The Brigalow Catchment Study: forty-five years of paired catchment monitoring in the Brigalow Belt of Australia

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Abstract The Brigalow Catchment Study was established primarily to determine the impact on hydrology when brigalow land is cleared for cropping or pasture. This paired catchment study commenced in 1965, when three catchments were selected in central Queensland, Australia, to represent the extensive brigalow bioregion of approximately 37 million hectares. After a 17-year calibration period (1965–1981) two of the three catchments were cleared, with one developed for cropping, another sown to improved pasture, and the third retained as an uncleared control. Monitoring of salinity, water quality, soil fertility and productivity also commenced at this time and analysis of these long-term data sets clearly indicates that paired catchment studies are capable of answering questions beyond their initial scope of hydrological change.

Key words Brigalow; land development; runoff; catchment; Vertosols; Dermosols; Sodosols

INTRODUCTION

The brigalow bioregions of Queensland and New South Wales occupy 36.7 million hectares, stretching from Dubbo in the south to Townsville in the north of Australia. The bioregion contains Queensland's largest catchment, the Fitzroy Basin, and nearly half of the second largest catchment, the Burdekin Basin, both of which drain directly into the Great Barrier Reef lagoon. Since European settlement, 58% of this bioregion has been cleared. In 1962, the Brigalow Land Development Fitzroy Basin Scheme commenced, resulting in the Government-sponsored clearing of 4.5 million hectares for cropping and grazing. This clearing represents 21% of all clearing in the brigalow bioregions and 32% of the Fitzroy Basin area. Broad scale land clearing continued in the basin until 2006 (McGrath, 2007), including the highest rate of land clearing in Queensland, which occurred between 1997 and 1999 (Wilson *et al.*, 2002).

In order to quantify the effect of this land clearing on hydrology and soil fertility, the Brigalow Catchment Study (BCS) commenced in 1965, during the UNESCO decade of hydrology. The study continues today, continuing to answer hydrological questions, but also having adapted to answer new research questions, and having answered questions unanticipated at its inception.

METHODS

The BCS (24.81ºS, 149.80ºE) lies in the Dawson sub-catchment of the Fitzroy basin, central Queensland, Australia. The region has a semi-arid, subtropical climate. Summers are wet, with 70% of the annual average calendar rainfall of 720 mm falling between October and March, while winter rainfall is low. Rainfall is highly variable, ranging from 11 mm or less in any month, to 165 mm in one day. Annual potential evaporation is 2133 mm, and average evaporation is at least twice the average rainfall in all months.

The BCS is a paired catchment study consisting of three small catchments of areas 11.7–16.8 ha. There have been three experimental stages (Table 1). Mean slope of the catchments is 2.5%. Soil types in the catchments comprise associations of Black and Grey Vertosols, some with gilgais, Black and Grey Dermosols, and Black and Brown Sodosols (Isbell, 1996). In their native state, the catchments were composed of three major vegetation communities, identified by their most common canopy species; brigalow (*Acacia harpophylla*), brigalow–belah (*Casuarina cristata*) and brigalow–Dawson Gum (*Eucalyptus cambageana*). Understoreys of all major communities are characterized by *Geijera* sp. either exclusively, or in association with *Eremophila* sp. or *Myoporum* sp. The catchments were good quality agricultural land, all equally suitable for cropping or grazing. The study has been reported comprehensively (Cowie *et al.*, 2007; Radford *et al.*, 2007; Thornton *et al.*, 2007; Silburn *et al.*, 2009).

Table 1 The land use history of the three catchments of the Brigalow Catchment Study.

		Land use by experimental stage		
		Stage I	Stage II	Stage III
Catchment	Area (ha)	(Jan 1965-Mar 1982)	(Mar 1982-Sep 1984	Sep 1984-Dec 2004
1	16.8	Native brigalow	Native brigalow	Native brigalow
2	11.7	Native brigalow	Development	Cropping
3	12.7	Native brigalow	Development	Improved pasture

The Stage I calibration phase (17 years) monitored rainfall and runoff from the catchments, allowing an empirical calibration between catchments to be developed. Three permanent soil monitoring sites (20 × 20 m) were established in each catchment: two on clay soil, in both an upper and lower-slope position, and the third on a Sodosol. Baseline measurements of soil fertility were taken in 1981.

Stage II commenced in March 1982, when catchment 2 (C2) and catchment 3 (C3) were developed by clearing vegetation with traditional bulldozer and chain methods. The fallen timber was burnt i*n situ* in October 1982. In C2, residual unburnt timber was raked to the contour and burnt. Narrow-based contour banks were constructed at 1.5 m vertical spacing. A grassed waterway was established to carry runoff water from the contour channels to the catchment outlet. In C3, any unburnt timber was left in place, and in November 1982 the catchment was sown to improved pasture by distributing buffel grass seed (*Cenchrus ciliaris* cv. Biloela) on the soil surface. The second soil fertility assessment was undertaken in December 1982, soon after burning. Catchment 1 (C1) was retained as an uncleared, undeveloped control.

Stage III commenced in 1984. In C2, the first crop sown was sorghum (September 1984), followed by annual wheat for nine years. Fallows were initially managed using mechanical tillage (disc and chisel ploughs), which resulted in significant soil disturbance and low soil cover. In 1992 a minimum tillage philosophy was introduced and in 1995 opportunity cropping commenced with summer (sorghum) or winter (wheat) crops sown when soil water content was adequate. No nutrient inputs were used. In C3, the buffel grass pasture established well with >5 plants/m^2 and 96% groundcover achieved before cattle grazing commenced in December 1983. Stocking rate was 0.3–0.7 head/ha (each beast typically 0.8 adult equivalent), adjusted to maintain pasture dry matter levels >1000 kg/ha without feed or nutrient supplementation.

Rainfall and runoff data continued to be collected. Water quality data was collected on an event basis using automated samplers to collect discrete, depth integrated samples of runoff. Soil fertility was assessed annually from 1981 to 1987 and then in 1990, 1994, 1997, 2000, 2003 and 2008, with samples retained after analysis in a long-term storage archive.

RESULTS

Runoff from the three catchments in their virgin state during Stage I averaged 34 mm/yr; approximately 5% of annual rainfall. Peak runoff rate averaged 3.4 mm/hr. Runoff data from Stage I was used to develop linear relationships to estimate runoff from C2 and C3 given known runoff from C1 (Fig. 1). The following equations describe the relationship between C2 and C3 relative to C1:

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

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

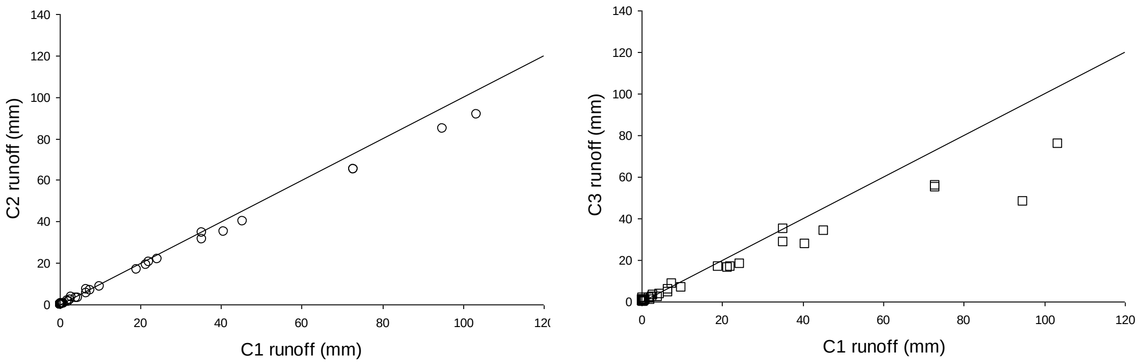

Fig. 1 Runoff data collected during Stage I, the calibration phase of the study shows the three catchments to be good hydrological pairs, with a linear calibration able to be developed to allow the prediction of runoff from catchments 2 and 3 given the known runoff from catchment 1.

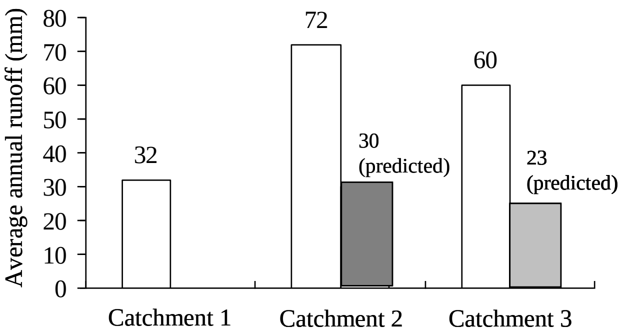

Fig. 2 Observed runoff from the three catchments during the land use comparison phase (Stage III) of the trial (□), and the predicted runoff from catchments 2 (■) and 3 (■) had they remained uncleared. All data has been rounded to zero decimal places.

This calibration was used to compare Stage III measured runoff from C2 and C3 with estimations of runoff had they not been cleared. This showed an increase of 42 mm/year when brigalow scrub is developed for cropping and 38 mm/year when developed for grazed pasture (Thornton *et al.*, 2007) (Fig. 2). Peak runoff rate from brigalow scrub increased to 6.6 mm/h in Stage III, however land development increased peak runoff rate by 9.1 mm/h, to 14.7 mm/h in C2, and by 3.4 mm/h to 8.9 mm/h in C3.

In 1981, prior to land development, soil chloride showed similar profiles across all sites, typically increasing to 0.4-0.6 m depth and then remaining relatively constant (Fig. 3). Chloride mass in the clay soils was similar, with 25 t/ha of chloride to 1.5 m depth, however chloride mass in the Sodosols was as low as 4.9 t/ha. During the land development phase (Stage II), the upper slope clay and Sodosol sites in C2 showed significant loss of soil chloride, while all sites in C3 showed significant loss.

Subsequent reductions in soil chloride under cropping were only significant in the upper clay soil, while under pasture, no further significant change occurred (Fig. 3). Chloride mass balance analysis indicates deep drainage of 0.17 mm/year for clay soils and 0.26 mm/year for Sodosols under virgin brigalow scrub. These drainage rates increased during the land development phase to 59 mm/year for C2 and 32 mm/year for C3. Since development, deep drainage has averaged 19.8 mm/year under cropping and 0.16 mm/year under pasture (Silburn *et al.*, 2009).

Both rainfall and runoff totals for the 2010 hydrological year were the largest measured during the study. Runoff from virgin brigalow scrub was 55 mm, while runoff from cropping was 175 mm and runoff from grazing was 109 mm. Reflecting the trend in runoff total, loads of sediment and nutrients in runoff from cropping were greater than both virgin brigalow scrub and pasture. However, loads from the pasture catchment were typically less than both cropping and brigalow scrub (Fig. 4).

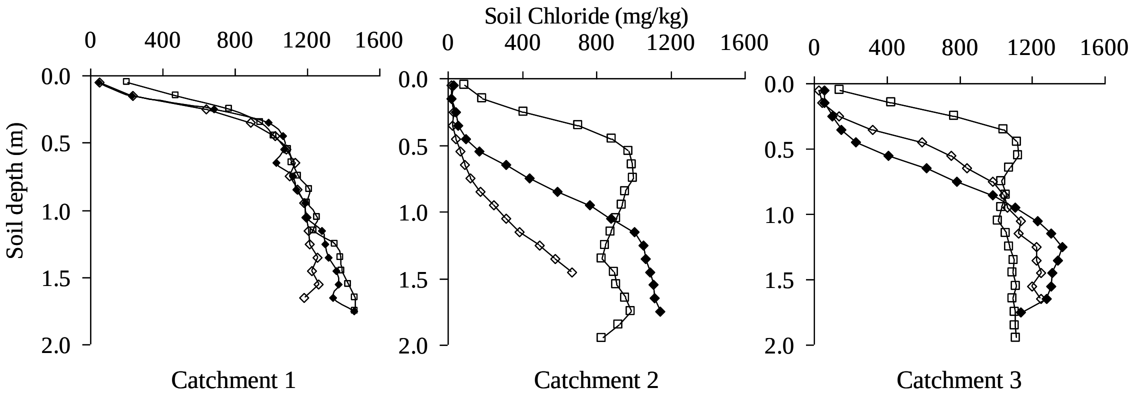

Fig. 3 Average soil chloride profiles for the upper slope clay soil in each catchment pre-clearing (1981) (□), immediately after land development (1983) (♦) and after 16 years of land use (2000) (◊).

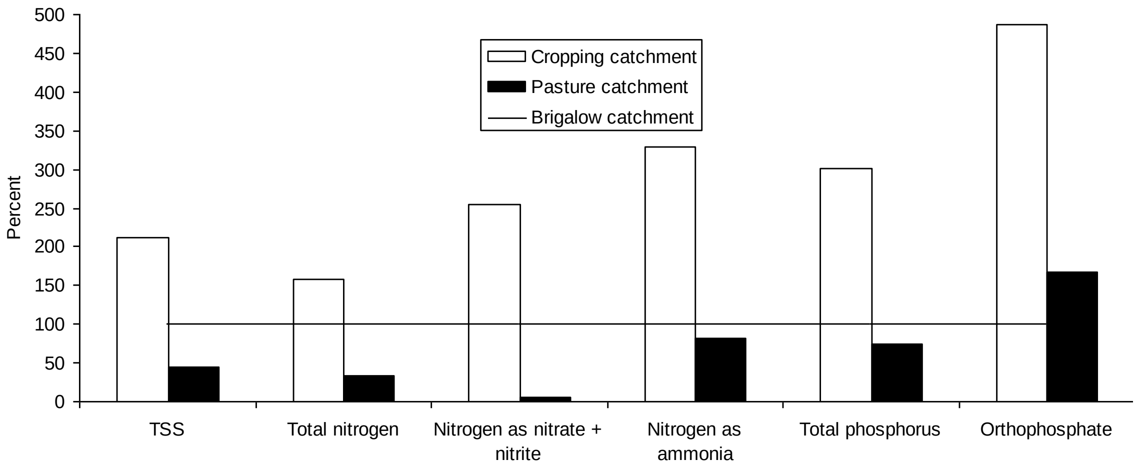

Fig. 4 The 2010 hydrological year sediment and nutrient loads from the cropping (butterfly pea) and pasture catchments of the Brigalow Catchment Study as a percentage of the load from the virgin brigalow scrub catchment.

The persistence of herbicides in runoff water from the cropping catchment is variable (Table 2). Both glyphosate applied at 585 and 900 g/ha, and metsulfuron-methyl applied at 4.2 g/ha, have been undetectable 31 days after application (Cowie *et al.*, 2004). Detections of 2,4-D applied at 313 g/ha have occurred up to 45 days after application, however it has not been detected in three instances more than 300 days after application. Fluroxypyr applied at 100 g/ha has been detected 267 days after application, however detection after more than 300 days post application has only occurred in one out of three instances. Atrazine applied at 1800 g/ha was detected, along with its breakdown products at 812 days after application.

While some of these chemicals are able to be detected in runoff waters long after they are applied, there were only two occasions from 31 samplings where >1% of the applied chemical was lost in runoff. Runoff 12 days after atrazine application at 1800 g/ha resulted in the loss of 1.2% of the total amount applied, while runoff 30 days after fluroxypyr application at 100 g/ha resulted in the loss of 3.8% of the total amount applied. On occasions when <1% of the applied chemical was lost in runoff, 87% of active ingredient loads were <1g/ha.

In their virgin state the three catchments had similar soil fertility. From 0-0.1m, levels of organic carbon (OC) (Walkley and Black) ranged from 1.8 to 2.2%, soil total nitrogen (TN) (Kjeldahl) from 0.18 to 0.21%, and extractable phosphorus (CP) (Colwell) from 10.3 to 11.0 mg/kg. No significant changes in OC levels occurred in the scrub or pasture catchments over the 26-year land use comparison; however, the cropping catchment showed a 48% decline in OC (Fig. 5).

Table 2 Presence/absence detections of herbicides in runoff water from the cropping catchment.

Chemical	Group	Days post application	Detected
glyphosate	glycine	31	No
metsulfuron-methyl	sulfonylurea	31	No
2,4-D	phenoxy	45	Yes
fluroxypyr	pyridine	373	Yes
simazine	triazine	274	Yes
atrazine (and breakdown products)	triazine	812	Yes

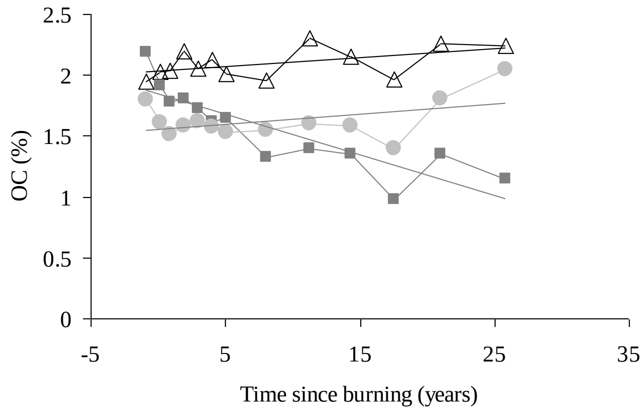

Fig. 5 Average organic carbon levels (0–0.1 m) in the untreated brigalow scrub catchment (Δ), linear trend (□), over 26 years, compared to levels in the catchment developed for cropping (■), linear trend (□), and the catchment developed for pasture (●), linear trend (□).

Similarly, no significant changes in TN levels occurred in the scrub or pasture catchments, while the cropping catchment showed a 64% decline in TN. Burning of the pulled timber in C2 and C3 resulted in significant increases of CP, to levels of 36.8 and 34.3 mg/kg, respectively. These levels decreased over the 26 years in both the cropping and pasture catchments by 45% and 65%, respectively (Thornton *et al.*, 2010).

DISCUSSION

The water balance studies undertaken have answered the key hydrological question posed at the commencement of this study. Land development for either cropping or grazing has doubled runoff and increased peak runoff rates. The collection of additional, non-hydrological data within the paired catchment study framework has allowed a more comprehensive understanding of the broader effects of this land use change.

A doubling of runoff and increased peak runoff rates under both agricultural systems resulted in increased risk of erosion and transport of nutrients and agricultural chemicals off-site. Agricultural production opportunities are also forgone as water for crop or pasture growth is lost.

An increased salinity risk is also of concern, primarily associated with the large increase in deep drainage and chloride leaching during the development phase of each land use and the ongoing deep drainage under cropping. The removal of chloride from the upper soil profile may however provide agricultural production benefits if initial chloride levels are a constraint to crop or pasture growth.

The three soil fertility parameters investigated all showed significant decline under cropping. Even if fertility decline is arrested via the application of fertiliser, the soil is unlikely to return to its virgin fertility level while continuing to be cropped. Modelling suggests that the application of nitrogen fertiliser to this system will improve TN levels, however limiting rainfall will not allow an increase in cropping frequency and hence dry matter production, so OC levels will not be improved (Huth *et al.*, 2009).

Unlike cropping, grazed pasture appears capable of maintaining both OC and TN levels, however significant amounts of TN are likely to be held in a plant-unavailable form, which may be limiting to pasture growth. The greater decline in CP in the pasture catchment compared to the cropping catchment suggests that even though more P is removed in grain than in beef, continuous production of dry matter in the pasture system results in less available P than in a cropping system, where dry matter production occurs for only a few months of the year.

These are the findings of planned scientific studies conducted in parallel with hydrological investigations using the paired catchment study technique. It is the findings of studies that have drawn on the BCS datasets in a manner not planned at the inception of the study that draw attention to the ability of long-term paired catchment studies to answer questions beyond their initial scope. For example, the calibration of the Rothamsted organic carbon turnover model for Australian conditions by Skjemstad *et al.* (2004) would not have been possible if it were not for the robust, paired catchment soil sampling program undertaken at the BCS. The unanticipated benefits of long-term studies are well documented (Pickett, 1991; Cowie *et al.*, 2007), and paired catchment studies are no exception.

CONCLUSIONS

The Brigalow Catchment Study clearly indicates that paired catchment studies are capable of answering questions beyond their initial scope of hydrological change. Development of brigalow lands for cropping and grazing has significantly altered water balance, with increased runoff and peak runoff rates. Multi-disciplinary research at the site has also shown that soil nutrient balances have also been significantly altered, drainage increased, soil OC, TN and CP decreased under cropping, and CP decreased under pasture. Based on these indicators, pasture appears more analogous to the native brigalow landscape than cropping.

The relevance of these findings to the larger brigalow bioregion will help to guide future investment in natural resource management. The length of record and breadth of data collected at this site can be considered a model in its own right, providing a point of truth for landscape and process modelling activities and a benchmark to assess the effects of slow, subtle and complex processes such as climate change on semi-arid subtropical Australian landscapes. The continued and unanticipated benefits of this study clearly demonstrate that there is value in the continuation of long-term catchment studies. To better facilitate these research activities, open access to BCS data is available online at www.derm.qld.gov.au/science/projects/brigalow/index.html.

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