Final report

Natural Resource Management

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Grazing impacts on cover, water, sediment and nutrient loss in the Upper Burdekin catchment (2006/07)

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Abstract

Poor land condition resulting from unsustainable grazing practices can reduce enterprise profitability and increase water and sediment yields from grazed catchments. This study has demonstrated that it is possible to improve ground cover and soil surface condition, as well as reduce hillslope sediment and nutrient yields, after just 5 years of improved land management in the form of wet season spelling. This will help retain valuable soil resources on the paddocks for future pasture growth and beef production, as well as potentially help reduce impacts on downstream ecosystems such as the Great Barrier Reef. Despite the reduced sediment and nutrient yields at the hillslope scale, there has not been a measurable reduction in yields at the sub-catchment outlet. This is because gully and bank erosion are the major erosion processes contributing sediments and phosphorus to the end of catchment. This will therefore make evaluating end-of-catchment water quality targets problematic as improvements in land management may not be seen for many decades.

Executive summary

Poor land condition resulting from unsustainable grazing practices can increase water and sediment yields from grazed catchments. MLA and regional NRM bodies are co-funding various Research, Development and Extension (RD&E) projects in an effort to maintain water, sediments and nutrients on hillslopes to sustain beef production, as well as to help reduce potential impacts from grazing lands on downstream ecosystems such as the Great Barrier Reef.

In a previous MLA funded project (NBP.314) CSIRO and QDPI&F assessed the linkage between grazing management, ground cover condition, and water and sediment/nutrient loss at the hillslope scale, by first establishing a monitoring program at three flume sites on Virginia Park Station, in the Weany Creek sub-catchment of the Burdekin Catchment, from 2002. In February of 2003 grazing strategies such as wet season spelling (WSS), as recommended by the EcoGraze project, were implemented and, for each of the subsequent wet seasons, changes in land condition and water and sediment run-off were measured.

The four wet seasons monitored from 2002-2005 had below-average rainfall conditions, and although changes in ground cover and soil surface condition were measured, the drought conditions did not provide significant rainfall and run-off to demonstrate whether improved grazing management had reduced hillslope water and sediment yields beyond that expected from natural climate variability. In the 2006/07 wet season, however, there was significantly higher rainfall and run-off, and this demonstrated that there was a decline in sediment and nutrient yields at 2 of the 3 hillslope flume sites. The two hillslopes that are showing signs of recovery are considered to have a ‘patchy’ cover arrangement (mixture of high and low cover areas) and importantly where there are low cover patches they are not in the main flow path for the hillslope. The recovery phase on these hillslopes is demonstrated by the fact that:

- End-of-dry season residual ground cover and pasture biomass levels are now above EcoGraze recommended rates four years after implementation of WSS.
- There has been an overall general shift in condition class from C to B and a reduction in area of D condition on all of the monitored hillslopes, although this recovery is considered to be very fragile due to the dominant species type (Indian couch), the patchy nature of the recovery, and the soil surface condition at the site.
- There has been a 60% reduction in hillslope sediment yields from 0.27 t/ha in 2002 to 0.1 t/ha in 2006 on the main research hillslope (Flume 1).
- There has been a 59% reduction in hillslope nitrogen yields (from 0.87 kg/ha in 2002 to 0.36 kg/ha in 2006) and 59% reduction in hillslope phosphorus yields (from 0.25 kg/ha in 2002 to 0.10 kg/ha in 2006) on the main research hillslope (Flume 1).

It is important to emphasise that this recovery has occurred on a grazing property that had biomass levels as low as 60 kg/ha of dry matter early in the project, and below average rainfall conditions in four out of five years of the study. Therefore these results demonstrate that significant recovery, in terms of both improved cover condition and water quality, is possible within 5 years in many parts of the Burdekin landscape.

The research also emphasises that the recovery, particularly with respect to pasture condition, is extremely fragile. Despite the surface pasture condition having improved, it is likely that the sub-surface soil health, and the proportion of 3P pastures, which are important for sustained infiltration and subsequent pasture production, has not yet returned to optimal levels. This is demonstrated by the fact that the percentage of hillslope run-off has not declined in the same way as sediment and nutrient yields. If improved ground cover and soil surface condition is maintained on these hillslopes into the future, it is hypothesised

that the hillslope run-off should also decline. Therefore, it is important to emphasise that a return to increased stock numbers and no wet season spelling could easily return the hillslopes to pre-trial conditions and jeopardise the full recovery of these sites.

On the third research hillslope (Flume 3) the lower 20% of the hillslope is characterised as having sodic soil and/or ‘scald’ D condition cover. This scald area is in the direct flow path for water leaving this hillslope. Unlike the other two hillslopes, there has not been a decline in sediment yields at the ‘scald’ flume despite receiving the same grazing management and WSS conditions. The lack of recovery on this hillslope is due to certain D condition patches being up to four times more likely to be heavily grazed than A and B condition pasture, and sodic soil communities being twice as likely to receive heavy grazing throughout the season compared with adjacent ironbark/bloodwood communities. These factors contribute to the failure of such areas to significantly improve in ground cover, herbaceous biomass and overall land condition. The scald area is the main source of sediments (and nutrients) for this hillslope, and because the main flow line from this hillslope passes through the scald area, there is high connectivity between the scald patch and the gully downstream. Therefore, although the areas upslope of the scald may have improved, the location and lack of recovery of the scald area means that the sediment yields from this hillslope remain high regardless of the grazing management implemented. Mechanical, biological or chemical treatment (or a combination of methods) on these scald areas is likely to be the only method of reducing their impact in terms of sediment and nutrient loss, and a research project that trials rehabilitation options would be very useful.

Despite the reduced sediment and nutrient yields at the hillslope scale (for 2 out of 3 sites), there has not been a corresponding reduction in yields at the sub-catchment outlet. This is because gully and bank erosion are the major erosion processes contributing sediments and phosphorus to the end of this sub-catchment. Only the nitrogen budget is dominated by hillslope sources. The study has also shown that climate, rainfall and land management conditions can cause the amount and source of sediments and nutrients coming from different erosion processes to switch between years. This will therefore make evaluating end-of-catchment water quality targets problematic as improvements in land management may not be seen for many decades. In addition, end-of-catchment load reductions that are a result of land use management changes will be masked by fluctuations in climatic conditions. Therefore, this study suggests that land condition targets need to be used in conjunction with end-of-catchment water quality targets. This will allow graziers to demonstrate that they are having a positive impact on downstream water quality with improved grazing practices in the short term (5-10 year period), and reduce the need to wait for improvements in downstream water quality loads that are likely to take many decades due to the temporal lag between when the erosion was initiated, and when any adverse impacts on down-stream water quality decline.

Acknowledgements

The research presented in this paper was funded by Meat and Livestock Australia and CSIRO; their support is gratefully acknowledged. We also thank Rob and Sue Bennetto for access to their property 'Virginia Park' to carry out this work. Thank you also to Joseph Kemei, Jamie Vleeshouwer and Justin Perry who assisted with field work and the collection of samples, and to Brigid Neilson (QDPI&F) who provided some of the figures and advice in this report. David Post also provided a review of an earlier version of this report, and his comments were greatly appreciated.

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1 Introduction

1.1 Background and objectives of study

This document represents the final report for the one year project (B.NBP.0321) 'Grazing impacts on cover, water, sediment and nutrient loss in the Upper Burdekin catchment'. This project builds on Project NAP3.224, which ran from 1999-2003 (Roth et al., 2003), and is largely a continuation of components of Project NBP.314 which ran from 2003-2006 (Post et al., 2006). Therefore while all attempts have been made to make this document a stand alone report, where details on methodology and results have been presented elsewhere, cross-referencing has been used to help reduce the length of the document. The primary geographical focus for this study was the Weany Creek catchment on Virginia Park Station in the Granodiorite country between Townsville and Charters Towers in the Burdekin catchment.

The main objectives of project B.NBP.0321 were to:

1. Provide an additional years' data from Virginia Park to add to the previous project's data for 2002-2005, and integrate all data into the analysis for the research site.
2. Improve the sediment and nutrient budget estimates for Virginia Park, and outline the implications of these results for the application of soil and nutrient movement models developed in the project NBP.314.
3. Where new information is available, produce an updated publication for producers on grazing management to minimize soil and nutrient loss from grazing management and maximize water retention in grazing paddocks.
4. Produce updated guidelines for the management of the Burdekin Catchment to assist in meeting water quality targets.

This report is in 5 main sections:

- Section 1 provides a description of the main field site, Virginia Park station, the grazing history and a brief description of the main hydrological study sites discussed in this report.
- Section 2 presents the main methods and results of the pasture, ground cover and land condition responses to application of sustainable grazing strategies (reduced utilisation, wet season spelling) at the hillslope and paddock scale over four years (2002-05) of NBP.314 and in the recent wet season (2006/07).
- Section 3 presents the main methods and results for the hydrology, sediment and nutrient yield research for (a) hillslopes and (b) at the end of the catchment. These data are then integrated and presented as revised sediment and nutrient budgets for the Weany Creek catchment.
- Section 4 summarises the key findings from the pasture and hydrology components of the study.
- Sections 5, 6 and 7 describe how the project objectives were met, outlines the benefits for the grazing industry and provides a summary and areas of further research, respectively.

1.1.1 Field site: Weany Creek catchment

Weany Creek is a 13.5 km2 sub-catchment of the Burdekin Basin (Figure 1). The catchment is located on a cattle property, Virginia Park Station, that is owned and run by Rob and Sue Bennetto and has been grazed for more than 100 years. The catchment was chosen for this study due to its location in an area identified as having high erosion rates (Prosser et al., 2001), but also because of the willingness of the landholders to trial sustainable grazing practices. The two primary management practices implemented on Virginia Park station include de-stocking and rotational wet season spelling (see Section 1.1.2 for details). It was anticipated that these grazing practices would (a) help maintain soil on their property to sustain cattle production and (b) help reduce sediment and nutrient export to downstream water bodies, and in particular the GBR.

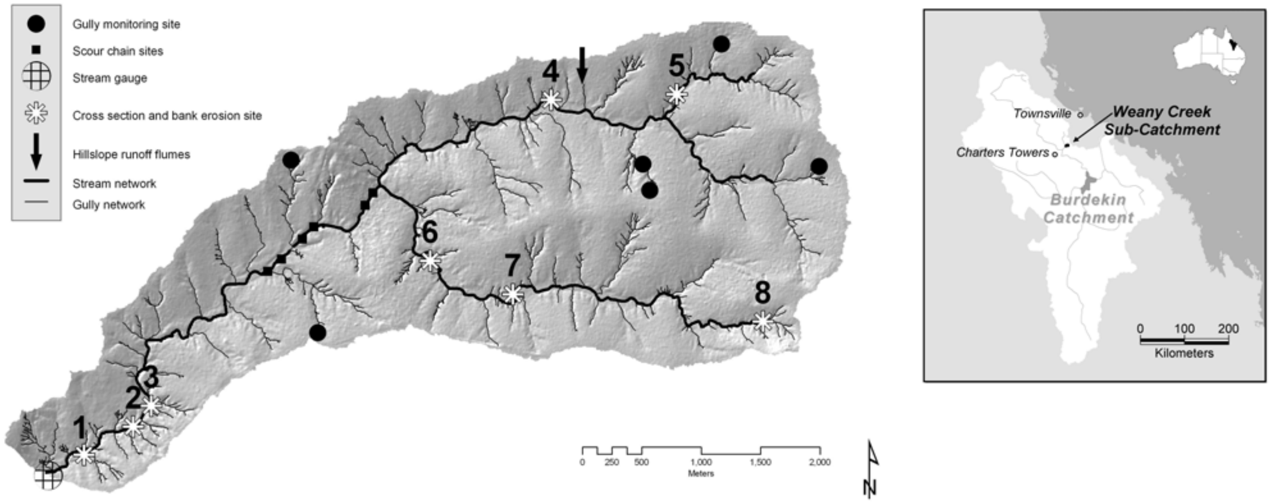


Figure 1: The Weany Creek catchment showing the location of field monitoring sites

1.1.2 Paddock configuration and grazing history

A map of the Virginia Park property, and the location of the four research demonstration paddocks that are located within the Weany Creek catchment are shown in Figure 2. The Aires paddocks (Top and Bottom Aires) received a series of wet season spells between 2002 and 2007 (see Table 1). Stocking rates and pasture yields for Bottom Aires paddock from 2003-07 (the period of NBP.314 grazing treatments) are shown in Figure 3. The hillslope run-off flumes are located in Bottom Aires paddock (see Figure 1 and Figure 2). Despite the end of the NBP.314 sustainable grazing treatments in June 2006, the owners of Virginia Park station have, for the most part, continued moderate stocking and wet season spelling regimes in 2006/07 and both of the Aires paddocks received a full wet season spell over the 2006-07 wet season.

While estimates of actual stock numbers, classes and grazing times for the Aires paddocks are less reliable since the conclusion of NBP.314, end of dry season 2006 paddock surveys indicated dry season utilisations of 47% for Bottom Aires (flume paddock) and 36% for Top Aires paddocks during the 2006 season (
Figure **4**). This represents a significant but temporary increase in utilisation over 2005 levels. This increase in stocking rate is the result of stock returning to the property that were agisted elsewhere during the 2002-2006 MLA funded project. The property owners anticipate a return to more moderate long term utilisation rates for these paddocks in the future. Consecutive wet season spells for Bottom Aires paddock in 2003-04 and 2004-05 allowed this paddock to sustain this temporary lift in dry season stocking pressure without significant impact.

As well as variations in the stocking rate over the last 4 years, there has been a steady increase in the average rainfall received at Virginia Park between 2003 and 2007 (Figure 5), however, with exception of the 2006/07 wet season, all years were under the long term average for nearby Fanning River (of ~584 mm) (Figure 6).

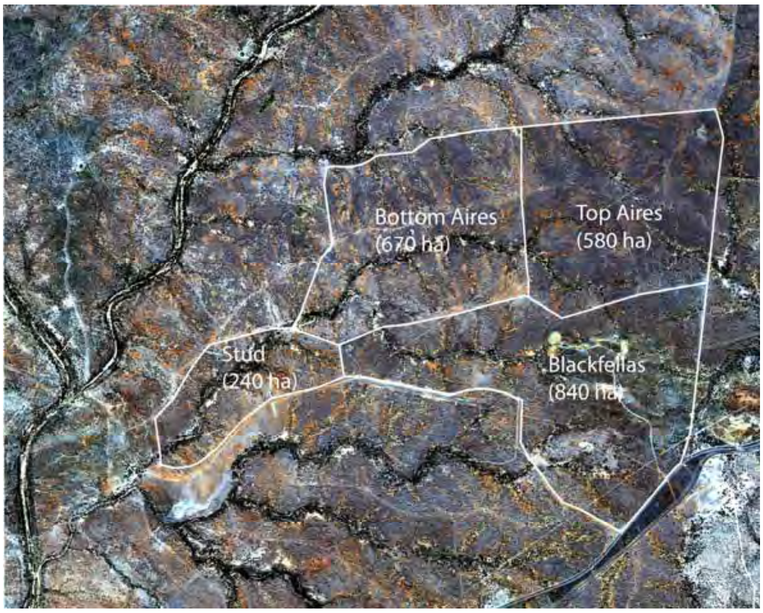


Figure 2: Paddock configuration at Virginia Park Station

Table 1: Wet season spelling regimes in Top and Bottom Aires paddocks Virginia Park Station, 2002-06

Paddock	2002-2003 Season	2003-2004 Season	2004-2005 Season	2005-2006 Season	2006-07 season
Top Aires	wet spell		wet spell		wet spell
Bottom Aires		wet spell	wet spell		wet spell

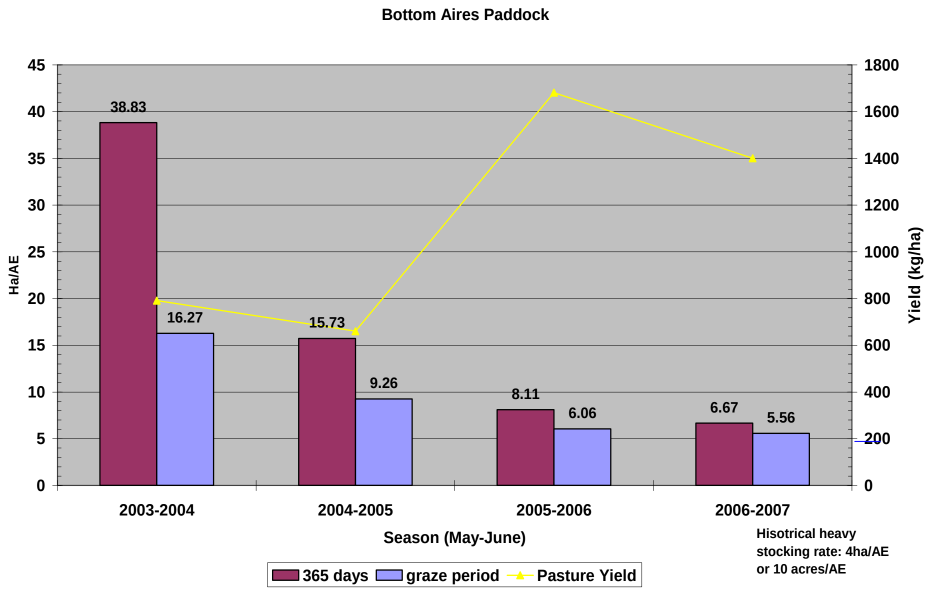


Figure 3: Stocking rates and wet season spells in Top Aires paddock (Virginia Park Station). The 'graze period' represents the actual time the cattle spent in the paddock during the demonstration period, and '365 days' is the converted stocking rate number of days

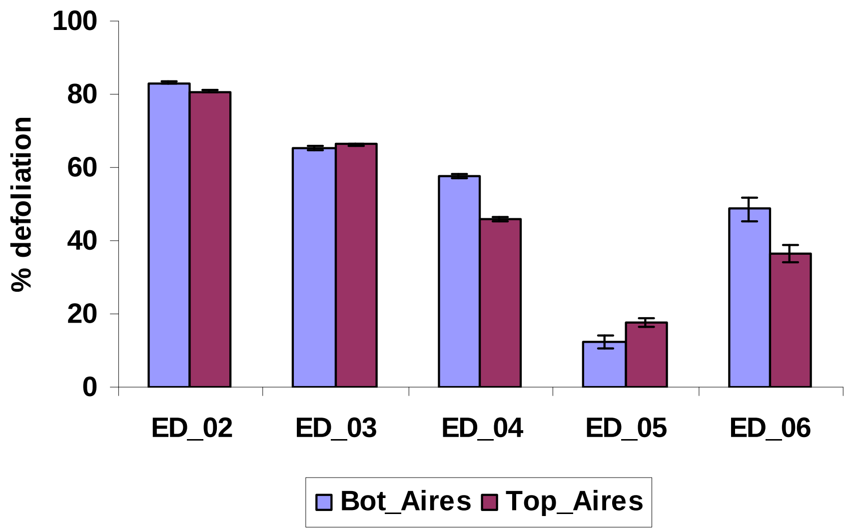


Figure 4: Trends in end of dry season defoliation (a measure of seasonal utilisation) for Top and Bottom Aires paddocks, Virginia Park, 2002-06 (means and standard error bars)

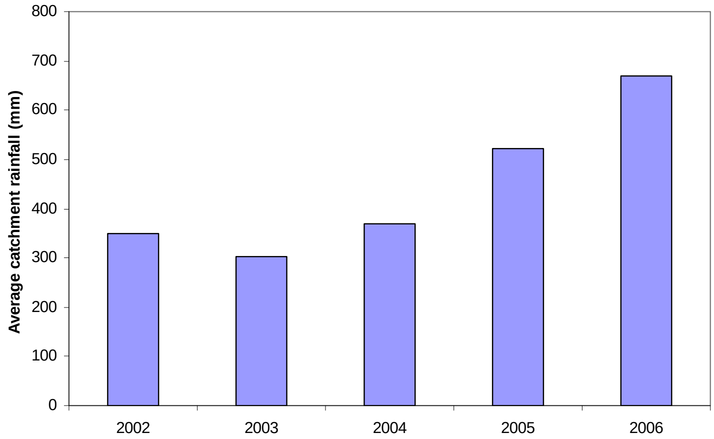


Figure 5: Average rainfall over the Weany Creek catchment (Virginia Park Station) over the 5 year study period

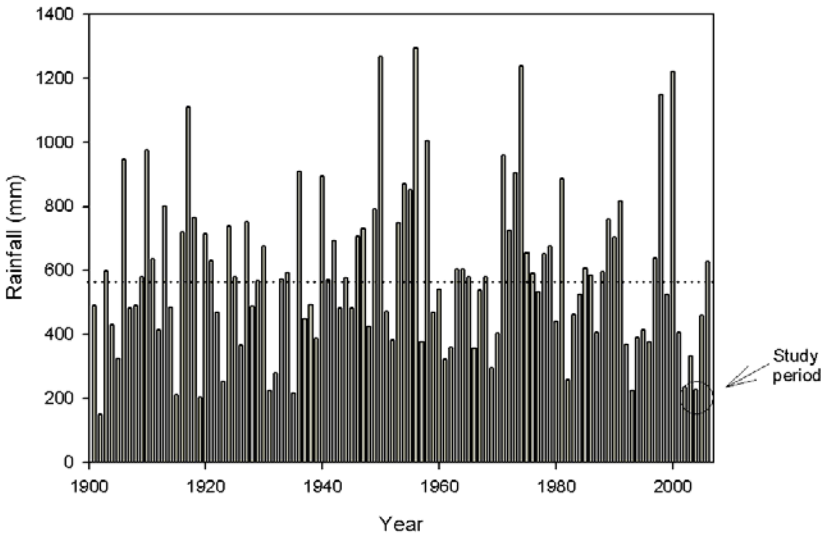


Figure 6: Long term rainfall conditions for Fanning River which is within 5 km of Virginia Park Station. The first 4 years of the study had below average rainfall conditions (2002-2005) and the 2006 wet season was slightly above average, however, is still not considered to be an extreme event based on the longer term pattern

1.1.3 Flume and end of catchment gauge sites

In this report, the two hydrological sites of interest are the hillslope run-off flumes and the end of catchment river gauge. A brief description of the flume sites is given in this section to put the Virginia Park pasture monitoring and hydrology research into context. Details of the end of catchment gauge have been described in detail in Roth et al., (2003) and in Bartley et al., (2007).

The three hillslope run-off flumes had similar morphological structure, but different arrangements in cover (Table 2). The initial ground cover at the beginning of the flume trial is given in Figure 7 and Figure 8, respectively. The three hillslopes were located within 400 meters of each other in the same field in bottom Aires paddock. On each hillslope, flumes were installed to quantify run-off and sediment loss following rainfall events (Figure 7). Data were collected over five wet seasons from November 2002 to April 2007. For the remainder of this report the sites will be referred to as Flume 1, Flume 2 and Flume 3.

Flume 1 is much larger than Flumes 2 and 3, and was chosen specifically to look at water and sediment yield at the large, or whole of hillslope, scale. Flume 1 is representative of the classic 'patchy' cover distribution of savanna landscapes (Figure 8A). Flumes 2 and 3 are of similar size, yet have very different cover patterns. Flume 2 has relatively uniform or 'micro' patch cover over the whole slope (Figure 8B), whereas Flume 3 has a more 'macro' patch distribution with areas of medium to high cover at the top of the slope, but low cover in the form of a large bare patch at the base of the slope adjacent to the flume (Figure 8C). The variation in cover on each of the flume hillslopes is a function of (a) the variable grazing pattern of cattle, (b) the natural distribution of soils and vegetation and (c) the size and location of each flume on the hillslope. The ground cover conditions for each flume at the beginning of the measurement period in 2002 is shown in Figure 8. Both Flumes 1 and 3 are located at the base of the hillslope and are influenced by the presence of the exposed highly erodible sodic soils adjacent to the riparian zone. These soils are prone to gully formation; a process which has been initiated down slope of both Flumes 1 and 3. Cattle also tend to prefer grazing and traversing near the riparian zones, which results in higher levels of disturbance in these lower hillslope areas. Flume 1 as well as being larger, also has a flow line down the centre of the hillslope (thalweg) that concentrates flow. This flow line is more of a depression than a defined channel, however, during the larger rainfall events it concentrates flow from the hillslope (Figure 7B). Flumes 2 and 3 do not have flow lines and therefore move water across the hillslope as sheet flow (see Figure 7). Details regarding DEM generation, hillslope cover measurements, flume design and sample collection are described in detail in Bartley et al., (2006) and will not be repeated here for brevity.

Table 2: Description of the major properties of the hillslope flume sites

	Flume 1 –Large flume	Flume 2 – Grass flume	Flume 3 – Scald flume
Area (m^2)	11,930 m^2	2,031 m^2	2,861 m^2
Mean slope (%)	3.9%	3.1%	3.6%
Slope length (m)	240	130	150
Soil type*	Red chromosol (Dalrymple series, eroded phase)	Red chromosol (Dalrymple series, eroded phase)	Transition from red chromosol to yellow sodosols (Bluff series)
Mean depth of A horizon (mm)**	~ 8 cm (varies from 5-40cm)	~ 9 cm (varies from 1-20cm)	~ 8 cm (varies from 0-15 cm)

* Rogers *et al.* (1999)

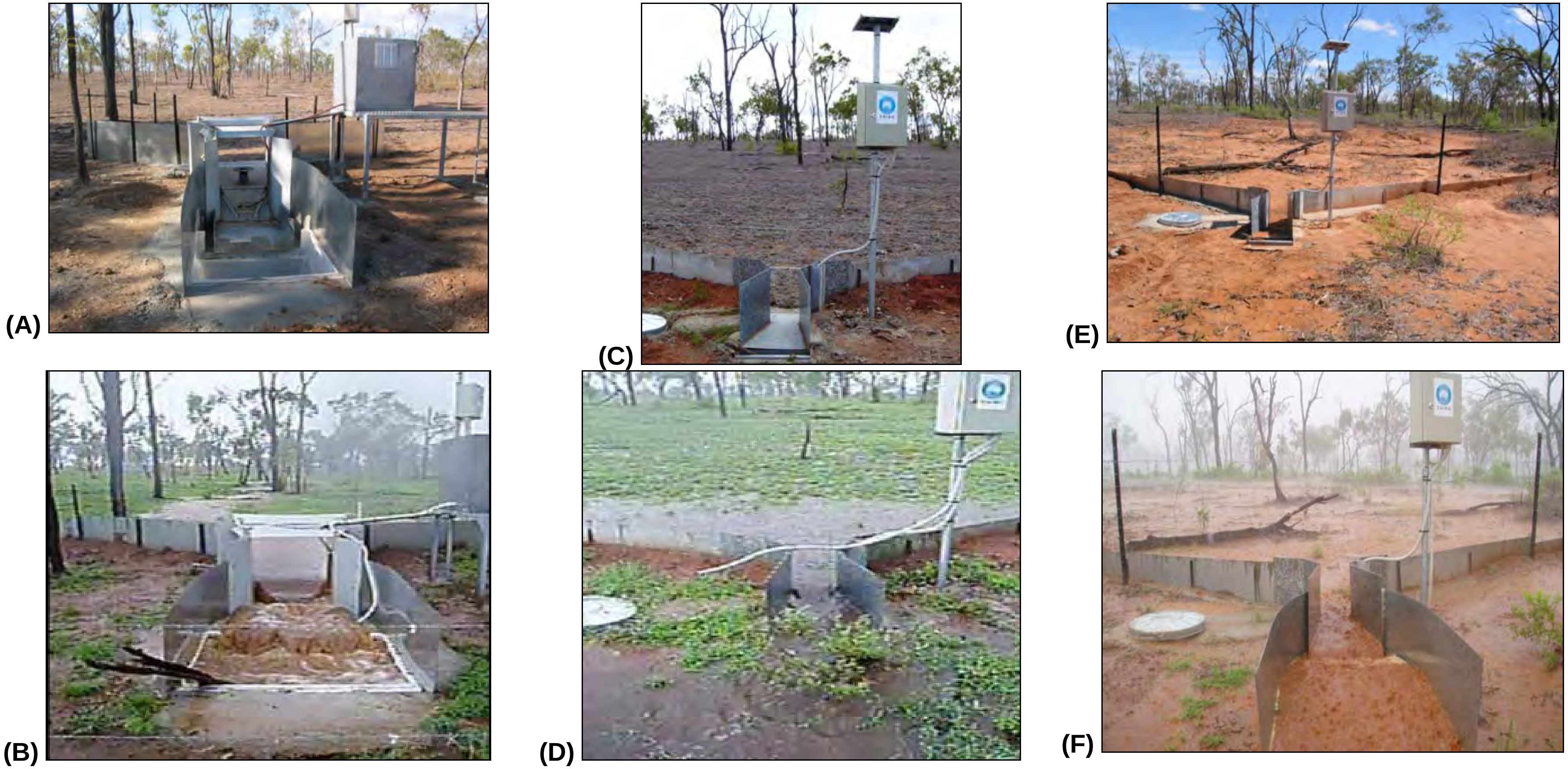
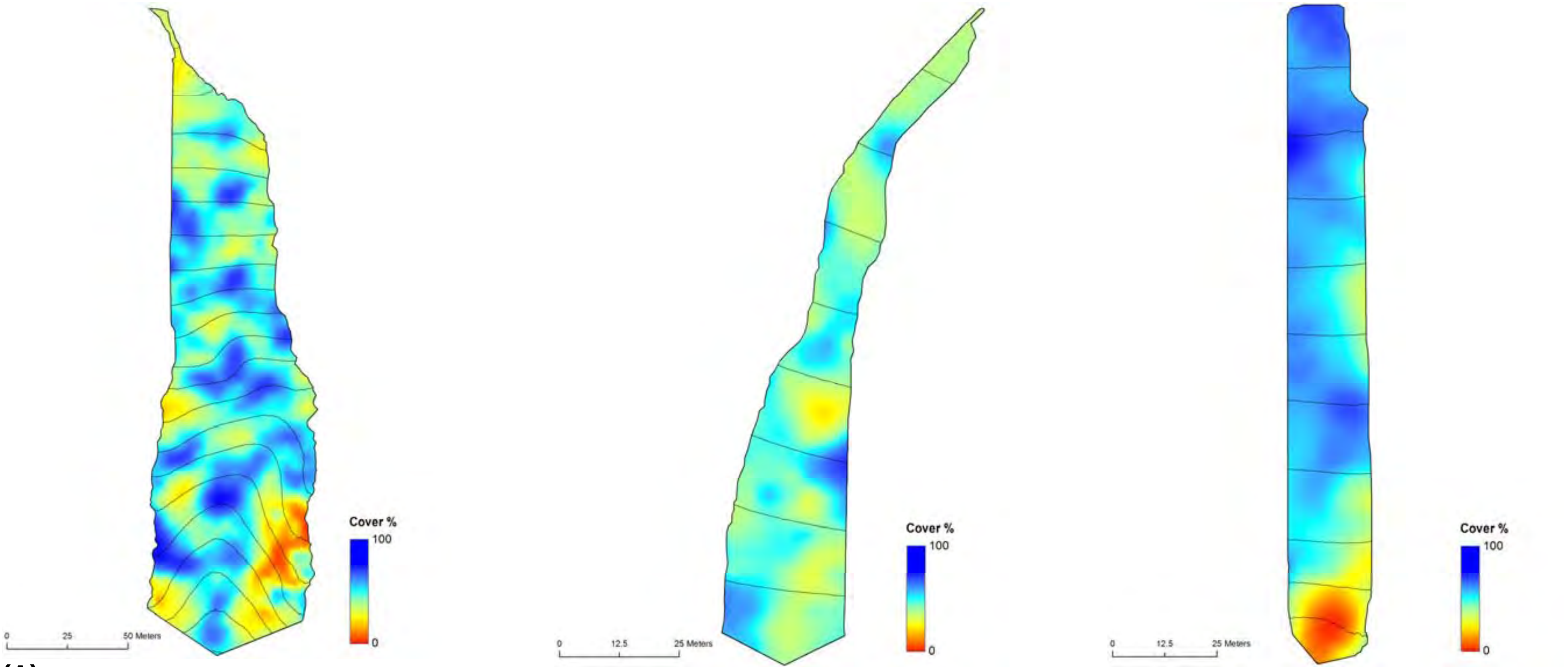


Figure 7: Images of the three flume sites: (A) is Flume 1 during the dry season (B) Flume 1 during a run-off event; (C) is Flume 2 during the dry season (D) Flume 2 during a run-off event; and (E) is Flume 3 during the dry season (F) Flume 3 during a run-off event



(A) (B) (C)

Figure 8: Representation of the measured cover (%) on each of the three hillslope flume sites at the beginning of the measurement period (October 2002). Flume 1 on the left (A), Flume 2 in centre (B) and Flume 3 on right (C). Note scale differences between Flume 1 and Flumes 2 and 3. The contour interval is 0.5 metres

2 Ground cover and biomass

2.1 Methods

This section outlines the continuation of the paddock scale pasture and land condition responses to applied grazing management strategies during the 2006-07 wet season. End of dry season grid surveys were conducted on all three flume hillslopes in December 2006 to assess changes in the amount and distribution of ground cover, litter cover, pasture composition and biomass and overall land condition trends immediately prior to the start of the 2006-07 wet season. This is the most critical measurement time in terms of understanding the relationship between end of dry season residual cover, biomass and land condition and rainfall event impacts on run-off, sediment and nutrient movement over the following wet season. Flume catchment survey methods used were those described in the NBP.314 final report (see Post et al., 2006).

End of dry and end of wet season grid surveys were also completed in the adjacent Top and Bottom Aires paddocks during the 2006-07 period to monitor cumulative paddock scale responses to grazing land management treatments applied during the life of NBP.314 and the subsequent 2006/07 wet season. This paddock scale monitoring helps to place the changes observed at the hillslope scale into context. End of wet season measures of pasture composition and biomass provide an insight into recovery of 3P grasses in response to wet season spelling (or grazing) and provide a firm estimate of available end of wet season forage biomass for the property owners to set against planned stocking decisions for forage budgeting purposes. Again, survey methods used and variables assessed were those described for Virginia Park paddock surveys in the NBP.314 final report (see Post et al., 2006).

2.2 Results

By the end of dry season 2006 both flume hillslope and whole of paddock mean end of dry season pasture cover and biomass levels equalled or exceeded those recommended in the recently released Managing Recovery toolkit (http://www.csiro.au/resources/ManagingRecovery.html) which were based on findings arising from the NBP.314 project. Table 3 shows end of dry season 2002-06 ground cover and biomass trends for the three flume hillslopes, and Table 4 shows similar trends for both Aires paddocks. End of dry season figures for 2006 indicate lower mean residual cover and biomass in Bottom Aires than Top Aires paddock, which reflects the higher dry season utilisation of pasture recorded there. Bottom Aires paddock as a whole had lower pasture biomass and cover levels than the flume catchments which are located within it, because much of the 2006 grazing effort was concentrated in the western part of the paddock, closest to the water point, whereas the flumes are located near the eastern end of Bottom Aires paddock.

Table 3: End of dry (EOD) season mean ground cover (%) and pasture biomass trends (kg/ha dry matter) for the Virginia Park flume hillslopes between 2002 and 2006. SE = Standard error

Variable	Unit of measure	Year	Flume 1 (whole hillslope flume)	SE	Flume 2 (up-slope flume)	SE	Flume 3 (scald flume)	SE
Ground cover	%	EOD_02	61.5	0.83	58.0	0.91	68.1	1.30
Ground cover	%	EOD_03	33.8	0.31	37.9	0.45	45.6	0.97
Ground cover	%	EOD_04	44.3	1.07	34.1	1.75	46.6	1.40
Ground cover	%	EOD_05	57.2	1.10	50.2	1.75	54.4	2.10
Ground cover	%	EOD_06	71.7	1.20	74.1	2.36	72.7	2.16
Pasture biomass	kg/ha D.M	EOD_02	347.4	6.86	392.6	13.90	321.4	7.47
Pasture biomass	kg/ha D.M	EOD_03	59.3	3.98	62.1	3.18	61.0	3.48
Pasture biomass	kg/ha D.M	EOD_04	239.6	14.09	153.0	12.32	145.5	10.51
Pasture biomass	kg/ha D.M	EOD_05	521.3	17.92	478.5	22.32	510.3	23.25
Pasture biomass	kg/ha D.M	EOD_06	914.5	44.43	782.2	39.50	667.3	38.47

Table 4: End of dry (EOD) season mean ground cover (%) and pasture biomass trends (kg/ha dry matter) for Aires Top and Bottom paddocks, Virginia Park station, between 2002 and 2006. SE = Standard error

Variable	Unit of measure	Year	Bottom Aires paddock.	SE	Top Aires paddock.	SE
Ground cover	%	EOD_02	73.1	1.63	62.1	1.99
Ground cover	%	EOD_03	33.7	1.22	32.1	1.21
Ground cover	%	EOD_04	48.1	1.86	43.9	2.38
Ground cover	%	EOD_05	52.0	2.52	47.8	2.09
Ground cover	%	EOD_06	56.0	2.48	68.1	1.89
Pasture biomass	kg/ha D.M.	EOD_02	229.0	19.1	240.0	12.98
Pasture biomass	kg/ha D.M	EOD_03	43.0	2.5	77.0	5.03
Pasture biomass	kg/ha D.M	EOD_04	270.0	27.0	410.0	29.56
Pasture biomass	kg/ha D.M	EOD_05	529.0	31.2	504.0	32.09
Pasture biomass	kg/ha D.M	EOD_06	670.3	55.50	992.7	55.00

2.2.1 Pasture composition response

Both the Aires paddocks and the flume hillslopes were dominated by the stoloniferous exotic grass Indian couch (Bothriochloa pertusa) at the commencement of NBP.314 and remain so five years later, in both percentage composition and biomass terms. Despite this, there has been a steady increase in the proportion of 3P grasses across the paddocks over time as indicated in Figure 9, with 3P grasses now contributing 23.1% of pasture biomass in Bottom Aires paddock and 29.8.1% in Top Aires paddock by end of wet season 2006-07. This compares with 2002 levels of 5.7% and 23.6% respectively for the same paddocks. Percentage composition can be misleading by itself as it can be highly influenced by grazing selectivity and should be viewed in the context of total standing biomass present that season. When viewed this way (Figure 9) it can be seen that 3P end of wet season standing biomass has increased over seven fold in Top Aires paddock since 2003 while in Bottom Aires, which started from a much lower 3P base, there has been a 23 fold increase in 3P biomass over the same period. Much of this 3P recovery was achieved during drought years, as was the case in the Ecograze project a decade before. With the return of better rainfall seasons this recovering 3P biomass contribution is often swamped by a rapid regeneration from seed of the less drought tolerant Indian couch (Post et al., 2006). Nevertheless the recovering 3P grasses play a crucial role in providing the architecture to trap litter and sediment on hillslopes and also deeper infiltration pathways around their crowns, with the associated root mass acting as a nutrient store.

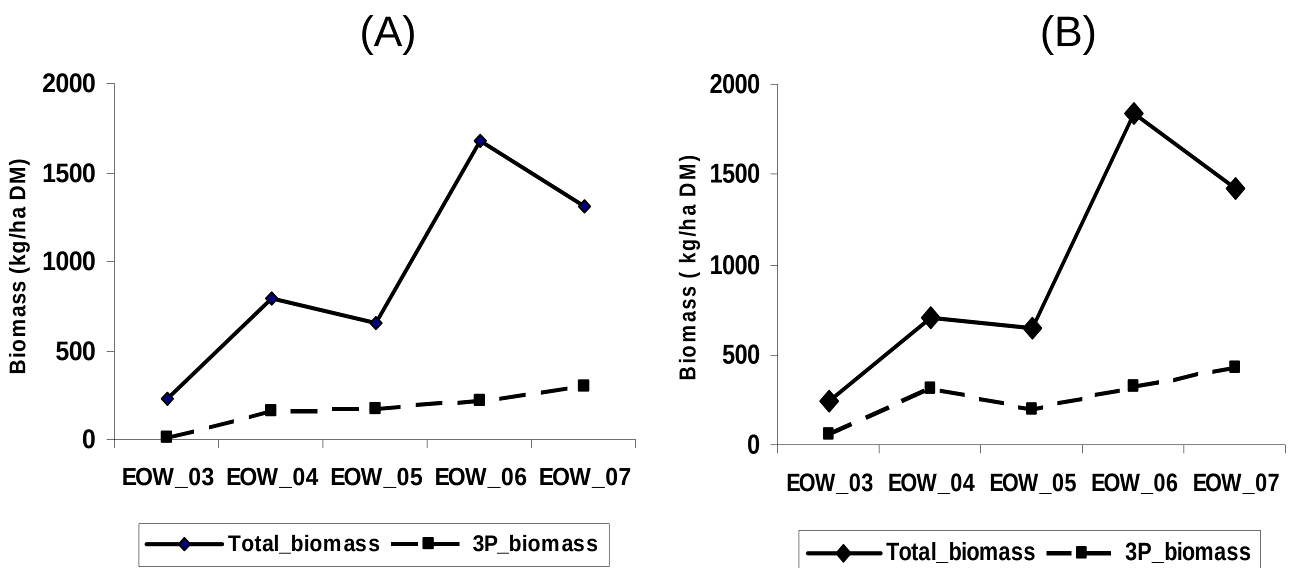


Figure 9: Total end of wet season biomass and component 3P biomass trends 2003-07 on (A) Bottom Aires and (B) Top Aires paddocks following application of sustainable grazing treatments (reduced utilisation and wet season spelling)

At the commencement of NBP.314 in December 2002 the three flume sites Flume 1, Flume 2 and Flume 3 had 9.6%, 6.8% and 12% 3P contribution to biomass respectively. By December 2006, 3P contribution as a percentage of total biomass was 11.6%, 7.0% and 13.8%, respectively. End of dry (EOD) season 3P percentages are usually lower than end of wet season figures due to the preferential grazing of 3P grasses over the dry season, which alters EOD composition. Though end of wet season 3P composition is not available for the flume sites it would be expected that they would be similar to those for Bottom Aires paddock as a whole and observations indicate similar recovery trends in composition and biomass contribution.

2.2.2 Land condition response

Figure 10 and Figure 11 show trends in ABCD end of dry (EOD) land condition proportions derived from PATCHKEY survey data for the period 2002-06 for flume hillslopes and the whole of Top and Bottom Aires paddocks, respectively. The charts indicate similar recovery trends at both hillslope and paddock scale, especially between Flume 1 and Bottom Aires paddock. They show a gradual shift back from C to B condition accelerating over time as ground cover and pasture biomass builds up in response to reduced utilisation rates and wet season spelling. By contrast, the proportion of D condition remains largely the same and in some cases increases slightly in the early years of recovery. This may be partly because of the continued preferential grazing selection of D condition patches, many of which are associated with lower slope sodic soil land types. The differential impacts on land condition recovery trends in contrasting land types is readily demonstrated in Figure 12 and Figure 13 which contrast land condition trends in the dominant ironbark/bloodwood communities of the upper and mid slopes with those of the lower slope sodic soil communities dominated by Carissa, Eremophila and other shrubby species.

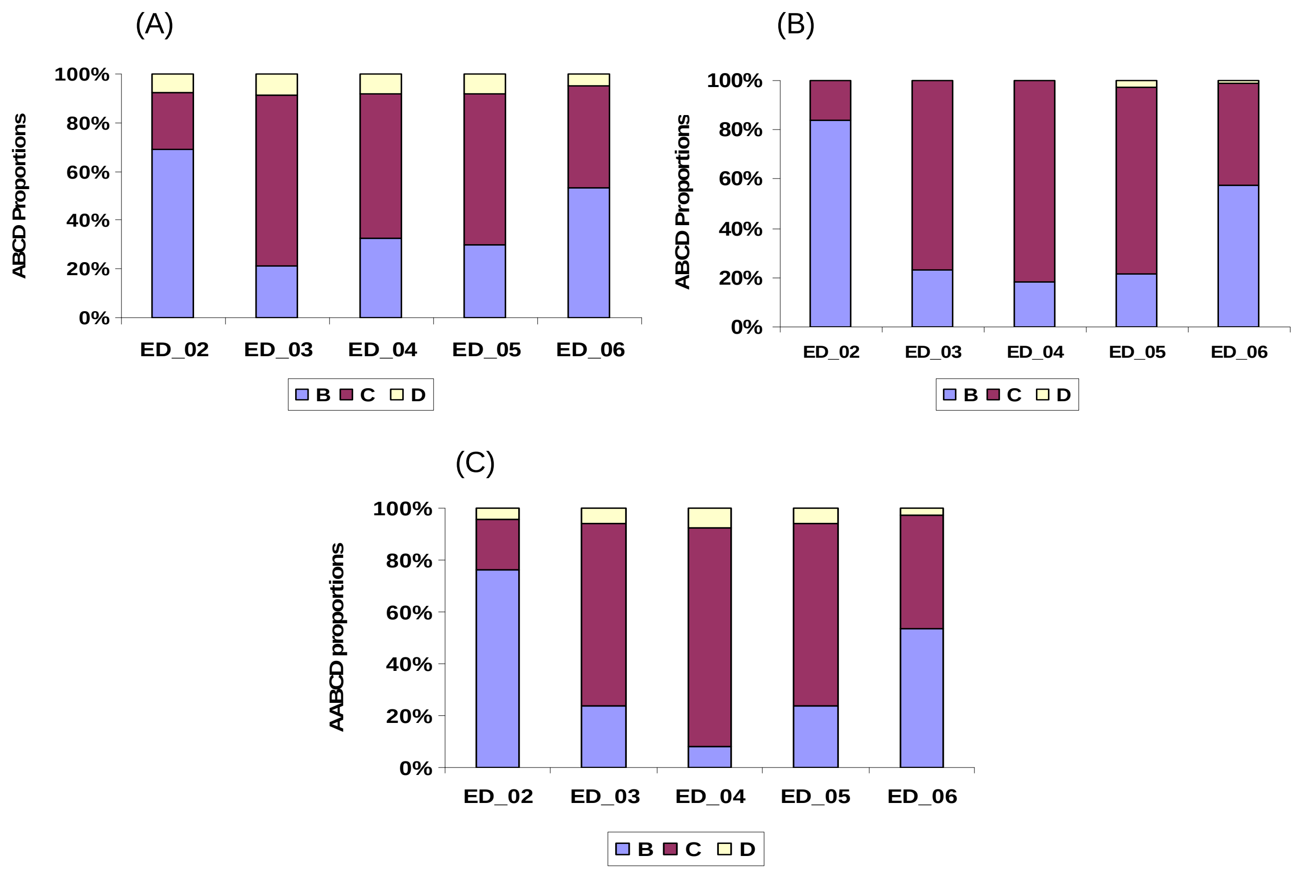


Figure 10: Trends in ABCD land condition proportions on flume hillslopes 2002-06 (A) Flume 1 (whole of slope), (B) Flume 2 (upslope), (C) Flume 3 (scald)

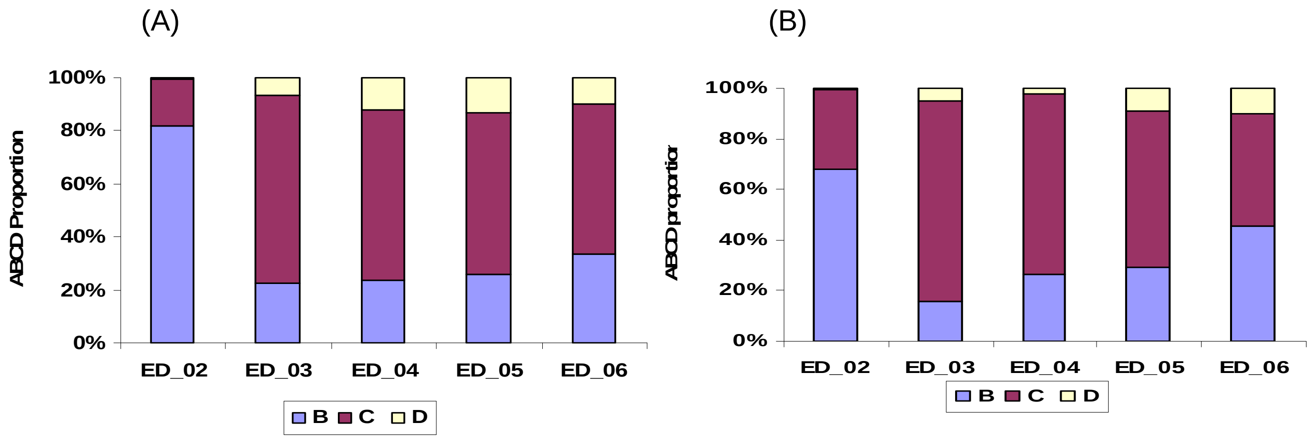


Figure 11: Trends in ABCD land condition proportions in (A) Bottom Aires and (B) Top Aires paddocks at Virginia Park, 2002-06

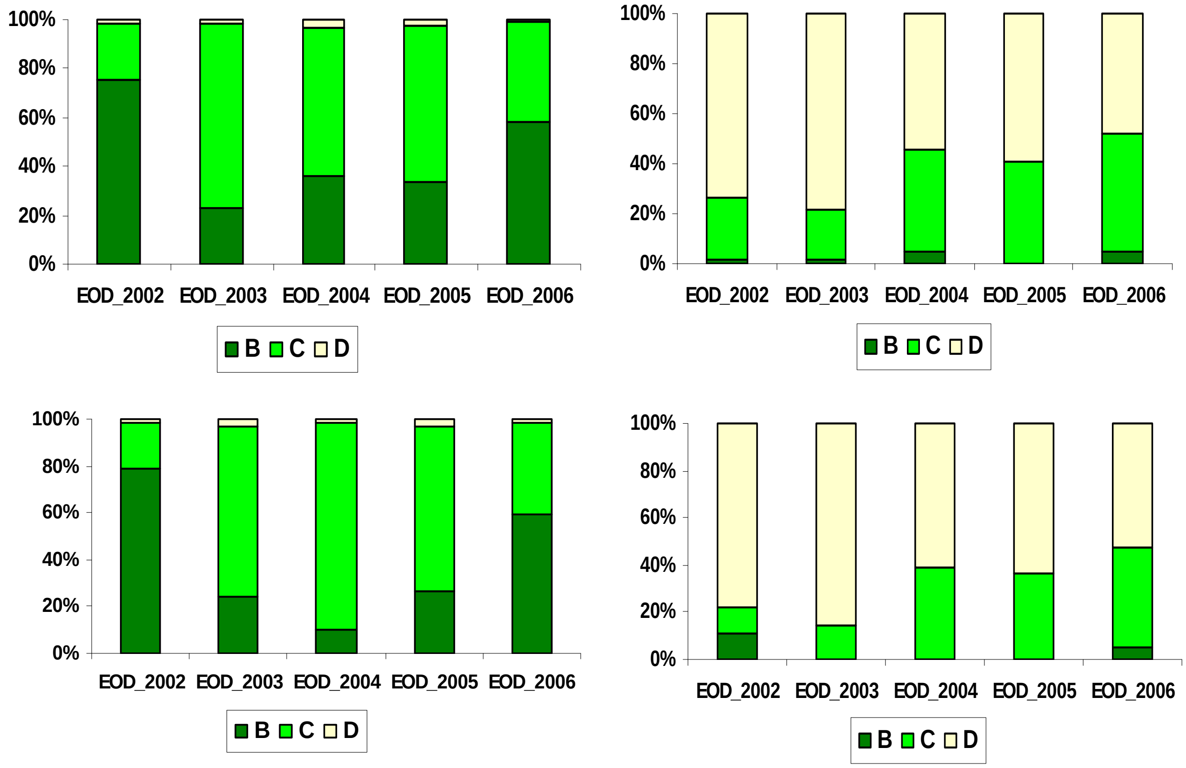


Figure 12: Comparison of trends in proportions of ABCD land condition (2002-06) for minority sodic soil areas dominated by *Eremophila mitchellii, Carissa ovata* and *Eucalyptus brownii* (box) species in Flume 1 and Flume 3 catchments in Bottom Aires paddock Virginia Park. Top left is Flume 1 ironbark-bloodwood; Top right is Flume 1 sodic areas; Bottom left is Flume 3 ironbark/bloodwood; and Bottom right is Flume 3 sodic area

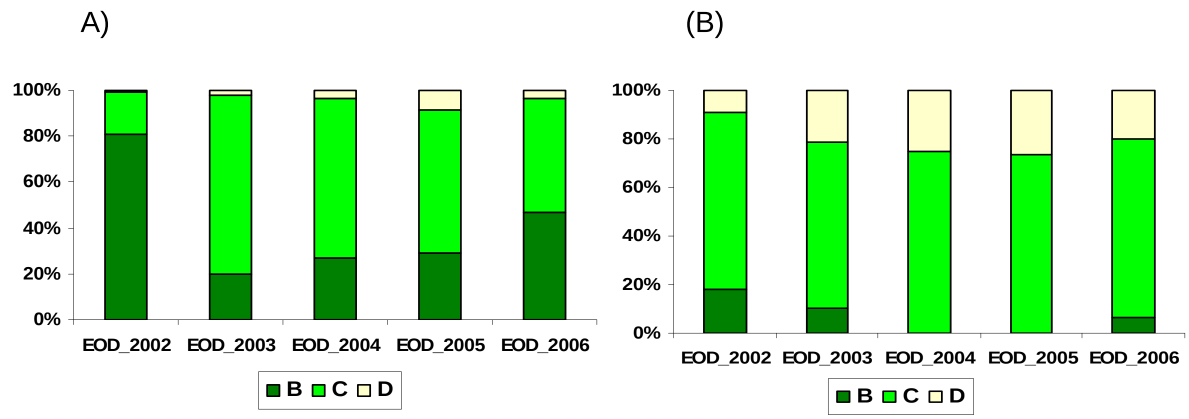


Figure 13: Comparison of trends in proportions of ABCD land condition (2002-06) in Top and Bottom Aires paddock Virginia Park between (A) the dominant ironbark-bloodwood vegetation type and (B) minority sodic soil areas dominated by *Eremophila mitchellii, Carissa ovata* and *Eucalyptus brownii* (box) species

The link between grazing selection preference and land condition trend for these contrasting land types can be readily seen in Figure 14 which shows that sodic soil communities within the flume sites and Aires paddocks generally are twice as likely to be heavily defoliated as patches of the dominant ironbark/bloodwood land type, according to defoliation data collected as part of 2006 flume and paddock surveys. Findings from NPB.214 studies (Post et al., 2006) also indicated that C condition patches were up to twice as likely to be repeatedly heavily grazed as A and B condition patches while D condition patches, often concentrated in lower slope sodic soil communities, were up to four times more likely to be heavily grazed.

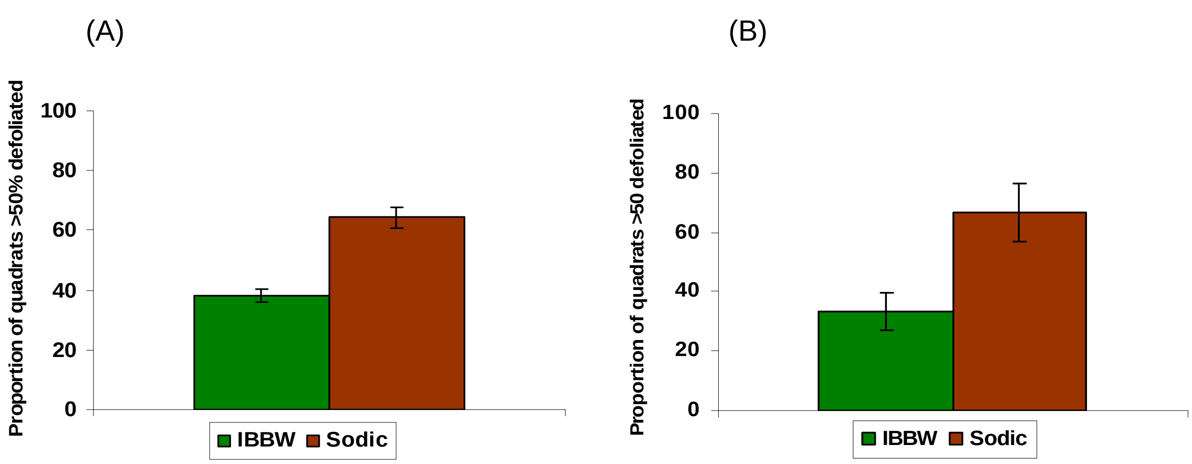


Figure 14: Relative proportion of heavily grazed (>50% defoliation) quadrats occurring in dominant ironbark/bloodwood an minority lower slope sodic communities in (A) Flume 1 and Flume 3 (scald) sites, and (B) the Aires paddocks, Virginia Park, 2006 surveys

2.2.3 Spatial and temporal recovery patterns at flume hillslope and paddock scale

The following interpolated surfaces show the spatial patterns of ground cover change between end of dry 2005 and end of dry 2006 for the whole of Aires paddock (Figure 15) and for the flume hillslopes (Figure 16). They indicate both the general improvement in overall ground cover level evident in Table 3 and Table 4 and the distribution patterns of cover changes at two different scales. In the case of the flume hillslopes the interpolated surfaces indicate a general reduction in the number and size of low cover and bare patches across the Flume 1 hillslope and a slight improvement in ground cover levels in the lower slope sodic soil areas, which coincides with the overall reduction in D condition indicated in Figure 12 and Figure 13.

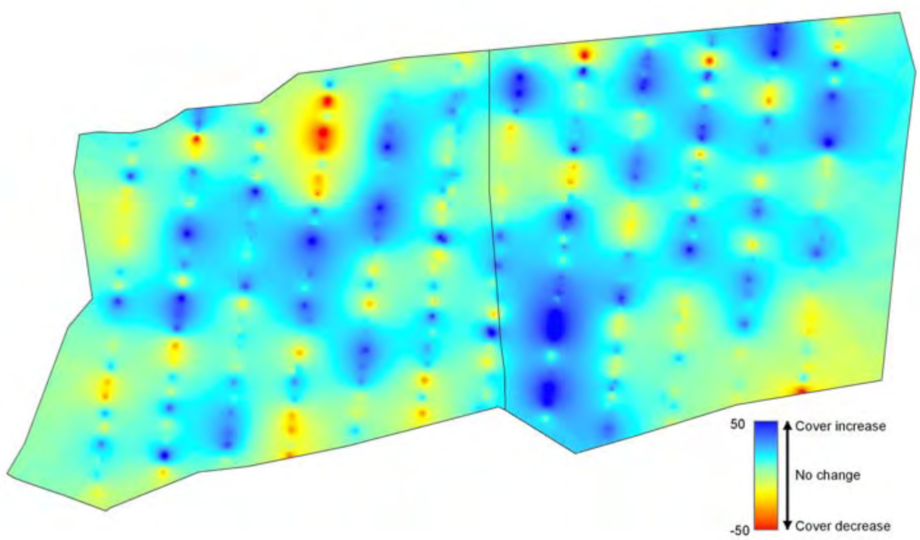


Figure 15: Interpolated surfaces of change in ground cover between Dec 2005 and Dec 2006 - Aires paddocks, Virginia Park station

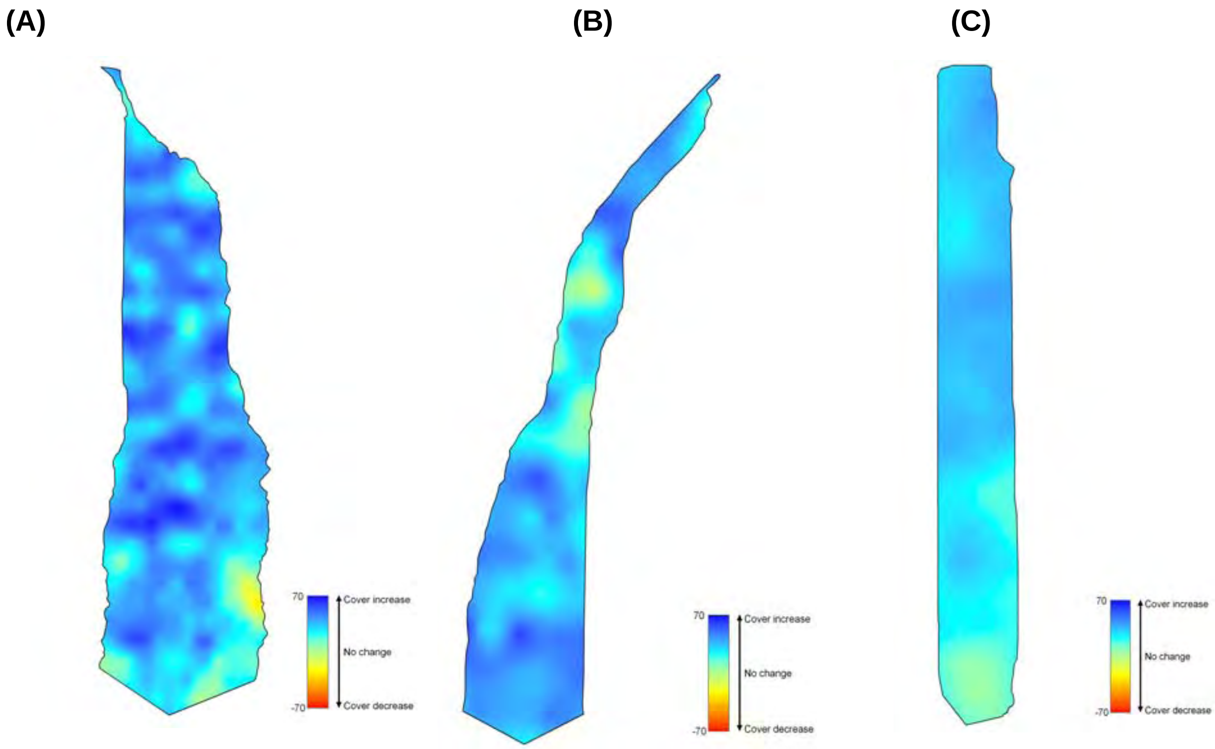


Figure 16: Interpolated surfaces of relative cover change on the three flume hillslopes (A) Flume 1, (B) Flume 2 and (C) Flume 3 in Aires paddock Virginia Park, between Dec 2005 and Dec 2006

Another way of exploring patchiness in cover distribution within different land types, vegetation communities and landscape location features present within paddocks and hillslopes is to examine ground cover trends. In the case of the flume sites there are only two major land types or vegetation communities present – the ironbark/bloodwood communities located across the entire hillslopes but dominating the mid and upper slopes and the lower slope sodic soil communities dominated by Carissa, Eremophila and other shrubby species. Figure 17 shows the temporal cover trends between these land types for both the Flume 1 and Flume 3 sites. Figure 17A shows that in the case of Flume 1, total ground cover levels on the lower slope sodic areas have remained relatively low (around 40%) but stable since 2002-03 while the remainder of the flume site, dominated by the ironbark/bloodwood community, has doubled in ground cover over the same period, in response to reduced utilisation and wet season spelling. Litter cover from shrub leaf drop accounts for a significant proportion of the ground cover within the sodic soil areas which support little herbaceous plant cover. Flume 3 (Figure 17B) shows a similar trend, with ground cover levels on the lower slope sodic areas dipping to around 20% during 2004-05 reflecting the fact that this area is dominated by a large bare scald with little pasture or shrub cover and very low residual litter.

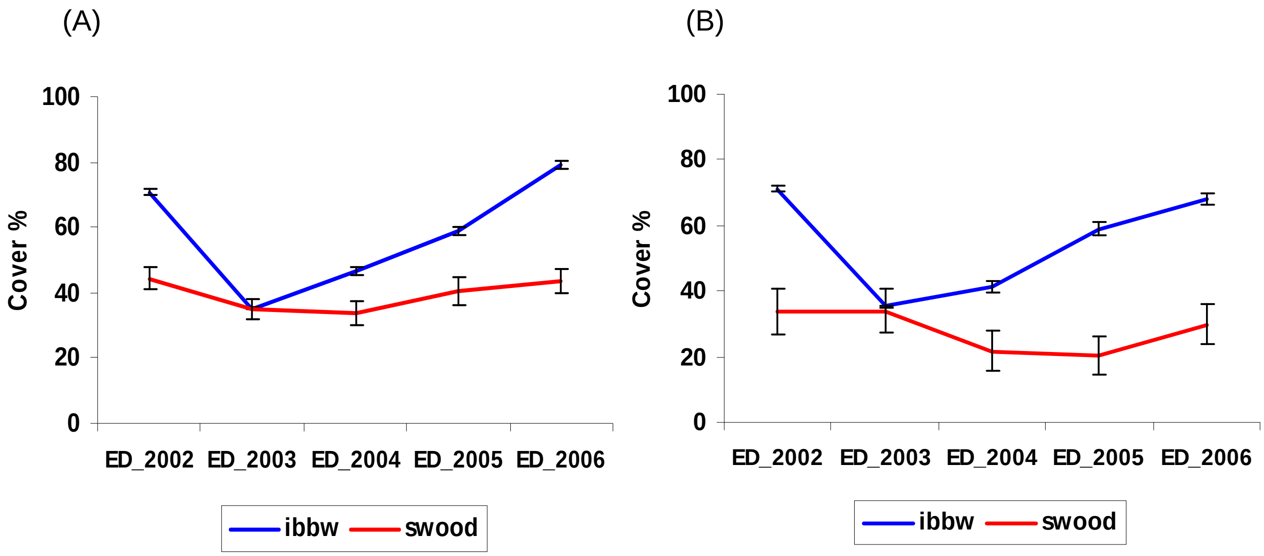


Figure 17: Relative seasonal trends in ground cover between dominant ironbark/bloodwood and minority lower slope sodic communities on (A) Flume 1 and (B) Flume 3 hillslope in Bottom Aires paddock, Virginia Park station (means and standard errors). Codes are ibbw = ironbark/bloodwood and swood = sandalwood/sodic communities

The larger standard errors associated with the sodic land type ground cover reflects the greater small scale variability in cover distribution across these patches. Similar trends apply to pasture biomass levels and distribution within these sodic soil communities. The failure of these areas to show any significant improvement in ground cover (or biomass) compared to other land types is in part due to the loss of A horizon material which often leaves sheeted or scalded surfaces relatively hostile to regeneration of herbaceous vegetation. The strong grazing selection preference for these areas, particularly at the patch margins where regeneration is more likely to commence, also plays a significant role in limiting recovery in herbaceous biomass and cover. This leaves such areas exposed to erosional forces, which accounts for their continuing disproportionate contribution to measured sediment and nutrient loss particularly from the Flume 3 hillslope (see Section 3) even when upslope cover has returned to above recommended end of dry season target levels. In fact, the relatively clean run-off now reaching these sodic scald areas may accelerate the erosion from such exposed areas, at least in the short term.

So what is happening in terms of lower slope land condition recovery outside these sodic soil communities? Figure 18 shows the temporal trends in ground cover for upper, middle and non-sodic lower slope areas. They indicate that the non-sodic soil lower slope areas have improved significantly in ground cover since 2002. During the severe drought of 2003 ground cover (and land condition) collapsed across all hillslopes from ~70% to ~35%. In the early stages of recovery during 2004-05, ground cover on the non-sodic lower and mid slopes of Flume 1 recovered faster than the upslope areas, which may reflect a shift in litter and sediment resources downslope during 2003-04, resulting in differential infiltration and resource accumulation. With the return of improved rainfall conditions in 2005-06 and the impact of consecutive wet season spells for Bottom Aires paddock in 2003-04 and 2004-05, end of dry season ground cover returned to pre 2003 levels and are once again reasonably even across the whole hillslope (excluding sodic soil areas). These temporal trends in ground cover across the main flume hillslope are also reflected in ABCD land condition trends for the same zones.

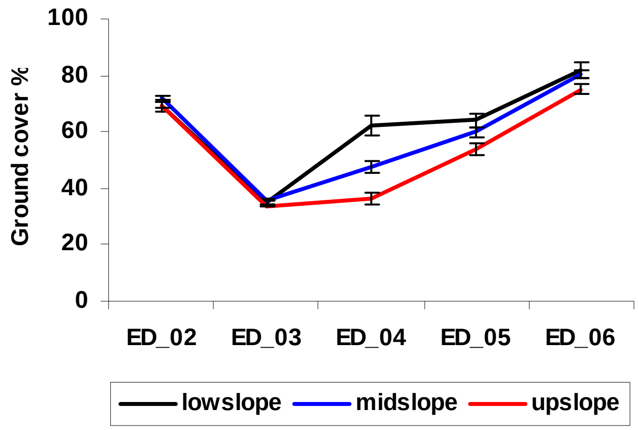


Figure 18: Effect of landscape position on temporal ground cover trends on the main flume hillslope at Virginia Park for the dominant ironbark/bloodwood land type

Another location-related area where differential recovery trends and grazing selectivity appear to be associated involves proximity to tree canopy cover. Analysis of end of dry 2006 flume hillslope data indicates that areas immediately under or adjacent to live tree canopy have up to 20% more ground cover and over 100% more litter cover than areas away from tree canopy ($P<0.005$). This may not be surprising considering the leaf litter rain from tree canopies. However areas under tree canopy also have up to 45% more pasture biomass than equivalent areas away from canopy, while frequency of 3P grasses was 27% higher under tree canopy ($p<0.005$).

2.3 Size and distribution of bare patches in relation to spatial and temporal recovery patterns

The relationship between location, land type and spatial and temporal recovery patterns in response to sustainable grazing strategies has been canvassed in the previous section. One of the most important elements influencing spatial and temporal recovery patterns is the size, location and condition of low cover or bare patches across the landscape at the beginning of the recovery process. It is these areas and their connectivity, which determines the leakiness of these landscapes and their ability to recover quickly. Recent analysis of high resolution Quickbird imagery taken on three occasions (May 2004, Dec 2005 and Dec 2006) clearly shows the patterns of change in bare ground associated with improvement of cover and pasture biomass on the flume hillslopes over this period. The images (Figure 19 and Figure 20) show the steady reduction in bare ground on the upper and mid slopes particularly where the original (2002) smaller patches of bare ground are disappearing and larger patches shrinking at the patch edges. They also confirm that there has been lower size reduction of the large bare scalded patches associated with the lower slope sodic communities in both the main flume and scald flume hillslopes. Analysis of this imagery data indicates a general trend from fewer and larger bare patches to more numerous but smaller bare patches within the dominant ironbark/bloodwood land types of the mid and upper slopes, as recovery proceeds (Figure 21).

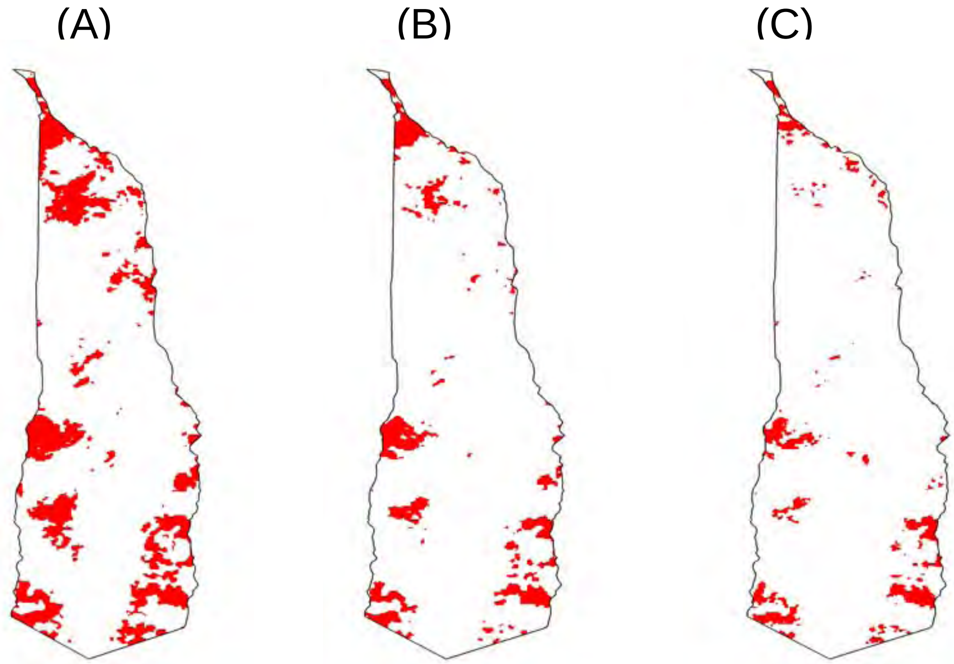


Figure 19: Trends in bare ground spatial distribution patterns on the Flume 1 hillslope, Virginia Park (May 2004 to Nov 2006) using data from pan sharpened *Quickbird* imagery

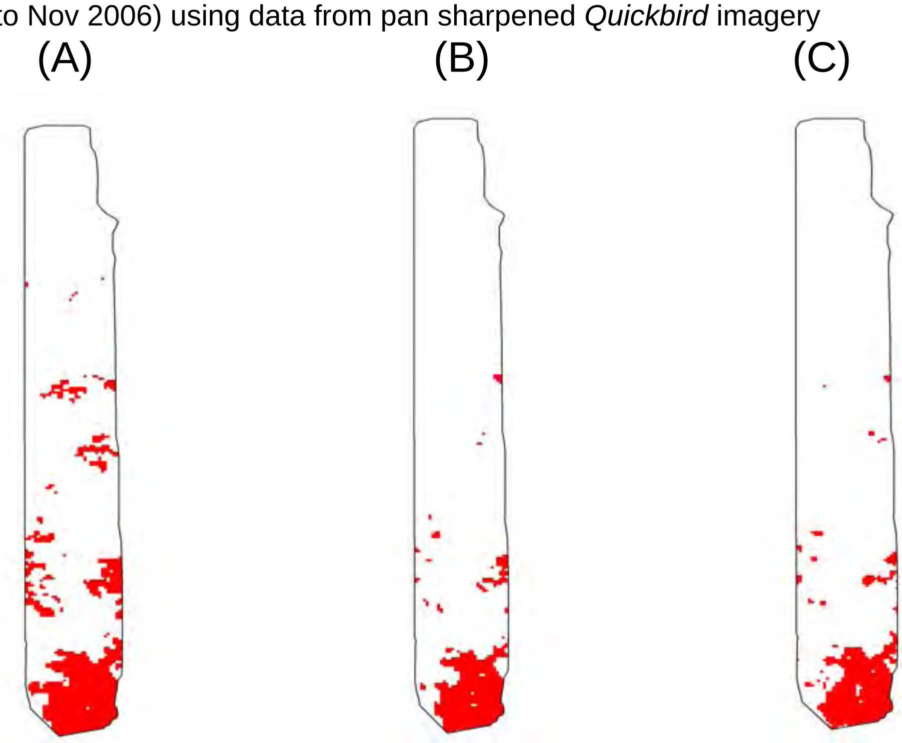


Figure 20: Trends in bare ground spatial distribution patterns on the Flume 3 hillslope, Virginia Park (May 2004 to Nov 2006) using data from pan sharpened *Quickbird* imagery

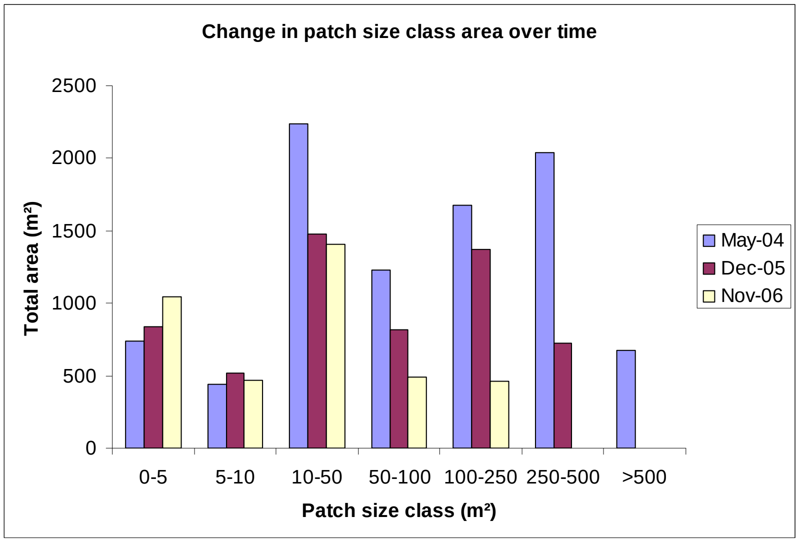


Figure 21: Time trends in total area occupied by various bare patch size classes during recovery on the Virginia Park flume hillslopes between May 2004 and December 2006

Figure 21 describes the total area of bare patches on the hillslopes in each patch size class through time, and Figure 22 refers to the influence of original patch size on the subsequent recovery (or covering over) of individual patches. Tracking of individual patches across the flume hillslopes, using analysis of the same high resolution satellite imagery, indicates that up to 90% of bare patches <10m2 in size have disappeared (covered over) between May 2004 and November 2006 compared to <50% of patches >500m2 in area (Figure 22). The greatest reduction in large patches have been in the upper and middle slopes (away from the sodic scald areas). The reduction in size of these large patches has been primarily though shrinkage around the patch edges rather than break up of the original patches.

This reflects the recovery patterns and processes observed during the Ecograze project, whereby litter bridges form around remnant tussock grasses or obstructions such as logs, dissecting existing smaller to mid-size bare patches and providing litter and sediment traps and “safe sites” for regeneration of herbaceous material. The “inter-patches“(resource shedding zones) between these new mini “patches” (resource accumulating zones) (Tongway and Hindley, 1995) gradually fill in with herbaceous vegetation, usually from downslope to upslope, eventually covering these original smaller to mid-size patches.

While the same process can also occur across the larger bare patches, because these are often associated with extensive sheeting, scalding and loss of the A horizon, there is usually less in the way of remnant grass tussocks, or residual ground cover within these large bare patches to kick-start the process. This is particularly so for the lower slope sodic areas, which accounts for their persistent low cover and herbage biomass condition. Therefore recovery, if and when it occurs, is more likely to commence around the patch margins, as the satellite imagery indicates.

While the proportion of bare ground on these two flume catchments is relatively small they contribute a disproportionate amount of sediment and nutrient export from these hillslopes (Bartley et al., 2006). Moreover, when viewed in the context of the whole sub-catchment, especially those hillslopes which adjoin and drain into Weany Creek, they constitute quite a large proportion of the land directly adjacent to the streams and riparian zones as seen in (Figure 23). With little effective perennial herbaceous cover in these riparian and adjacent frontage zones there is little to stop or slow the sediment and nutrient losses from these eroded sodic soil locations into gullies and stream channels.

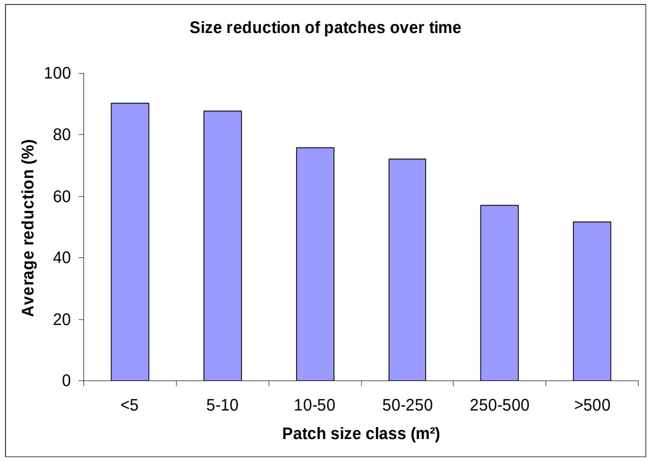


Figure 22: Influence of original patch size on recovery of bare patches on flume hillslopes at Virginia Park, 2004-2006

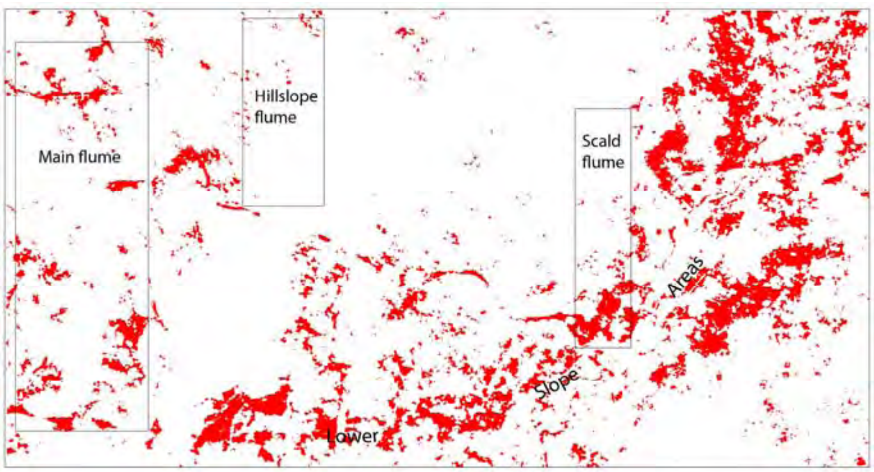


Figure 23: Classified *Quickbird* image showing the part of Weany Creek catchment surrounding and adjacent to the flume sites. The image highlights the proportion of the lower slope and frontage areas in D condition (D6, D7 within PATCHKEY framework or <10% ground cover) as of December 2006

2.3.1 Placing Indian couch landscapes within the ABCD framework – implications for monitoring "real" land condition change

As stated at the beginning of this section, the grazed landscape we are working with at Virginia Park was originally dominated by Indian couch and remains so five years into recovery, despite a steady improvement in 3P grass contribution and a substantial increase in both ground cover and pasture biomass. So, just what condition are these landscapes in, with respect to 'ABCD'?

Many areas of this couch dominated landscape have functional (and even productive) capacity similar to those normally associated with B and A condition tussock grass communities, in terms of measured infiltration, landscape leakiness calculations etc. Yet they are still dominated by an exotic, largely stoloniferous perennial grass, Indian couch (Bothriochloa pertusa). What is the implication for land condition assessment under the ABCD framework?

Just where Indian couch dominated pastures sit within the ABCD framework (Chilcott et al., 2003) is still a point of much debate. The C (poor) condition category within the ABCD framework can be defined as having either significantly reduced 3P contribution, bare ground >50% - but <80%, obvious erosion signs or erosion susceptibility, general thickening of woody plants, alone or in combination. Leaving aside woody thickening, C condition can still be a “broad church” representing a diverse array of pasture composition, ground cover and erosion permutations and combinations within this definition. Indeed this is precisely why C condition includes the largest array of patch types under the PATCHKEY framework (Corfield et al., 2006).

On one hand Indian couch dominated pastures could be always classed as C condition under the 3P contribution criterion, even though in all other respects (perennial tussock basal area, ground cover, landscape/hydrological function and productivity) they may match B condition. When developing PATCHKEY, we sought advice from local QDPI&F users of ABCD on where to place such otherwise good condition couch pastures within the ABCD framework. The consensus was that they should be placed in B condition but identified as distinct patch types within PATCHKEY – advice we subsequently adopted.

The resultant application of this principle in assessing and monitoring land condition changes at Virginia Park has resulted in us recording more rapid shifts between C and B condition than might have be expected or have been observed in Indian couch free, tussock grass environments. This is due primarily to the more ephemeral nature of Indian couch, which has both stolons and tussock crowns. Indian couch is generally shallower rooted than 3P tussock grasses and also less drought tolerant. This results in more rapid changes in the basal cover of the couch (stoloniferous perennial grass) than the equivalent in perennial tussock grass communities.

If tussock basal cover (along with total ground cover) is to be used as criteria for ABCD classification of Indian couch dominant landscapes, then we have to accept that these more rapid land condition changes can occur. On the other hand, if such rapid shifts are not considered to represent true changes in ABCD condition, then we need to find another way of classifying otherwise good condition (and productive) Indian couch and possibly other exotic perennial grass dominated landscapes within both the ABCD and PATCHKEY frameworks.

3 Hydrology, sediment and nutrient yields

3.1 Methodology

This section of the report provides a brief description of the hydrological methods used to estimate run-off, sediment and nutrient yields from hillslopes (Section 3.1.1) and the end of the catchment (Section 3.1.2). Section 3.1.3 then provides a brief description of how these data, in conjunction with other erosion measurements, are integrated to develop revised sediment and nutrient budgets for the Weany Creek catchment.

3.1.1 Hillslope flumes

A description of the hillslope flume sites was given in Section 1.1.3 to put the ground cover and biomass work into context. To measure water and sediment run-off, Flume 1 used a large cut-throat flume for measuring high flows, and a combination weir for measuring low flows. Flumes 2 and 3 were 9 inch Parshall flumes. Details of the logger setup and associated instrumentation can be found in Bartley et al., (2006). The water quality samples collected from Flume 1 were stratified according to flow depth, and for Flumes 2 and 3 they were collected as bulk samples from a collecting drum following each major run-off event. The number of total suspended solids (TSS) samples collected for each flume, for each wet season is given in Table 6. All samples were returned to the lab for analysis of EC, pH, turbidity, TSS, sediment size, total and dissolved nitrogen and phosphorous. TSS samples are considered to represent the silt (0.002-0.06 mm) and clay (<0.002 mm) sediment fractions. Bedload samples (that are generally between 0.063 –64 mm) were collected manually from bedload traps in each of the 3 sites and were assessed for volume and grain size distribution. To estimate sediment loads the arithmetic mean approach (Letcher et al., 1999) was applied to data collected from each event when both concentration and discharge data were available, otherwise average wet season concentration values were applied.

3.1.2 Weany Creek end of catchment sediment and nutrient loads

To estimate discharge and sediment yield at the outlet of Weany Creek, an automatic gauging station was installed in 1999. Between 1999 and 2007, water depth was measured using a Dataflow pressure transducer. Turbidity and velocity were recorded at 1 minute intervals when the stream depth was > 30 cm using a Greenspan turbidity meter and Starflow Ultrasonic Doppler Velocity meter. The velocity meter was located in the centre of the stream, and it was checked for accuracy using a Global Water FP101 handheld velocity meter at 1 m intervals across the stream during two flow events. The starflow meter appeared to be underestimating velocity by ~7%, however, not enough data could be collected safely to warrant any further calibration of the in-situ velocity metre. A tipping bucket rain gauge was located adjacent to the gauge.

Water samples were collected during events using an ISCO automatic water sampler and samples were returned to the laboratory for analysis of turbidity, total suspended solids (TSS) and sediment size distribution. The gauge site was surveyed to determine the mean cross-section dimensions. A relationship between suspended sediment and turbidity was derived and used to determine flow weighted suspended sediment concentration (after Gippel, 1995; Grayson et al., 1996). These data, along with the velocity and channel dimensions, were used to calculate the sediment load at the catchment outlet during events (see Post et al., 2006). The event based sediment loads were then totalled for each wet season to provide an annual suspended sediment yield at the catchment outlet. Examination of the uncertainty bounds on the relationship between turbidity and TSS, measurements of velocity, and variations in velocity across the stream (data not shown) suggest that the estimates of suspended sediment fluxes from the end of the Weany Creek catchment have errors associated with them of the order of ± 20%.

3.1.3 Weany Creek sediment and nutrient budget methods

To develop the sediment and nutrient budgets for Weany Creek, traditional erosion measurement methods (e.g. flumes, erosion pins and cross-section changes) were employed to estimate soil loss and movement from five main processes: (1) hillslope erosion, (2) gully erosion and deposition, (3) bank erosion, (4) channel bed erosion/storage and (5) fine sediment export at the catchment outlet. The methods described in Sections 3.1.1 and 3.1.2 were used to estimate losses from hillslope erosion and the catchment outlet, respectively. The methods used to estimate erosion from gullies, channel banks and the channel bed are summarised in Table 5 and described in detail in Bartley et al., (2007).

We are aware that these methods are subject to considerable error when extrapolated to the sub-catchment scale, nonetheless, these methods were considered the most appropriate to obtain estimates of the sources and sinks of sediment in a savanna catchment of this size. The field measurements and monitoring equipment for each of the processes were installed at different times over the 6 year period (1999-2006) based on the availability of research funding, and the grazing and seasonal climate conditions in the catchment. For consistency in the analysis, in this report we have only used data for the five wet seasons starting in the year 2002 to 2006.

Table 5: Overview of processes, methods and timescales over which data were collected

Process/variable measured	Method used	Period data was collected
Net hillslope sediment loss	Flumes	2002-2006
Gully head cutting	Erosion pins	six years for three gully heads (1999-2005) and three years for five gullies
Gully side wall erosion/deposition	Pins and cross-sections; GPS with Wild TC total station	six years for one gully system (1999-2005) and three years for five gullies
Erosion/deposition of gully floor	Pins, x-sects and scour chains	six years for one gully system (1999-2006) and three years for five gullies
Bank erosion	Erosion pins	2002-2006
Channel sediment storage	Bench marked cross-sectional change	2002-2006
Sediment yield at catchment outlet	Gauging station	2000-2006*

* only data for 2002-2006 was included in final budget

3.2 Results

3.2.1 Hillslope flumes: general results

For each of the five years of monitoring the % run-off was on average 5 and 7 times higher for Flume 3 than for Flume 1 and 2 (Figure 24). Both flumes 1 and 2 have average % run-off values of 11% and 8%, respectively. Flume 3 has an average of 57% run-off which means that 57% of the rain that falls on the hillslope is lost and does not infiltrate the soil.

Given the similarity in cover conditions between Flume 2 and the top half of Flume 3 (see Figure 8), we attribute the differences in run-off conditions (and subsequent sediment and nutrient yields) to the presence of the large scald patch at the bottom of Flume 3. If we assume that the average % run-off for Flume 2 is representative of the top section of Flume 3, then ~86% of the run-off coming from Flume 3 is being generated by the scald. The higher run-off on Flume 3 means that there was less infiltration, and therefore less water available for pasture growth. The higher run-off also equates to higher stream powers available to erode the bare sediments at the bottom of the hillslope.

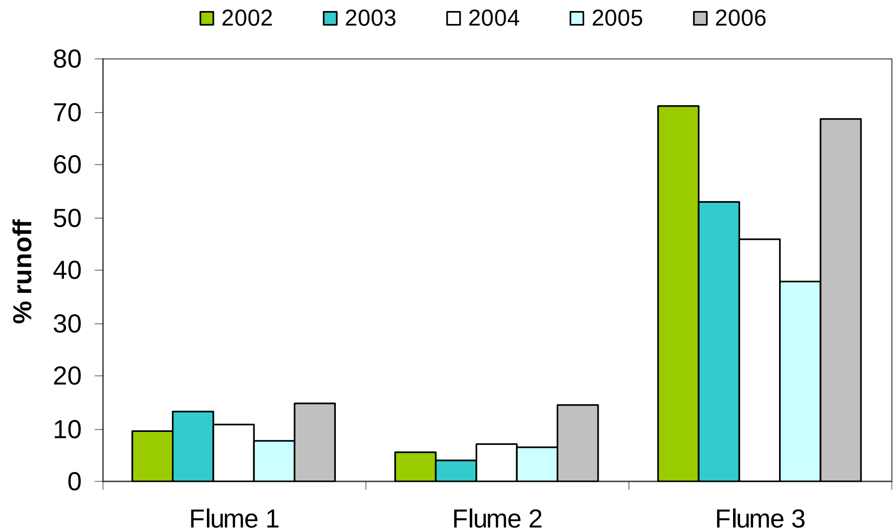


Figure 24: Percent run-off from the three flumes over the five years of measurement

The sediment yields from each of the three hillslopes for the 5 years of monitoring are given in Table 6. Nutrient (total nitrogen and phosphorus) data were collected from Flume 1 only and the results are given in Table 7. As with the run-off data, Flume 3 has much higher sediment yields than both Flume 1 and 2. Over the 5 year study period, Flume 3 has on average 54 times more sediment loss than Flume 2, and 19 times more sediment loss than Flume 1. The other major difference is that coarse sediment (sandy soil) represents ~ 20% of the total sediment load for Flume 3 and less than 3% of the load for the other flumes (see Figure 25). This suggests that Flume 3 is eroding coarser B horizon soils and is representative of the initiation of gully features in the landscape.

Table 6: Summary of sediment loss results from the three flumes

Year wet season began		Flume 1	Flume 2	Flume 3
2002	Fine soil loss (t/ha) (n = no. of TSS samples analysed)	0.27 (n =3)	ND	2.92 (n =5)
	Coarse sediment loss (t/ha)	0.0025	0.0032	0.18
	Total sediment loss (t/ha)	**0.2725**	**>0.0032**	**3.1**
	Bedload as % of total loss	0.91	ND	5.8
2003	Fine soil loss (t/ha) (n = no. of TSS samples analysed)	0.25 (n=19)	0.04 (n=3)	1.65 (n=2)
	Coarse sediment loss (t/ha)	0.00077	0.00025	0.807
	Total sediment loss (t/ha)	**0.25077**	**0.04025**	**2.46**
	Bedload as % of total loss	0.31	0.63	49.1
2004	Fine soil loss (t/ha) (n = no. of TSS samples analysed)	0.09 (n=28)	0.06 (n=3)	1.83 (n=3)
	Coarse sediment loss (t/ha)	$0.06*10^{-3}$	NA	0.68
	Total sediment loss (t/ha)	**0.09406**	**>0.06**	**2.51**
	Bedload as % of total loss	0.06	-	27.1
2005	Fine soil loss (t/ha) (n = no. of TSS samples analysed)	0.084 (n=28)	0.09 (n=3)	3.44 (n=4)
	Coarse sediment loss (t/ha)	0.0049	0.0011	0.357
	Total sediment loss (t/ha)	**0.0889**	**0.0911**	**3.797**
	Bedload as % of total loss	5.5	1.2	9.4
2006	Fine soil loss (t/ha) (n = no. of TSS samples analysed)	0.109 (n=43)	0.031 (n=4)	2.36 (n=5)
	Coarse sediment loss (t/ha)	$5.87 *10^{-5}$	$1.42* 10^{-5}$	0.87
	Total sediment loss (t/ha)	**0.109**	**0.031**	**3.23**
	Bedload as % of total loss	0.05	0.046	26.94

ND = no sample analysed due to sampler malfunction; NA = no sample produced

Figure 25: Visual evidence of the high suspended (left) and bedload (right) measurements observed at Flume 3

Table 7: Total nitrogen and phosphorus yields from Flume 1 for the 5 year period (2002-2006). Note no nutrient data were collected in the 2002 wet season

	Year wet season began				
	2002	2003	2004	2005	2006
Total Nitrogen (kg/ha)	-	0.87	0.37	0.28	0.36
Total Phosphorus (kg/ha)	-	0.25	0.11	0.08	0.10

3.2.2 Is reduced stocking and wet season spelling making a difference to hillslope yields?

As described in Section 1.1.2 the paddocks containing the hillslope run-off flumes (bottom Aires paddock) underwent de-stocking and wet season spelling for a number of seasons (see Table 1). Between 2002 and 2006 there was also a steady increase in rainfall with the lowest rainfall recorded in the 2003/04 wet season (~300 mm) and the highest rainfall measured in the 2006/7 wet season (~670 mm) (see Figure 5 and Figure 6). Due to the combination of grazing management and improved rainfall conditions over the study period, there was an improvement in the average ground cover conditions at all of the flume sites (Figure 17 and Figure 26).

For the Flume 1 hillslope there has been a reduction in the percentage of bare ground (see Figure 19), and there has been a corresponding reduction in hillslope sediment (t/ha) and nutrient yields (kg/ha) over the five year monitoring period (see Figure 27, Figure 28 and Figure 29). The reduction in sediment yields on Flume 1 can mainly be attributed to a reduction in the sediment concentrations. Run-off conditions have not declined in the same manner, as the % run-off was highest in 2006/07 which corresponded to the highest rainfall, and rainfall intensities, for the study period. The sustained high run-off suggests that hillslope run-off is not necessarily controlled by cover alone, and other factors such as rainfall intensity and the antecedent soil conditions when the rain fell, are more important than ground cover. Also, the fact that the % run-off has not declined along with sediment and nutrient yields may suggest that although the surface cover has improved, this is not matched by a recovery in the biological health and the infiltration capacity of the soil.

Continued monitoring of the site will help provide an insight into a link between surface cover and soil infiltration at the hillslope scale.

Despite the higher % run-off in 2006/07 for Flume 1, the sediment yields were less than half that recorded in 2002 and 2003. The higher ground cover conditions are obviously reducing the amount of sediment leaving the hillslope by (a) reducing the amount of soil that is physically detached from the hillslope surface and/or (b) increasing the trapping efficiency of vegetation that is intercepting the sediments and nutrients and retaining them on the hillslope.

However, there has not been a decline in sediment yields at Flume 3 for the same period, despite a slight decrease in the proportion of bare ground exposed on this hillslope between 2004 and 2006 (Figure 20). This is because the large scald or bare patch at the base of the Flume 3 hillslope has not changed in cover significantly over the study period, and this is the major source of sediment for this hillslope.

Figure 26: Visual comparison of ground cover conditions on Flume 1 hillslope between 2002 (left) and 2007 (right)

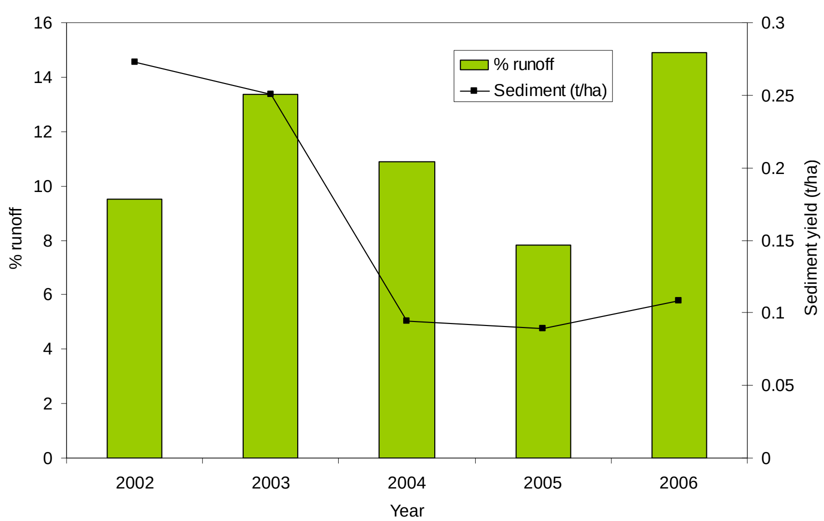


Figure 27: Change in percentage run-off and sediment yield (t/ha) for Flume 1 between 2002 and 2006

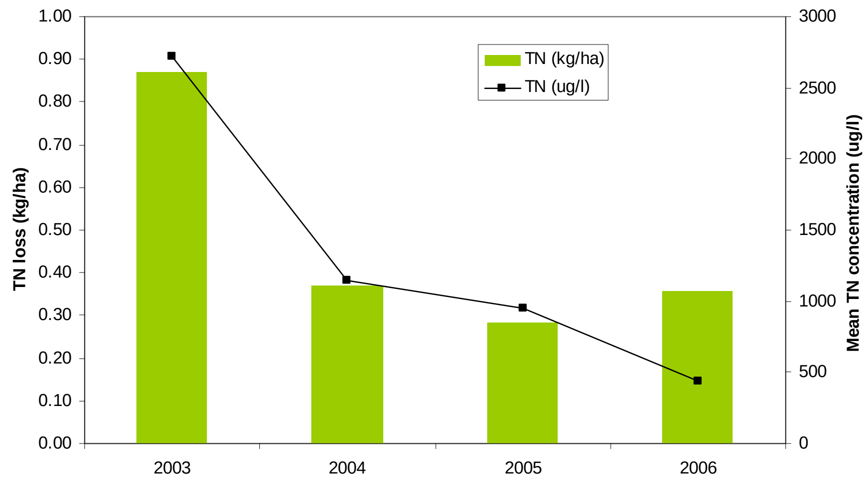


Figure 28: Total nitrogen (TN) losses from 2003 – 2006 for the large flume (Flume 1)

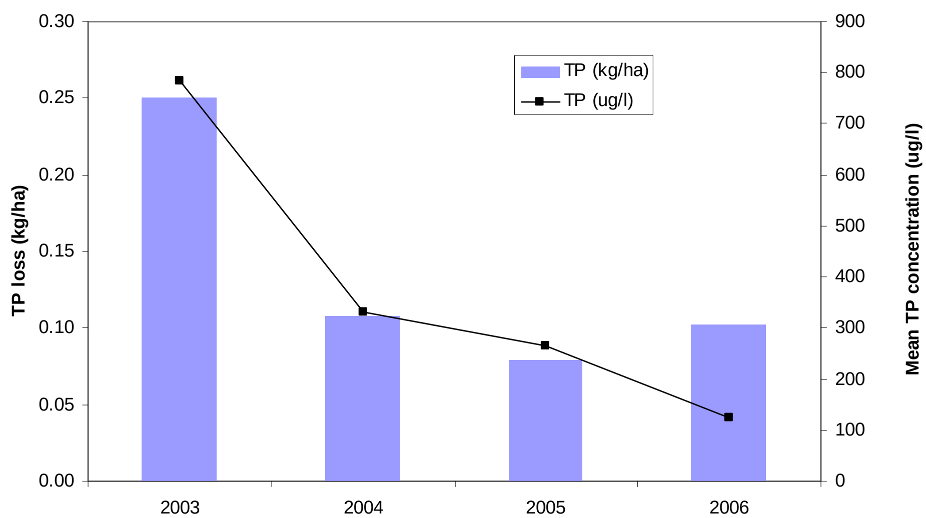


Figure 29: Total phosphorus (TP) losses from 2003 – 2006 for Flume 1

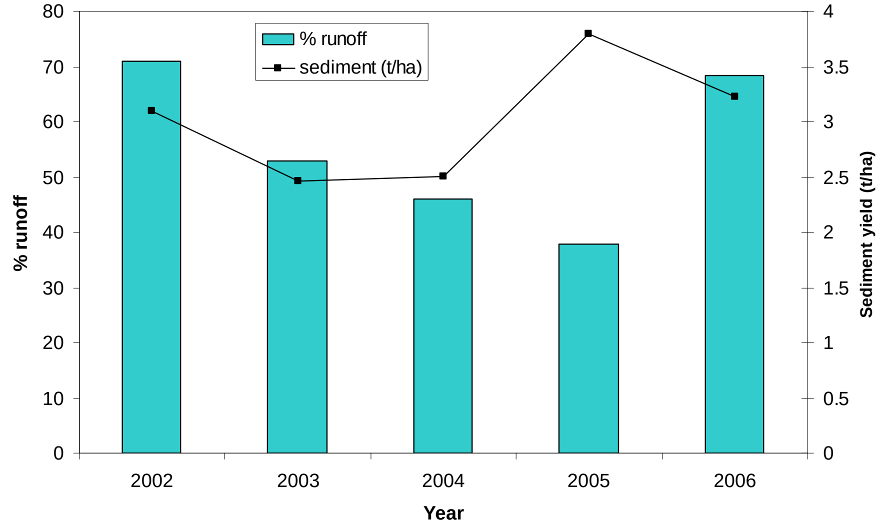


Figure 30: % run-off and sediment yield losses for Flume 3 for the five years of measurement. Note nutrient data was not collected for this flume

3.2.3 Weany Creek end of catchment sediment and nutrient loads

End of catchment sediment and nutrient loads for Weany Creek for the seven year period (2000-2006) are given in Table 8. The loads largely follow annual total rainfall conditions (e.g. Figure 31) and there are strong relationships between annual sediment and nutrient yields and annual run-off conditions (Figure 32 and Figure 33). The strong relationships between annual sediment and nutrient export and run-off imply that over the longer term (> 5 years) mean annual run-off may be a useful predictor of relative sediment and nutrient yields for grazed savanna catchments. This is an important insight that has been gained by having one of the longest records of sediment and nutrient loads for a savanna catchment anywhere in Australia.

It is important to note that despite the reduction in hillslope sediment and nutrient yields observed on Flumes 1 and 2, there has not been a corresponding reduction in sediment and nutrient yields at the end of the Weany Creek catchment over the same period (Table 8 and Figure 31). This is because the end of catchment sediment and phosphorus loads are dominated by channel rather than hillslope sources, as described in Section 3.2.4. It is important to note, however, that much of the sediment that is currently being mobilised from bank and gully erosion is due to the increased run-off from the hillslopes over the 100 years of grazing on this property. Although there is not a direct measurable link between the initial hillslope recovery described here, and a reduction in sediment and nutrient yields at the catchment outlet, it is hypothesised that if the hillslope conditions continue to improve, then the end of catchment yields will also decline due to a reduction in run-off and stream power.

Table 8: Run-off, sediment and nutrient loads for the seven years of catchment monitoring

Year (wet season begins)	Rainfall (mm) at gauge	Run-off (mm)	% Run-off	Sediment yield, t (t/ha)	Phosphorus, kg (kg/ha)	Nitrogen, kg (kg/ha)
2000	367	23.88	6.51	480 (0.35)	273 (0.20)	900 (0.66)
2001	576	24.66	4.28	777 (0.57)	540 (0.40)	1337 (0.99)
2002	397	15.49	3.90	512 (0.38)	244 (0.18)	875 (0.65)
2003	362	6.40	1.77	363 (0.27)	152 (0.11)	581 (0.43)
2004	364	30.50	8.38	784 (0.58)	406 (0.30)	1398 (1.03)
2005	559	9.54	1.71	334 (0.25)	156 (0.11)	562 (0.41)
2006	638	46.05	7.22	1542 (1.06)	712 (0.49)	2094 (1.44)

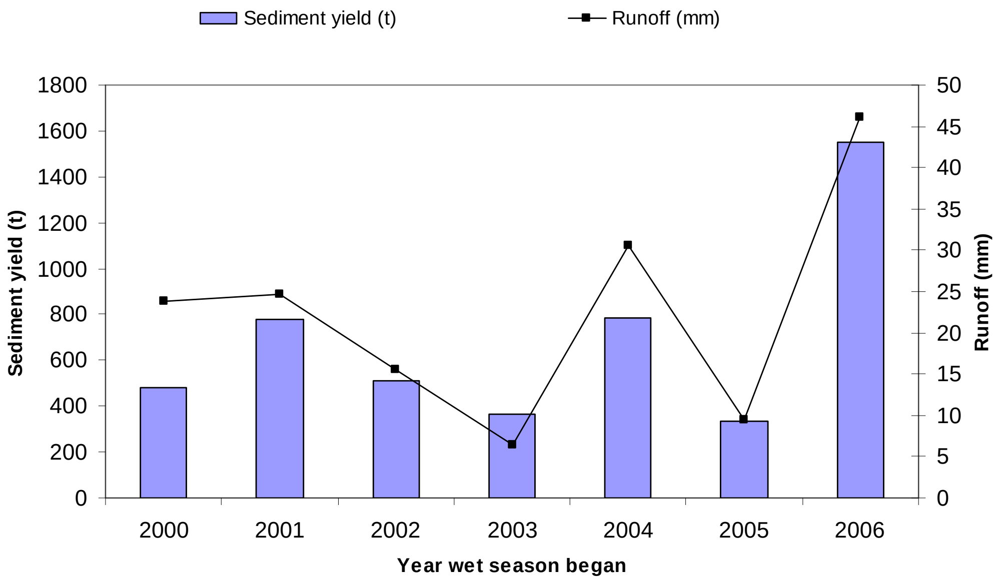


Figure 31: End of catchment sediment yield and corresponding run-off conditions between 2000 and 2006

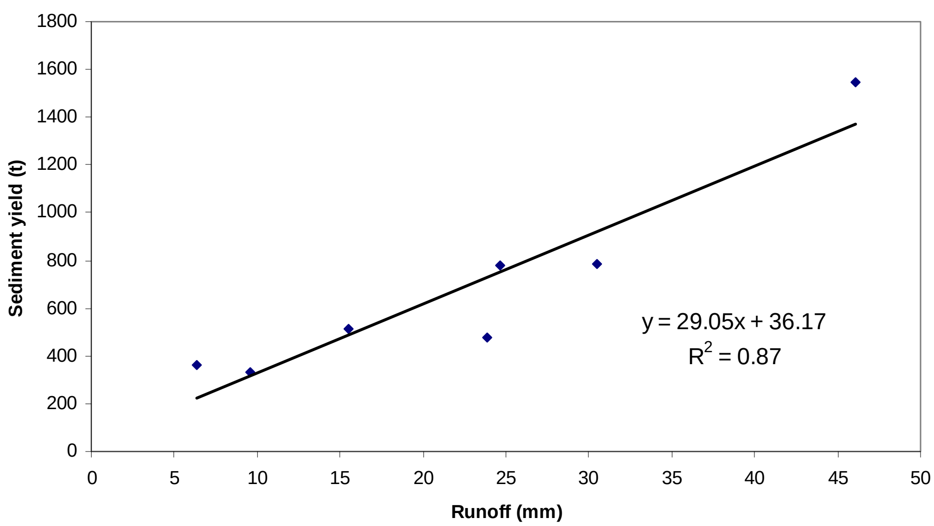


Figure 32: Relationship between annual run-off (mm) and annual sediment yield (t) in Weany Creek

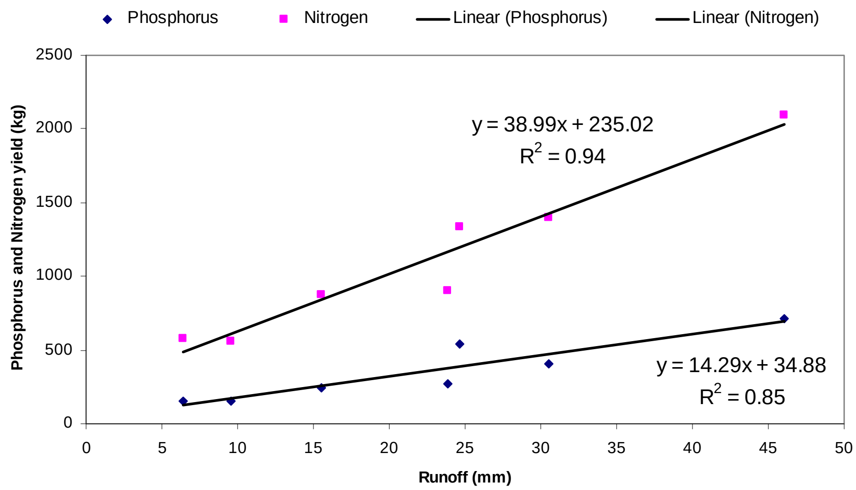


Figure 33: Relationship between annual run-off (mm) and annual nitrogen and phosphorus yields in Weany Creek

3.2.4 Weany Creek sediment and nutrient budgets

Summary sediment budget

Sediment budgets are used to determine the relative amounts and sources of sediment coming from different erosion and depositional processes in a catchment. In this report, only the fine (< 0.2 mm) sediment budget is reported as this is the component of most interest to both downstream water quality as well as soil loss from a grazing perspective. For comparison, a full sediment budget including both fine and coarse material for Weany Creek was presented in Bartley et al., (2007).

A schematic diagram of the ‘average’ fine sediment budget (sediment < 0.2 mm) for the 5 year monitoring period at Virginia Park is given in Figure 34. Results for the gully, bank and channel monitoring are not given explicitly in this report in an attempt to reduce the length of the document, however, the results for 2002-2005 can be found in Bartley et al., (2007) and data for subsequent years can be obtained from the authors.

Channel sources, gully and bank erosion, dominate the fine sediment budget for Weany Creek with on average, 877 t/yr and 723 t/yr of sediment being delivered to the stream network from these processes, respectively. Hillslope erosion represents a much smaller source of sediment contributing an average of ~ 314 t/yr of sediment each year. On average over the 5 year period, both the gully floor and stream channel bed act as sediment sinks storing ~ 803 t/yr and 55 t/yr, respectively, however, this can change in any one year depending on the rainfall and run-off (as outlined below). Using the sediment budget approach, the total fine sediment loss estimated for the catchment over the 5 year period averages 962 t/yr or 0.71 t/ha/yr. This is within 33% of the fine sediment load measured at the end of the catchment gauge. Given the errors associated with scaling up point measurements, as well as the estimated errors in the end of catchment sediment load calculations (of between 20- 50%), the variations between methods is considered reasonable. These results suggest that the relative proportions coming from each of the processes are within the right order of magnitude.

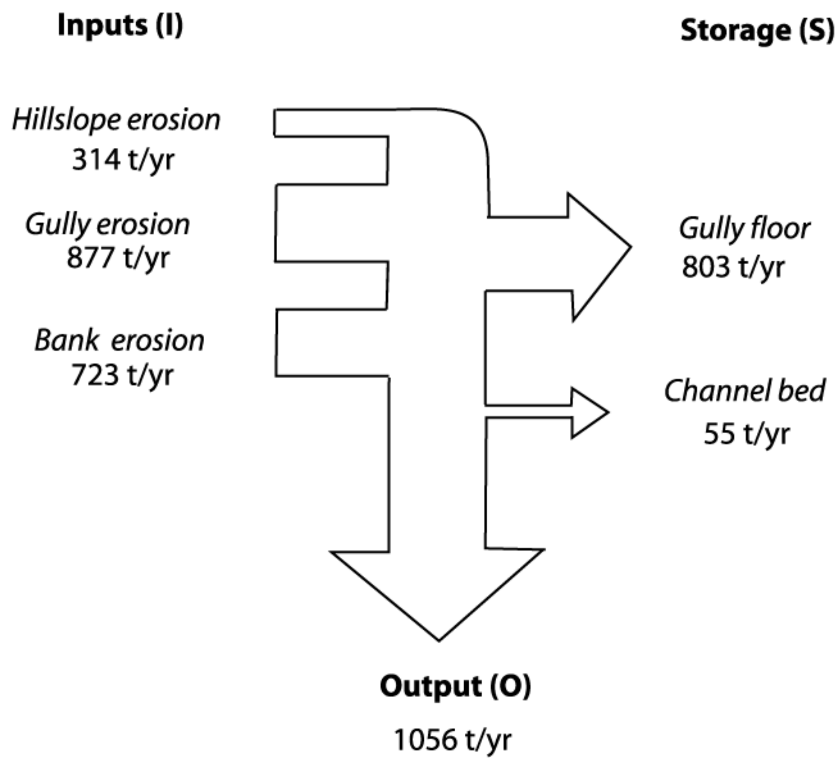


Figure 34: Average fine sediment budget for the Weany Creek catchment (2002-2006)

Weany Creek nutrient budget

The budgets for nitrogen and phosphorus are given in Figure 35 and Figure 36, respectively. Table 9 presents the average source values for the whole measurement period between 2002 and 2006. The phosphorus budget is similar to the sediment budget as the main sources of phosphorus are from the channel (gully and bank erosion). However, the nitrogen budget is dominated by hillslope erosion rather than channel sources, with almost twice as much nitrogen coming from the hillslope than either gully or bank erosion. This highlights that management of hillslope erosion is important for helping to address the loss of nitrogen from paddocks.

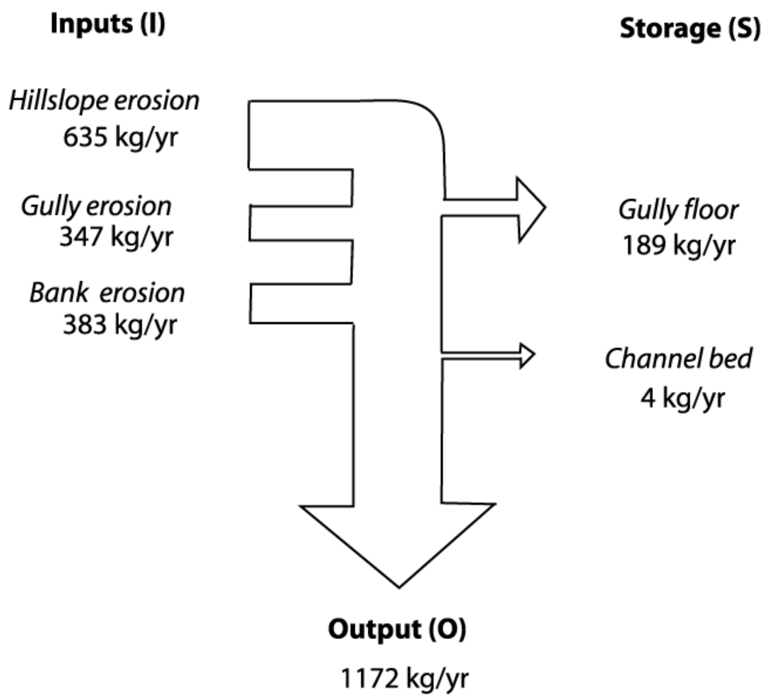


Figure 35: Nitrogen budget for Weany Creek for the five year period between 2002 and 2006

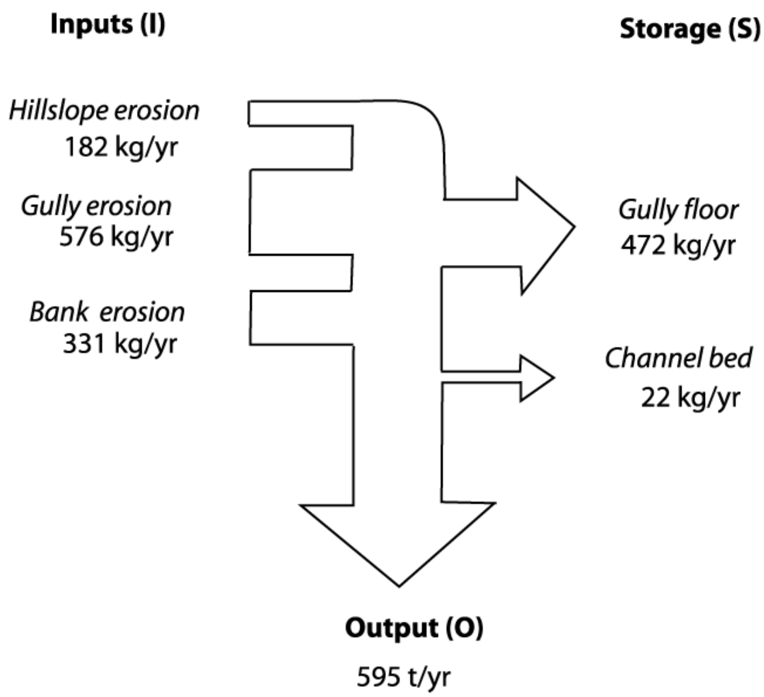


Figure 36: Phosphorus budget in Weany Creek for the five year period between 2002 and 2006

Table 9: Average nitrogen and phosphorus budgets based on the fine sediment budget for Weany Creek Catchment for the whole 5 year measurement period (2002- 2006). Positive values represent sediment loss or erosion and negative values represent sediment deposition or storage

	Nitrogen (kg/yr)	Phosphorus (kg/yr)
Hillslopes	635	182
Net gully flux	158	104
Banks	383	331
Channel bed	-4	-22
Total load estimated by summing source terms (kg)	**1172 (0.87 kg/ha)**	**595 (0.44 kg/ha)**
Mean annual load measured at catchment outlet	1102	334
% difference between measures fine sediment load estimates	6%	44%

Comparison of sediment budgets between wet and dry years

Analysing the sediment budget data for wet (above average) and dry (below average) rainfall conditions, highlights how much the erosion processes can vary both with run-off and land management (see Table 10).

For example, in the drought or below average rainfall years between 2002 and 2005, gullies were a net sediment sink. That is, all the sediment that was eroded from hillslopes and gullies was stored in the gully network and generally did not enter the stream system. Also in drought years, the channel bed was a net sediment source. This means, on average, the amount of sediment being eroded from the stream bed was greater than that being deposited. Conversely, in the wetter year (2006/07), and on average for the 5 year study period, gullies represented a net sediment source and the channel bed a net sediment sink (see Table 10). The 5 year average conditions are more representative of the processes that are modelled in SedNet and Annex and these results emphasise the importance of having long term data sets and measurement records to (a) estimate catchment sediment and nutrient budgets, and (b) to compare against modelled estimates. Other studies have shown that sediment budgets can change considerably over relatively short time scales (e.g. Roberts and Church, 1986), depending on land use and climate conditions. Graf (1983) has also suggested that modern instrumented records (of around 10 years) provide an inadequate estimate of long term sediment movement due to the strong inter-annual variability. The results are also shown to vary with land management as the amount of sediment contributed to the stream network from hillslope erosion declined from 333 t/yr for the drought period from 2002-2005 to 237 t/yr for the 2006/07 wet season, despite the higher run-off and rainfall in the 2006/07 wet season. Implications of these results for water quality target setting will be discussed in Section 6.2.

Table 10: Average fine sediment budget (<0.2 mm) for Weany Creek Catchment for the drought period between 2002 and 2005, the wetter conditions in 2006/07, and for the whole 5 year measurement period (2002- 2006). Positive values represent sediment loss or erosion and negative values represent sediment deposition or storage

	Mean fine sediment Yield (tonnes/yr)		
	2002-2005 (drought period)	**2006 (above average rainfall)**	**Average (5 year period)**
Rainfall (mm) **Run-off (mm)**	386 mm 16 mm	638 mm 46 mm	443 mm 22 mm
Hillslopes	333	237	314
Net gully flux	-80	404	74
Banks	600	1093	723
Channel bed	130	-542	-55
Total sediment estimating by summing source terms	**984 (0.73 t/ha)**	**1192 (0.88 t/ha)**	**1056 (0.78 t/ha)**
Mean annual load measured at catchment outlet	498	1549	709
% difference between measures fine sediment load estimates	49%	30%	33%

4 Discussion

4.1 Key findings and messages from the cover and biomass research

The one year extension of the flume hillslope and paddock scale pasture and land condition monitoring at Virginia Park has provided the opportunity to follow the spatial and temporal trajectory of early pasture and land condition recovery through a wetter (or at least near average) rainfall period. This opportunity has allowed us to reinforce some of the initial NBP.314 findings and gain further insights into what drives the patterns of land condition recovery at the hillslope scale. A number of key findings have arisen as a result of the one year extension. These include:

- Reducing stocking rates to recommended levels and introduction of whole of wet season spelling has successfully restored end of dry season residual ground cover and pasture biomass levels to above recommended rates within four years of implementation, despite several years of well below average rainfall.
- Reinforcement of the NBP.314 finding that C condition patches are twice as likely to receive heavy grazing than A and B condition patches and that certain D condition patches are up to four times likely to be heavily grazed.
- Reinforcement of the NBP.314 finding that sodic soil communities are twice as likely to receive heavy grazing throughout the season compared with adjacent ironbark/bloodwood communities.
- These above two factors combined contribute in part to the failure of such areas to significantly improve in ground cover, herbaceous biomass and overall land condition, even though the majority of paddocks show major improvements in these metrics in response to introduction of sustainable grazing practices. The other major contributing factor is the loss of the A horizon and associated sheeted or scaled soil surfaces which represent a hostile environment for the recruitment and regeneration of herbaceous material.

- Reinforcement of NBP.314 findings that landscape location can have a significant impact on rates and patterns of land condition recovery. This is because different parts of the landscape trap and store resources differently. For example lower slopes and areas under tree canopies are better able to trap and accumulate resources and provide “safe sites” for regeneration of herbaceous material. In particular, this highlights the important role trees play in the landscape, acting as nutrient pumps, infiltration hotspots and higher fertility safe sites for regeneration of 3P grasses.
- The starting size and location of bare patches within C and D condition granodiorite landscapes of the upper Burdekin has a strong bearing on the spatial and temporal patterns of recovery. There is a gradual shift from fewer and larger patches to smaller and more numerous bare patches as medium to larger size patches begin to fill in during recovery, especially within the mid and upper slopes. Thus, the size and frequency of bare patches may be a useful indicator both of land condition and condition trend.

4.2 Key findings and messages from the hydrology research

The four wet seasons monitored from 2002-2005 had below-average rainfall conditions, and although detectable changes in ground cover and soil surface condition were measured, the drought conditions did not provide significant rainfall and run-off events to demonstrate whether improved grazing management has reduced hillslope water and sediment yields. In the 2006/07 wet season, however, there was sufficient rainfall and run-off to help demonstrate changes in sediment and nutrient yields at a number of scales. This provided a number of new research findings, including that:

- Best practice grazing land management, such as wet season spelling, can significantly reduce sediment and nutrient yields on most hillslopes after 5 years.
- There has not been a corresponding reduction in the percentage of run-off from these hillslopes which suggests that run-off is not as sensitive to cover as sediment and nutrient loss, and/or that the improvements in surface ground cover do not necessarily mean there has been an improvement in soil health and infiltration.
- Hillslopes with large bare (scald) patches at the base of the hillslope (in the main flow line) do not show the same response to wet season spelling as hillslopes without large bare patches. These scald patches continue to act as a major source of sediments and nutrients from grazed hillslopes.
- On hillslopes with large bare (scald) patches, up to 20% of their sediment loss is coarse (bedload) material and these features are considered to be in the initial phase of gully development.
- At the catchment scale, gully erosion is the dominant erosion source in the sediment and phosphorus budgets (e.g. Figure 37). Gully network extension can cause a peak in catchment sediment yield 2–3 orders of magnitude larger than yields prior to gully development, and this peak can last for several decades (Wasson *et al.*, 1998). Once a gully is established, it can concentrate run-off and continues to yield sediment at approximately one order of magnitude higher than yields prior to gully development, through widening and erosion of the gully walls. This can lead to losses of productive grazing lands. Gully erosion also dissects the landscape, increasing the connectivity of hillslopes to deliver surface-derived sediment to the river network.
- Hillslopes are the main erosion source in the nitrogen budget and also play an important secondary role in controlling the amount of gully and bank erosion. When there is ‘good’

cover on hillslopes, infiltration is higher and run-off and erosive stream powers are reduced. This helps reduce gully and bank erosion downslope.

Figure 37: (left) gully erosion in the Bowen catchment and (right) gully erosion near Blue Range in the Upper Burdekin

4.3 Implications of results for water quality target setting and large scale sediment and nutrient budget models

Figure 38 presents a conceptual diagram of the relative changes in sediment yields in grazed areas of the Burdekin catchment. This figure shows that the major increase in sediment (and associated nutrient yields) in these landscapes most likely occurred in the late 1800's or early 1900's with the initiation of gully erosion that followed the reduction in ground cover. Now, in 2007, we are starting to demonstrate that best practice grazing land management is reducing sediment and nutrient yields from hillslopes, however, this is not having a parallel change in end of catchment sediment and nutrient loads because of the dominance of gully (and to a lesser extent bank) erosion. It is not possible to put a specific date on the initiation of these erosion processes without a rigorous geomorphic study using dating techniques such as OSL (optical stimulated luminescence) (e.g. Rustomji and Pietsch, In Review), however, there is other evidence available that suggests that sediment yields did increase in the late 1800's (McCulloch et al., 2003) and this was likely to be due to the initiation of scald zones along the river frontages and expansion of the gully network.

The sediment and nutrient budget results in this study provide an important message to the grazing industry in terms on the water quality target setting policy debate. In particular, the results presented in Section 3.2.3 highlight how total sediment and nutrient loads, and the associated erosion sources can change considerably between wet and dry years. This means that although setting water quality targets based on an estimate of 'average' long term condition may be appropriate, evaluating how a catchment and a given land use is meeting this target in any one year will be highly dependent on a combination of the rainfall and run-off conditions, history of land use and current land use condition. It will therefore be very difficult to observe an improvement in land management for any particular process (e.g. hillslope erosion), using end of catchment yields, against the background of climate variability, climate change and history of land use change.

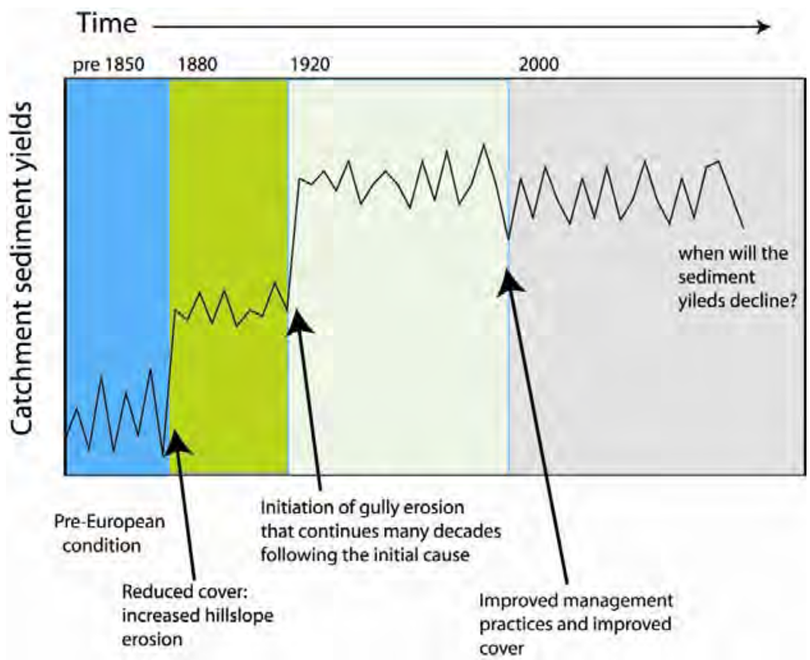


Figure 38: Conceptual diagram of the changes in sediment yields over time in grazed landscapes in the Upper Burdekin catchment

Implications of this study for large scale catchment modelling

The main models that are used by MLA and other regional bodies in the Great Barrier Reef region are the catchment scale sediment and nutrient budget models SedNet and ANNEX (see http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit.woa/wa/productDetails?productID=1000013).

These models are relatively unique within the catchment modelling industry as they can estimate end of catchment sediment and nutrient loads, but more importantly, they can also determine where in the catchment the sediments and nutrients are likely to be coming from in terms of both location and erosion process (see Post et al., 2006). This is extremely important for identifying potential areas for remediation or improved land management.

In addition to the recommendations made in Post et al., (2006) and Post (2007), the results from this property scale field measurement based study have highlighted a number of issues for the development and future application of SedNet and ANNEX within the rangeland areas of northern Australia. These include:

- That these models may be useful for setting long term average end of catchment sediment and nutrient load targets, however, it will be difficult to use the models to evaluate whether catchments or specific land uses (e.g. grazing) can meet these targets due to (a) the often non-linear interaction between rainfall and run-off, history of land use and current land use condition; and (b) the unknown temporal lags between improved land management and reductions in end-of-catchment sediment and nutrient yields.
- The end of catchment water quality targets should be coupled with specific land management targets such as mean ground cover conditions or fertiliser application rates. This will provide the agricultural industries with a more positive method to evaluate improvements in land management. Using indicators such as ground cover, agricultural industries can potentially

show improvements in land management within 5-10 years, instead of the 10+ years that are expected to be required to see changes in water quality.

- If on-ground measurements are to be used in association with end of catchment loads as part of the 'target' setting approach, then further on-ground field research is required to get a better understanding of the link between on-ground measurements and satellite imagery based data for factors such as ground cover and gully extension.
- To evaluate changes at the hillslope and paddock scale it will be necessary to use other modelling applications. The model of choice will depend on the specific question and whether pasture growth, sediment, nutrients or water are the main parameter of interest. Some of the other models that may be useful at the hillslope and paddock scale include Savanna.au (Liedloff et al., 2005), LISEM (Kinsey-Henderson et al., 2005a), SubNet (Kinsey-Henderson et al., 2005b), GRASP etc

It is important to highlight that although we have focused on some of the potential limitations of these models, they are still the most successful and appropriate models for estimating end of catchment sediment loads, and a plethora of research has shown that with the appropriate application they can be very useful for informing catchment management at the regional level (Bartley et al., 2004; Harrison et al., In Press; Rustomji et al., In Press; Wilkinson et al., 2006).

5 Success in achieving objectives

The objectives for this research project were to:

1. *Provide an additional years' data to the previous projects data for 2002- 2005, and integrate all data into the analysis for the research site.*

   This has been achieved and documented in Section 2 for the ground cover and biomass work, and Section 3 for the hydrology, sediment and nutrient yield work.

2. *Improve the sediment and nutrient budget estimates for Virginia Park, and outline the implications of these results for the application of soil and nutrient movement models developed in the project NBP.314.*

   Sediment and nutrient budget estimates for Virginia Park were updated using data from the 2006/07 wet season and also compared with the budgets from the previous below average rainfall period (see Section 3.2.4). Implications of these results for both end of catchment water quality target setting and the use of large scale catchment models was given in Section 4.3.

3. *Where new information is available, produce an updated publication for producers on grazing management to minimize soil and nutrient loss from grazing management and maximize water retention in grazing paddocks.*

   Given the recent release of the 'Managing Recovery' brochures to ~1200 graziers in the Burdekin catchment (http://www.csiro.au/resources/ManagingRecovery.html), an updated publication for producers was not warranted. However, different aspects of this research has been presented at a number of other forums including:

   - Queensland State Government Public seminar, Indooroopilly, October 2006
   - Australian and New Zealand Geomorphology Conference, Canberra, February 2007.
   - MLA NABRC Conference, Townsville, March, 2007
   - PATCHKEY Workshop, Charters Towers, May 2007
   - 5th Australian Stream Management Conference, Albury, May 2007

- MLA annual review meeting, Townsville, October 2007

4. *Produce updated guidelines for the management of the Burdekin Catchment to assist in meeting water quality targets.*

Issues related to the application of water quality targets for the grazing industry were discussed in Section 4.3.

6 Impact on meat and livestock industry and regional water quality policy

This section looks at the impacts that this research will have on both the Meat and Livestock industry as well as the Great Barrier Water Quality policy debate. There are overlaps between these two issues and the outcomes are not exclusive to either area.

6.1 Impact on meat and livestock industry

The results of this research, in conjunction with the results from the parent project documented in Post et al., (2006), have a number of specific outcomes for the Meat and Livestock Industry. These include:

- Demonstration that reduced stocking rate and wet season spelling can recover land that was in ‘crisis’ mode with positive outcomes in terms of economic profitability, improved pasture condition and improved downstream water quality.
- An improvement in the science behind the many of the tools (such as Ecograze and PATCHKEY) that are currently being used by extension staff and graziers for assessing improved grazing land management.
- An understanding of the property management considerations required to implement best management practice, such as wet season spelling, including the issues of fencing, agistment, stock and pasture management, pasture recovery and economic returns at the property level.
- The ability of the grazing industry to demonstrate improvements in water quality that will eventually help downstream industries such as the Great Barrier Reef Tourism sector. This should help lift the profile of the grazing industry in this politically sensitive area.

6.2 Impact on the Reef water quality target setting policy debate

The National Action Plan for Salinity and Water Quality (NAPSWQ), the Great Barrier Reef Catchment Water Quality Action Plan (GBRWQAP) and the Reef Water Quality Protection Plan (Reef Plan) were released in 2000, 2001 and 2003, respectively. These policy initiatives focused the attention of the agricultural industries on the effects of terrestrial run-off from grazing lands on water quality in receiving marine environments. The research carried out in this MLA funded project has considerably improved our understanding of a range of key processes, and in particular it has helped inform this debate by providing:

- An understanding of the magnitude of the erosion processes contributing to end of catchment sediment and nutrient yields in the Burdekin catchment using both field data and modelling. These results have helped identify hot spot areas and the associated erosion processes contributing to the excess sediment and nutrient loads. It has now been identified that gully erosion may play a much larger role in delivering sediments and nutrients to the rivers and GBR than first thought (see Figure 37);

- Knowledge on how ground cover quality and quantity changes, both throughout the year and also under different grazing regimes such as wet season spelling. The influence of the variation in ground cover in both space and time on hillslope run-off and sediment yields was investigated showing that it is important to have good ground cover at the base of hillslopes and at the beginning of the wet season to reduce sediment and nutrient losses.

7 Conclusions and recommendations

7.1 Synthesis and recommendations

As this project only represents an additional year of data, there are not a lot of new recommendations that can be made that differ from those already outlined in Roth et al., (2003) and Post et al., (2006). Therefore in this section we have adapted the recommendations made by Roth et al., (2003, p.114) to include the more recent findings from this project.

To help achieve recovery of degraded river frontage with the aim of (a) improving the condition of ground cover on grazed hillslopes and (b) reducing sediment and nutrient export the following steps are recommended:

1. Establish fencelines between hillslope areas and frontage country. In particular, (and where practical) areas of severely degraded frontage country should be fenced off as stock are shown to preferentially graze these sites which increases the size of these features, reducing the area available for grazing and increasing sediment and nutrient loss to the stream system;
2. Initiate pasture recovery on frontage areas with at least one complete wet season spell (or two consecutive spells where possible), followed by the introduction of more conservative stocking rates to achieve utilisation rates of ~30%;
3. To protect the soil surface from early storms, and improve infiltration, aim for at least 60% ground cover, and 800-1000 kg DM/ha, of pasture at the end of the dry season;
4. Relocate existing natural or artificial watering points near watercourses to the upslope fenceline;
5. Where appropriate and practical, establish a fenceline on the stream or river bank to fence off the riparian vegetation and watercourses from the frontage paddock to stop cattle access to the watercourse and increasing bank erosion;
6. Where necessary, fence off gully systems. This should include the pasture areas immediately upslope of active gullies to help promote pasture recovery, increase infiltration and reduce the run-off that is fuelling the gully head-cut erosion;
7. On well-drained alluvial soils, this can be supplemented by active scald and gully remediation works, however, advice should be sort from local QDPI&F staff prior to the initiation of remediation activities.

It is acknowledged that the configuration of paddocks, fence lines and infrastructure is different on each property, and all of the recommendations outlined above may not be practical. However, any attempt to accelerate recovery on degraded river frontage and hillslopes has been shown not only to be helpful in improving pasture growth and reducing sediment and nutrient loss, but wet season spelling has been shown to be economically viable as well (see Post et al., 2006). If resources available to the producer are limited, these stages can be carried out sequentially, but it would be preferable for some of the stages to occur simultaneously (e.g. stages 2, 3 and 4). It is possible that government initiatives such as the Envirofund and NHT3 might provide incentives to producers to carry out some of the stages listed above.

7.2 Areas of future research

Based on the results and outcomes of the research presented in this report, there are a number of areas of future research that would greatly improve our understanding of grazing land management and its impact on grazing production and downstream water quality. Some of these areas include:

- Conducting scientific trials of a range of rehabilitation/remediation options for D class and ‘scalded’ grazing land. Although there is a large amount of largely ‘grey literature’ on how to remediate poor condition land, very little of this has been scientifically trialled and assessed from a pasture, ecology, hydrology and economic perspective. Research from South Africa suggests that sodic riparian patches (e.g. Figure 39) have increased in area 3-fold over the last 50 years (Khomo and Rogers, 2005). If this phenomenon is the same Australia, then this may be having a large impact on the grazing industry in terms of lost productivity, as well as increased sediment and nutrient loads downstream.
- There is a need for more research on understanding the link between patch condition on the ground and patch class or condition identified using satellite imagery techniques.
- In conjunction with above, we need an improved understanding of how processes operating at a patch or paddock level ‘scale up’ to the property and catchment level. Ludwig et al., (2007) has shown that there are non-linearities between patch and hillslope scale measurements for water and sediment loss. Further work is required to understand these processes.
- It would be useful to trial wet season spelling strategies on larger commercial properties in different landscape types (other than Granodiorite) to see if the same improvements and time frames for the recovery of pasture and hillslope run-off are observed.
- A study into the economics of reducing sediment yield at both the property and catchment level (as well as for downstream industries such as tourism on the Great Barrier Reef) would be very useful for helping quantify the potential economic gain or loss from carrying out improved grazing land management such as wet season spelling or scald remediation.

Figure 39: Examples of scald or bare foot-slopes at (A) Virginia Park and (B) along the Upper Burdekin River near Greenvale

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