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Journal of Hydrology 310 (2005) 253–265

Journal of Hydrology

www.elsevier.com/locate/jhydrol

The response of flow duration curves to afforestation

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Received 1 October 2003; revised 22 December 2004; accepted 3 January 2005

Abstract

The hydrologic effect of replacing pasture or other short crops with trees is reasonably well understood on a mean annual basis. The impact on flow regime, as described by the annual flow duration curve (FDC) is less certain. A method to assess the impact of plantation establishment on FDCs was developed. The starting point for the analyses was the assumption that rainfall and vegetation age are the principal drivers of evapotranspiration. A key objective was to remove the variability in the rainfall signal, leaving changes in streamflow solely attributable to the evapotranspiration of the plantation. A method was developed to (1) fit a model to the observed annual time series of FDC percentiles; i.e. 10th percentile for each year of record with annual rainfall and plantation age as parameters, (2) replace the annual rainfall variation with the long term mean to obtain climate adjusted FDCs, and (3) quantify changes in FDC percentiles as plantations age. Data from 10 catchments from Australia, South Africa and New Zealand were used. The model was able to represent flow variation for the majority of percentiles at eight of the 10 catchments, particularly for the 10–50th percentiles. The adjusted FDCs revealed variable patterns in flow reductions with two types of responses (groups) being identified. Group 1 catchments show a substantial increase in the number of zero flow days, with low flows being more affected than high flows. Group 2 catchments show a more uniform reduction in flows across all percentiles. The differences may be partly explained by storage characteristics. The modelled flow reductions were in accord with published results of paired catchment experiments. An additional analysis was performed to characterise the impact of afforestation on the number of zero flow days (N_{zero}) for the catchments in group 1. This model performed particularly well, and when adjusted for climate, indicated a significant increase in N_{zero}. The zero flow day method could be used to determine change in the occurrence of any given flow in response to afforestation. The methods used in this study proved satisfactory in removing the rainfall variability, and have added useful insight into the hydrologic impacts of plantation establishment. This approach provides a methodology for understanding catchment response to afforestation, where paired catchment data is not available.

Keywords: Afforestation; Flow duration curves; Flow reduction; Paired catchments

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0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2005.01.006

1. Introduction

Widespread afforestation through plantation establishment on non-forested land represents a potentially significant alteration of catchment evapotranspiration (ET). Using data collated from multiple catchment studies, researchers have demonstrated a consistent difference in ET between forests and grass or short crops, and the relationship between ET and rainfall on a mean annual basis (Holmes and Sinclair, 1986; Vertessy and Bessard, 1999; Zhang et al., 1999, 2001). Once annual rainfall exceeds 400–500 mm, there is an increasing divergence between forest and grassland ET (Zhang et al., 2001). Research from South Africa in particular has demonstrated flow reduction following afforestation with both pine and eucalypt species (Bosch, 1979; Van Lill et al., 1980; Van Wyk, 1987; Bosch and Von Gadow, 1990; Scott and Smith, 1997; Scott et al., 2000). In regions, where water is an increasingly valuable resource, prediction of the long-term hydrologic impact of afforestation is a prerequisite for the optimal planning of catchment land use.

Zhang et al. (1999, 2001) developed simple and easily parameterised models to predict changes in mean annual flows following afforestation. However, there is a need to consider the annual flow regime as the relative changes in high and low flows may have considerable site specific and downstream impacts.. Sikka et al. (2003) recently showed a change from grassland to *Eucalyptus globulus* plantations in India decreased a low flow index by a factor of two during the first rotation (9 years), and by 3.75 during the second rotation, with more subdued impact on peak flows. The index was defined as the 10 day average flow exceeded 95% of the time, obtained from analysis of 10-day flow duration curves. Scott and Smith (1997) reported proportionally greater reductions in low flows (75–100th percentiles) than annual flows from South African research catchments under conversions from grass to pine and eucalypt plantations, while Bosch (1979) found the greatest reduction in seasonal flow from the summer wet season. Fahey and Jackson (1997) reported the reduction in peak flows was twice that of total flow and low flows for pine afforestation in New Zealand. The generalisations that can be drawn from annual analyses, where processes and hydrologic responses are to a certain extent integrated may not apply on a seasonal or shorter scale. Further, the observed impacts of any land use change on flows may be exaggerated or understated depending on the prevailing climate. Observations of flow during extended wet or dry spells, or with high annual variability can obscure the real impacts. Fig. 1 plots annual FDCs over 12 years of plantation growth for one of the catchments used in this study, Pine Creek. The net change in flow is obscured by rainfall variability; e.g. the greatest change in the FDC is in 1996, with the stream flowing $<20\%$ of the time. This may be compared with 2000, where there is substantially higher flows.

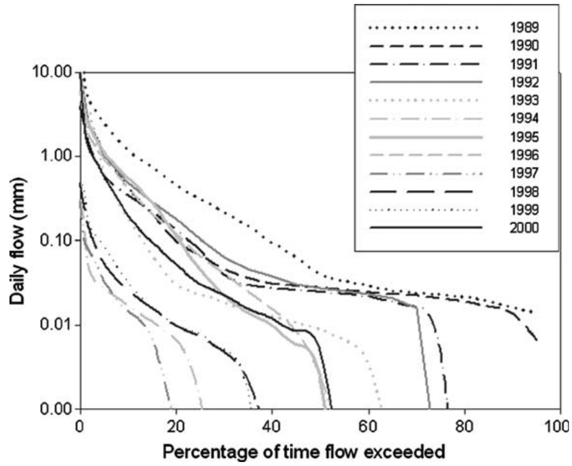

Fig. 1. Annual flow duration curves of daily flows from Pine Creek, Australia, 1989–2000.

This paper presents the results of a project aimed at quantifying changes in annual flow regime of catchments following plantation establishment. The flow regime is represented by the flow duration curve (FDC). The key assumption was that rainfall and forest age are the principal drivers of evapotranspiration. For any generalisation of response of the FDC to vegetation change, the variation in the annual climate signal must be removed. The time-tested solution to this problem is the paired-catchment (control versus treatment) experiment. The benefits in such studies are manifold: unambiguous measures of trends, insights into the processes driving those trends, excellent opportunities for model parameterisation and validation. However these data are not readily available for the range of treamtments and environments required. Consequently, the aims of this project