characterised by lutites and arenites interbedded with mudstones, siltstones and shales (Peou, 1978). Lutites dominate at higher elevations and have produced deeper (>1 m) and redder soils than the shallower (<1 m) yellow soils formed on the arenites at lower levels (Elliot, 1978; Table 2). All soils are highly structured, friable and most have significant organic horizons (Elliot, 1978) with the main soil groups being xanthozems and brown podzolics with euchrozems, yellow earths and red and yellow podzolics also occurring as a result of lithology and topographic position (Table 2). Riley (1984) reported that organic horizons were up to 10 cm thick on slopes <15° but were absent or patchy on the steeper slopes. Thickness of the A horizon averaged 20–40 cm on slopes with low gradients and <10 cm on steeper slopes (Riley, 1984).

Prior to treatment the catchments carried stands of tall (>35 m) wet sclerophyll forest dominated by Sydney Blue Gum (*Eucalyptus saligna*), Silvertop Stringybark (*E. laevopinea*), Brush Box (*Lophostemon confertus*) and Mixed Rainforest types (Table 2). Cornish (1993) reported little evidence of disturbance in the stands prior to logging and estimated that the mature stands were between 100 and 500 years old. Sydney Blue Gum (stocking rate 30 stems ha^{-1}, basal area 28.2 m^2 ha^{-1}) and Silvertop Stringybark (stocking rate 14 stems ha^{-1}; basal area 12.8 m^2 ha^{-1}) dominated the overstorey of the pre-treatment stands, while Rainforest species (stocking 700 stems ha^{-1}, basal area 31.6 m^2 ha^{-1}) dominated the understorey (Cornish and Vertessy, 2001).

2.2. Logging treatments

Two of the eight catchments, Sassafras and Crabapple, were retained as controls (C) while the remaining six catchments were logged during 1983 using three duplicated treatments. The treatments used were:

(i) Logging with a regeneration burn (L+). Sawlogs and pulpwood were harvested, followed by a regeneration slash burn. No planting or seeding was carried out.
(ii) Logging without a regeneration burn (L−). Sawlogs and pulpwood were harvested but no burning was undertaken. Some planting of *E. laevopinea* was carried out in the larger openings.

Table 1
Karuah catchment characteristics, including area, 1983 logging treatments and soil depths.

Catchment	Area (ha)	Treatment[a]	% Logged	Dates of logging	Estimated mean soil depth (m)
Crabapple	14.7	C	0	NA	1.4
Sassafras	25.3	C	0	NA	0.7
Corkwood	41.1	L+	40.4	January–December 1983	1.4
Jackwood	12.5	L+	78.8	January–December 1983	0.7
Barratta	36.4	L−	25.4	March–December 1983	1.4
Bollygum	15.1	L−	32.4	March–December 1983	1.0
Kokata	97.4	P	29.1	January–October 1983	1.4
Coachwood	37.5	P	60.7	January–October 1983	0.7

[a] C: control; L+: logging with a regeneration burn; L−: logging without a regeneration burn; P: plantation establishment following tractor clearing.