The Brigalow Catchment Study: Increases in runoff associated with land development can still be detected in flood events at a small catchment scale

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Abstract

The Brigalow Catchment Study has unequivocally shown that developing brigalow lands for cropping or for pasture doubles runoff volume and more than doubles peak runoff rate at the small catchment scale (<20 ha). However, the persistence of these land use effects on catchment response during high flow conditions are hotly debated within the international literature. Typical hypotheses are that these changes are reflected in smaller events and that the effects of forests, land cover and land use tend to converge during high flows, which have been defined as events with a return period of as short as two and ten years.

During 2010 and 2011, much of Queensland, Australia was subjected to consecutive record wet seasons. Data from the Brigalow Catchment Study, near Theodore in central Queensland, showed 2010 to be the third wettest year since records commenced in 1965; this was eclipsed by 2011 rainfall totals. These extreme seasons provided a unique opportunity to investigate the impacts of land use change on runoff and peak runoff rate in high flow conditions using a paired, calibrated catchment approach.

During the height of flooding in 2011, the brigalow scrub yielded 183 mm of runoff, cropping yielded 224 mm and pasture yielded 197 mm. Gross increases in runoff were 28% from the cropping and 50% from the pasture compared to that expected had they remained brigalow scrub. Increases in runoff as a result of land development were found in the three wettest years on record using a number of analytical approaches.

These findings lend strong support to the hypothesis that increases in runoff associated with land development can still be detected in flood events at a small catchment scale.

1. INTRODUCTION

Review of the literature shows that the impacts of forests on flood events are unclear (Alila *et al* 2009; van Dijk *et al* 2009). Forests are generally thought to have a flood mitigation effect (Bradshaw *et al* 2007), however this is likely restricted to more frequent, less extreme rainfall and subsequent flooding (Bathurst *et al,* 2011; van Dijk *et al*, 2009). Some studies fail to differentiate between the effects of land use change and forest presence or absence on runoff, and often use the terms interchangeably. Paired catchment studies are often cited as key references for determining the effects of forest cover on flood events, however debate continues on the suitability of methods for looking at changes in both magnitude and frequency (Alila *et al,* 2009; Alila *et al,* 2010; Lewis *et al,* 2010).

The 1998, 2010 and 2011 hydrological years at the Brigalow Catchment Study site in central Queensland, Australia, all had rainfall totals greater than the 15 year recurrence period. The 2011 season was the wettest in the study history, resulting in the most runoff from each catchment in both a season and in a single event. These extreme wet seasons were chosen to determine if increases in runoff due to land use change are still prevalent in high flow conditions on both an annual and individual event basis using both regression techniques typically associated with paired catchment studies and flow duration curves.

2. METHODS

2.1. Experimental site and study history

The BCS is a paired, calibrated catchment study consisting of three catchments. The study was established in 1965 to determine the impact on hydrology, productivity and resource condition when brigalow land is cleared for cropping and grazing. The study has been thoroughly documented elsewhere in this series (Elledge & Thornton 2012; Thornton & Yu 2012).

The study consists of three adjoining catchments, each of approximately 15 ha. Soils within each catchment are predominantly grey and black Vertosols, with an average slope of 2.5%. In their native state, all catchments were vegetated with brigalow scrub communities. Each catchment was instrumented to measure runoff using a 1.2 m steel HL flume with a 3.9 m by 6.1 m concrete approach box. Water height through the flumes was recorded using mechanical float recorders. Rainfall was recorded at the head of the three catchments.

During Stage I of the study, from 1965 to 1982, runoff was measured from the catchments in their native state. Stage II of the study commenced in 1982, when two of the three catchments were cleared with bulldozer and chain, and the fallen timber burnt in-situ. Catchment 2 (C2) was developed for cropping, with the construction of contour banks and grassed waterways, while catchment 3 (C3) was developed for grazing by the planting of improved pasture. Catchment 1 (C1) was left in its native state as a control. Stage III of the study was land use comparison, commencing in 1984.

2.2. Methods of analysis

Increase in runoff due to land use change was determined using two methods. Firstly, the calibrated catchment regression analysis approach of Thornton *et al* (2007) was used to compare Stage I runoff from C2 and C3 against C1. These relationships were then applied to C1 runoff from Stage III to estimate runoff from C2 and C3 had they not been cleared and developed for agriculture. The difference between observed runoff during Stage III and these estimates of runoff from the catchments is attributed to land use change. The three wettest hydrological years on record, 1998, 2010 and 2011 were chosen for this analysis. This approach was applied on an event basis, on an annual basis, and using the annual maxima sequence.

Secondly, catchment by stage flow duration curves were constructed using the program HYFLOW (Kisters, 2010) to show the percentage of time that a specific 9 am total daily discharge was equaled or exceeded. The order and magnitude of the curves between catchments was compared between Stage I and Stage III. Changes in the flow duration curve for C1 reflect changes in climatic sequence, while changes in the relationships between C2 and C3 to C1 reflect changes in runoff due to land development.

3. RESULTS

Average hydrological year rainfall at the site in the period 1965 to 2011 was 647 mm. Total rainfall for 2011, the wettest year on record was 1009 mm. Total rainfall for 1998, the second wettest year was 987 mm, while 2010, the third wettest year was 958 mm.

Equations 1 and 2 describe the event based runoff relationships of the catchments in their native state and allow the prediction of runoff from C2 and C3 given the known runoff volume from C1. The equations are robust, including an event of over 100 mm from C1 (Figure 1).

$$\text{C2 runoff (mm)} = \text{C1 runoff (mm)} \times 0.9539 \quad (R^2 = 0.95,\ n = 37) \tag{1}$$

$$\text{C3 runoff (mm)} = \text{C1 runoff (mm)} \times 0.7176 \quad (R^2 = 0.887,\ n = 40) \tag{2}$$

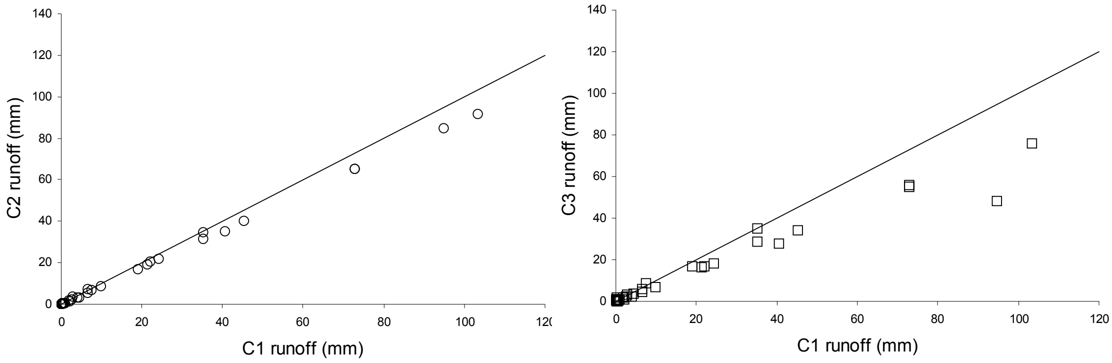

Figure 1 Event based runoff data collected during Stage I of the study shows a robust linear relationship between the catchments.

On an annual hydrological year basis, developing brigalow land for either cropping or grazing consistently shows an increase in runoff during extremely wet years (Table 1). This finding continues to hold on an individual event basis when using annual maximum series for the three years (Table 2).

Table 1. Observed annual runoff for the three wettest hydrological years of the study, compared to estimated runoff from C2 and C3 had they not been developed.

	C1	C2 - cropping				C3 – grazed pasture			
Year	Total runoff (mm)	Total runoff (mm)	Total estimated runoff* (mm)	Increase (mm)	Increase as % of estimated runoff*	Total runoff (mm)	Total estimated runoff* (mm)	Increase (mm)	Increase as % of estimated runoff*
1998	121	231	115	116	100	287	87	200	231
2010	47	175	45	130	293	111	34	46	137
2011	184	246	175	71	41	220	132	88	67

* Estimate of runoff from the catchment had it remained undeveloped, using either Equation 1 or 2.

Table 2. Annual maximum series runoff for the three wettest hydrological years of the study, compared to estimated runoff from C2 and C3 had they not been developed.

	C1	C2 - cropping				C3 – grazed pasture			
Event	Total runoff (mm)	Total runoff (mm)	Total estimated runoff* (mm)	Increase (mm)	Increase as % of estimated runoff* (mm)	Total runoff (mm)	Total estimated runoff* (mm)	Increase (mm)	Increase as % of estimated runoff* (mm)
Apr 1998	50	84	47	37	77	115	36	79	222
Feb 2010	44	63	42	21	51	50	31	18	59
Dec 2010	183	224	175	49	28	197	131	65	50

* Estimate of runoff from the catchment had it remained undeveloped, using either Equation 1 or 2.

Flow duration curves for Stage I show that total daily flows from C1 exceed those of C2 and C3 across the full range of probabilities (Figure 2). During Stage III, low flows (flows exceeded for >70% of the time) show similar probabilities of occurrence. However, flows exceeded for <25% of the time in C2 and C3 had greater daily totals than C1 (Figure 2).

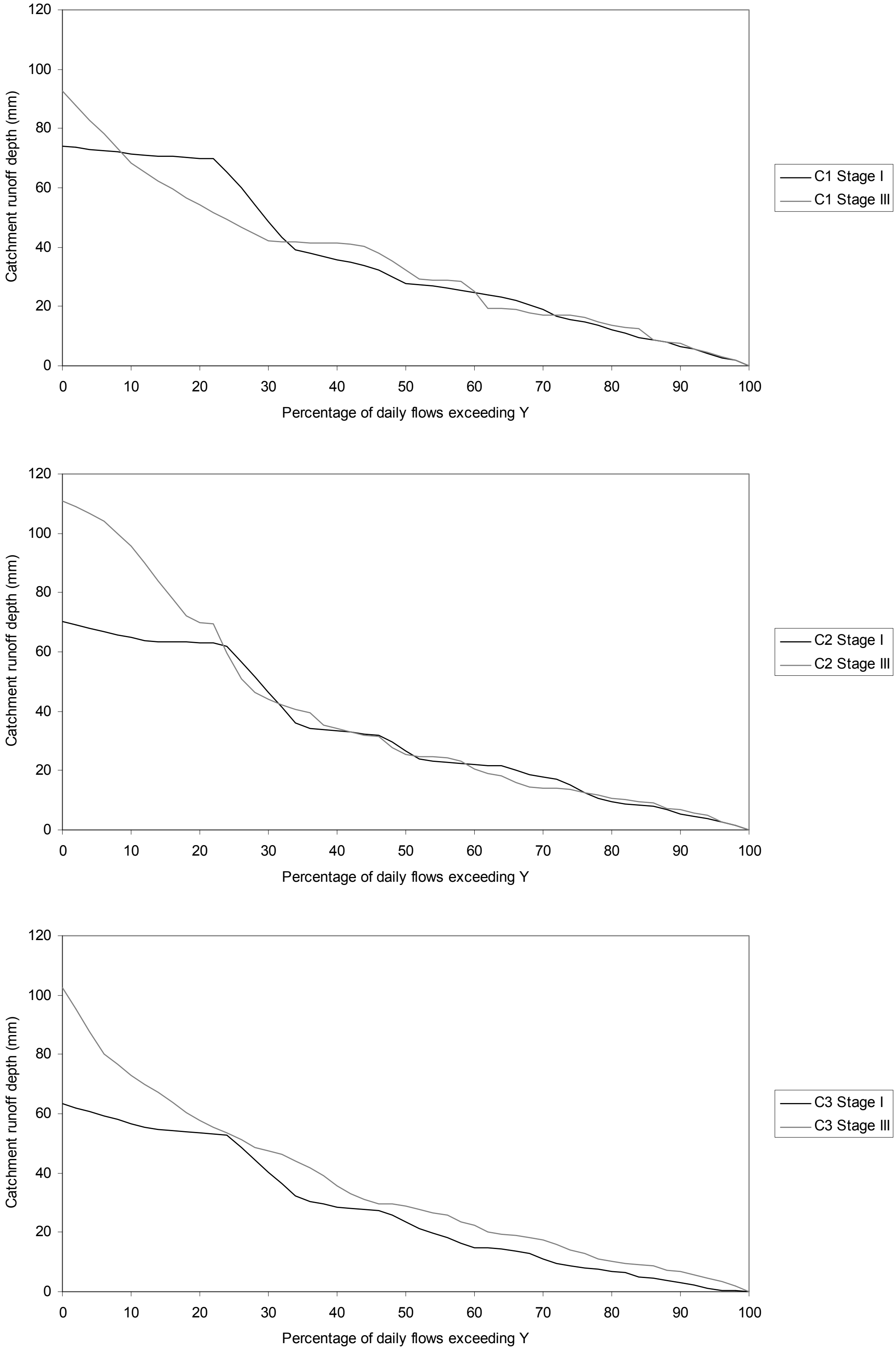

Figure 2 Flow duration curves for the three catchments in both Stage I and Stage III. The curves are derived from daily 9 am total catchment runoff depth data.

4. DISCUSSION

The paired, calibrated catchment study approach shows that increases in runoff from catchments developed for cropping or for grazing on improved pasture can be seen for extreme wet years and for individual high flow events. During 2011, the wettest year on record, with the highest ever total annual runoff from C1, total annual runoff increase from C2 was 169% of the long-term mean annual increase (71 mm cf. 42mm), while total annual increase from C3 was 231% of the long-term mean annual increase (88 mm cf. 38 mm) (Thornton *et al,* 2007). On an individual event basis, the increase in runoff from C2 as a result of land development was 117% of the long-term mean annual increase, while the increase in runoff from C3 as a result of land development was 171% of the long-term mean annual increase.

This pairing of events as a consequence of identical climatic sequence, irrespective of land use or location is robust for a number of reasons. Firstly, all flows were considered in developing the regression equations 1 and 2 to describe runoff from the catchments in their native condition. Secondly, when using these equations to estimate flows from C2 and C3 had they not been developed, the corresponding runoff from C1 was within the range of observations used to generate equations 1 and 2 for all events except for the largest on record. Thirdly, when considering the three years of data presented in the annual approach, all events were considered.

Implicit in its approach, annual maxima analysis does not consider all events. It may also suffer from the maxima event in one catchment in a given year being generated from a different climatic sequence to the maxima in an adjacent catchment. This was not the case in this analysis, with the annual maxima in all catchments generated from the same climatic sequence, making this analysis simply a subset of all three years of paired, calibrated catchment data. While it may be argued that inferring from a small sample of events that increases in runoff as a result of land development are still present in flood events, this pattern reflects that found in the long-term data from this site, and continues to hold for the largest event on record.

In addition to examining increases in flood magnitude as a result of land development, flow duration curves for C2 and C3 indicate higher daily flow totals for all probabilities of occurrence, as a result of land development. The greatest increase in magnitude is shown in flows occurring less than 25% of the time.

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