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Sustainable Grazing for a Healthy Burdekin Catchment

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Abstract

This project implemented grazing land best management practices (full wet season spelling and forage budgeting) on Virginia Park Station in the Burdekin catchment in order to examine the impact of these practices on land condition recovery, landscape health and the consequent leakiness of water, sediment, and nutrients both from the hillslope and the catchment. We found that despite a sustained drought during the period of the study, the management practices implemented led to a shift in land condition from C to B through both improved pasture composition and cover levels in the monitored paddocks. Despite these improvements in landscape health, the duration of the study was too short and inter-annual variability too large to link these improved conditions to a reduction in the export of sediment and nutrients, either at the hillslope or catchment scale. However, representing these improvements in landscape condition in a hillslope model has shown that the improvements seen in this study should lead to significant reductions in the loss of sediment and nutrients from hillslopes. Reductions in sediment and nutrient export at the catchment scale are more difficult to quantify as this study suggests that residence times in the stream may be significantly longer than previously thought, and the state-of-the-art in catchment scale modelling (SedNet) is not able to represent these lag times. Research is currently underway in the CSIRO Water for a Healthy Country program to improve catchment-scale modelling and determine residence times of sediment.

1 Executive Summary

This four-year field study in the Burdekin catchment sought to measure the impact of recommended grazing practices on forage production, groundcover, and runoff of water, sediment and nutrients, as well as to develop improved models for predicting sediment and nutrient export from grazed landscapes into waterways and throughout the catchment. The latter included the first-ever measured estimates of gully and bank erosion for the Upper Burdekin catchment.

The primary research site was on Virginia Park Station where, in collaboration with the owners, we implemented improved grazing practices on the 'goldfields' land type common in the eastern part of Dalrymple Shire. The area in general has a history of sustained periods of over-grazing and much of the original native tussock-grass pasture is now dominated by Indian couch.

Improving land condition involved three complimentary grazing practices:

- Moderate utilisation rates (consuming <30% of pasture produced each season).
- Wet season spelling to protect recovering C (poor) condition patches, especially those with remnant 3P grasses, from preferential wet season grazing.
- Pasture budgeting to retain adequate end-of-dry-season pasture cover and biomass levels to protect the soil surface, slow run-off and provide the litter necessary for improved infiltration and nutrient cycling.

The study period had very low rainfall (decile 2) and this affected the extent of response in most measures of pasture and land condition. Despite these conditions, important findings emerged, including:

1. Under such dry conditions, all three grazing practices (modest utilisation, wet season spelling and pasture budgeting) were required to achieve significant recovery of 'C' (poor) condition landscapes dominated by Indian couch.
2. Recovery in these pastures was spatially and temporally patchy due to the interaction of land condition, land type, topography and grazing preference operating at the scale of the grazed patch. (Analysis of patchiness was greatly assisted by development of PATCHKEY, a tool which uses multiple criteria to classify patches in relation to land condition categories.) In practice, the rate of recovery will depend on the location, size and arrangement of individual patches, the presence of 3P tussocks and the amount of bare ground within patches. Patches with a high proportion of bare ground have the highest risk of continuing to degrade and those with some 3P grasses have the highest chance of improvement. C condition patches in run-on areas also have a better chance of improvement than those on ridges and steep slopes due to the capture of resources flowing down the hillslope.
3. Cattle had a clear preference for C condition patches (existing C condition patches were twice as likely to be heavily grazed as B condition patches). Cattle also preferentially grazed riparian and sodic (dispersible soils with false sandalwood shrub cover) land types. C condition patches occurring on these preferred land types were therefore at particular risk of accelerated degradation, even though the paddock as a whole may have been improving in condition.
4. To recover C condition paddocks in years of well below-average rainfall, whole of wet season rest (rather than just an early spell for 6-8 weeks) appears to be required for any significant recovery response. While steady recovery may be achieved with biennial wet season resting, consecutive full wet season spells in the early years of recovery will accelerate this response.

5. Earlier studies at this site found that 75% ground cover is the threshold below which long-term hydrological function begins to decline, and that the 40% cover threshold commonly recommended for minimising erosion processes in sub-coastal grazing lands is too low, at least for these land types. Patch scale studies gave further support for these higher ground cover thresholds.
6. The modest improvement in land condition achieved at Virginia Park did not result in measurable reductions in sediment and nutrient loss at either the hillslope or catchment scales during the course of the study. However, simulation studies with a computer model of hillslope erosion predicted that the observed changes in pasture composition and ground cover would eventually reduce the losses of sediment and nutrients at the hillslope scale. Importantly, measurements taken 6-12 months after the end of this study period, and following significant rainfall, have confirmed a significant reduction in sediment and nutrient loss at the hillslope scale.
7. Measuring impacts of improved land condition beyond the hillslope scale, at the sub-catchment and catchment scales, is more problematic, as we found there was extensive storage of fine and particularly coarse sediment in gullies and stream channels. This means that there is a lag time, perhaps of some years, between changes in grazing practices and potential impacts on export of sediment from the river mouth.
8. To minimise erosion and accelerate recovery of Indian couch pastures, at least 60% ground cover and 800-1000kg/ha of pasture dry matter are required at the end of the dry season. For tussock grass pastures, the minimal levels are even higher: at least 70% ground cover and 1000kg/ha of dry matter. Though such cover and biomass threshold targets may be difficult to achieve in practice in the early years of recovery, they form an important part of 'best practice' sustainable grazing strategies for improving land condition. Soil loss models predict that improving the overall condition of hillslopes from C condition by just 20% towards B condition can almost halve runoff and soil loss.
9. The arrangement and location of the ground cover on hillslopes also affected the quantity of water and soil that was lost from the study sites. Hillslopes with large bare patches at their base had up to 10 times more runoff and 50 times more soil loss than similarly-covered hillslopes without large bare patches at their base.

As the demonstration was only over three wet seasons (2002/2003-2005/2006) and took place during well below-average rainfall seasons, we can only speculate about the long-term benefit and superiority of consecutive full wet season resting vs. biennial wet season resting of pastures. However, it seems that longer and more frequent wet season spells are the key to shifting C condition Indian couch pastures on Goldfields country towards B condition. In any case, our results show that, even under very adverse conditions, appropriate management can improve land condition.

Recovery of poor condition land is beneficial for animal production and profitability. Landscapes that are improving in condition showed evidence of increased diversity of patch types and increased pasture growth which in turn, will likely result in more even grazing pressure and higher carrying capacities.

We used the improved measurements and understanding of hillslope and other erosion processes from this study to improve the *SedNet* and *ANNEX* models for the Burdekin catchment. *SedNet* and *ANNEX* are the commonly used tools for predicting sediment and nutrient exports, respectively, from different landscapes into waterways and throughout catchments. Our main improvements to the models were in *SedNet* and included:

1. A spatially variable cover-factor in grazing lands (~95% of total modelled area), allowing for hillslope erosion rates from the Revised Universal Soil Loss Equation (RUSLE) to be related directly to estimated ground cover levels.

2. Improved spatial resolution of the slope-factor in the RUSLE estimates of hillslope erosion.
3. Revised gully cross-sectional area estimates based on field measurements.
4. Improved estimates of channel width and depth based on field measurements, allowing for improved estimates of channel deposition and bank erosion.
5. Use of the transient bedload model available now in *SedNet*

The main findings from application of the improved SedNet and ANNEX models to the Burdekin catchment included:

1. Hillslope erosion is the highest contributor of sediment, followed by bank and then gully erosion. Earlier models had determined that gully erosion was the largest contributor to sediment yields, but this was based on using a default cross-sectional gully area instead of the measured values from this study.
2. SedNet predicts end of sub-catchment sediment yields reasonably well, with all but one of the six studied sub-catchments being within 60% of the measured values. Given the differences in the rainfall patterns used to calculate the measured and modelled loads, and the inherent uncertainty with both modelled and measured estimates, these differences are reasonable and somewhat expected.
3. The match between the measured and modelled nutrient values are much poorer than for sediments. In four out of five cases *ANNEX* over-predicted both nitrogen and phosphorus yields by as much as 600%, and these large over-predictions could not be entirely explained by climatic conditions.
4. The estimates of gully and bank erosion for the Upper Burdekin catchment from this study are the first reported datasets to quantify these erosion processes in the tropical or sub-tropical grazing lands, and are therefore important data sets for general improvement of catchment scale models such as SedNet.

Current sediment and nutrient models such as *SedNet* and *ANNEX* are not designed to examine the impact of temporal changes in land cover on sediment and nutrient export. In addition, a new modelling approach is required that can handle the impacts of lags and storages in the system. An example of such an approach is the *E2* model currently under development within the e-water CRC.

It is extremely important to highlight the immense value of the data sets that have been gathered within this study. We have been able to monitor ground cover and pasture condition, erosion, and sediment and nutrient yields from grazing lands for up to 6 years, which represents the data set of highest duration for extensive grazing lands anywhere in Australia.

Future work should focus on continued testing of grazing and spelling strategies to determine recovery times; testing of the PATCHKEY tool for identifying early changes in condition trend; and determining residence times of fine and coarse sediments. These field investigations should be integrated with the development of a modelling framework which is able to deal with sediment storages and lag times.

2 Background to the study

This study commenced in October 2002 and built on the findings and outcomes of the previous study *Reducing sediment export from the Burdekin catchment* NAP 3.224 (Roth *et al*, 2003). This study clearly demonstrated a link between low ground cover and loss of sediment and nutrients at the plot (but not hillslope or catchment) scale. Additionally, these changes in ground cover had not been linked to grazing management, nor had the effects of improved grazing management on forage production, cover, and runoff of water, sediment and nutrients been established.

At around the same time. the National Action Plan for Salinity and Water Quality and the Great Barrier Reef Catchment Water Quality Action Plan (GBR-WQP) were released. These served to focus attention on the effects of terrestrial runoff from grazing and sugar lands on water quality in receiving marine environments. The GBR-WQP was released in September 2001 and reviewed historical and current conditions, and proposed fairly significant quantitative targets for reductions in sediment and nutrient runoff. It prioritised the 26 GBR catchments according to the ecological risk they pose to the GBRL and recommended minimum targets for pollutant loads. Under this plan, the Burdekin River catchment is rated a medium/high risk catchment due to its large size (130,000 km^2). Sediment and phosphorus exports are classified as high risk for the GBR with estimated current loads of 2.4 million tons/year of sediment and 2.4 thousand tons/year of phosphorus. Nitrogen exports pose a medium risk with an estimated current load of 11.1 thousand tons/year. Proposed targets are load reductions of 50% for sediment and phosphorus and 33% for nitrogen by the year 2011.

These targets were developed by a scientific working group within GBRMPA, independently of the NAPSWQ process, with little consultation of researchers outside GBRMPA and with no consultation of industries, resulting in little regard to what might be realistic and achievable targets. No indication was given to how and where in the catchment changed management practices might contribute towards improved water quality, and how end of catchment water quality targets might relate to action on the ground.

Subsequently, involvement of community groups as part of the NAPSWQ process was accepted as the appropriate pathway for the federal and state governments to deliver water quality targets for GBR catchments, both within the NAP catchments (Burdekin, Fitzroy) and to deliver NHT2 funds to other catchment groups. Development of realistic water quality targets was viewed as a critical first phase in a staged approach to reverse trends in declining water quality and to eventually allow for the recovery of inshore reef and riverine ecosystems.

From the work conducted in the preceding project (NAP 3.224), we were able to develop a catchment sediment delivery model (SedNet) that enabled us to obtain a good understanding of the spatial distribution of the key erosional processes (sheet, gully and channel erosion) and their relative contribution to the overall sediment budget (Prosser *et al*., 2001). The main finding is that about 60% of sediments delivered to the mouth of the Burdekin are from hillslope erosion and have their origin in fairly localized hotspots in the north-eastern parts of the Upper Burdekin and within the Bowen River catchments. As hillslope erosion is mainly controlled by the proportion of attached ground cover present, there are significant opportunities for the grazing community in the Burdekin to address sediment and nutrient export through more sustainable grazing management practices, for which guidelines have been made available to the industry through the ECOGRAZE project.

The previous project also established more clearly that it is not just a matter of how much ground cover is maintained, but that there are significant interactions between the duration of high levels of ground cover, its composition and soil surface condition. Results obtained by comparing infiltration on heavily grazed areas with that of an exclosure and an area that after several years of exclosure had received only moderate grazing, show that high levels of sustained ground cover alone are not sufficient to induce high infiltration in the presence of continued high grazing pressure. Rather, it is the proportion of attached foliar cover and incorporated litter that significantly alter and actually promote a full rehabilitation of soil hydrological function. Reduction in grazing pressure is the key to ensuring sufficient pasture biomass to produce the high quality foliar and litter cover required to improve hydrological function.

This project was designed to satisfy many of the requirements of the NAPSWQ process. It was designed to provide knowledge of the key processes leading to sediment and nutrient loss from grazing properties; document the consequences of landscape rehabilitation in terms of improved water quality, and provide tools for setting realistic and measurable targets.

3 Project objectives

1. Develop sustainable grazing management practices and tools for evaluating and documenting effects of a range of management practices.
2. Refine computer models for predicting sediment and nutrient transport into waterways and throughout catchments.
3. Provide quantitative measures of the short-term effectiveness of recommended sustainable grazing management practices (e.g. ECOGRAZE) and their impacts on forage production, cover, and runoff of water, sediment, and nutrients for reducing sediment and nutrient export from grazed lands.
4. Refine and validate tools for setting realistic and measurable targets for reductions in sediment and nutrient loads in rivers (NAP) based on robust and reliable modelling tools.
5. Have all beef producers in the Burdekin informed and more knowledgeable about implementing best-practice management guidelines and their impacts on forage production, water use efficiency, and runoff.

4 Methods

4.1 Research framework

This project is divided into three components as illustrated in **Figure 1**.

Component C involves the derivation and implementation of grazing land best management practices (full wet season spelling and forage budgeting) on Virginia Park Station in the Burdekin catchment.

Component B provides an assessment of the impact of these best management practices on grazing patterns, forage production, pasture composition and ground cover.

Component A provides an assessment of these grazing patterns and cover levels on sediment and nutrient export across a range of scales from hillslope to whole-of-catchment.

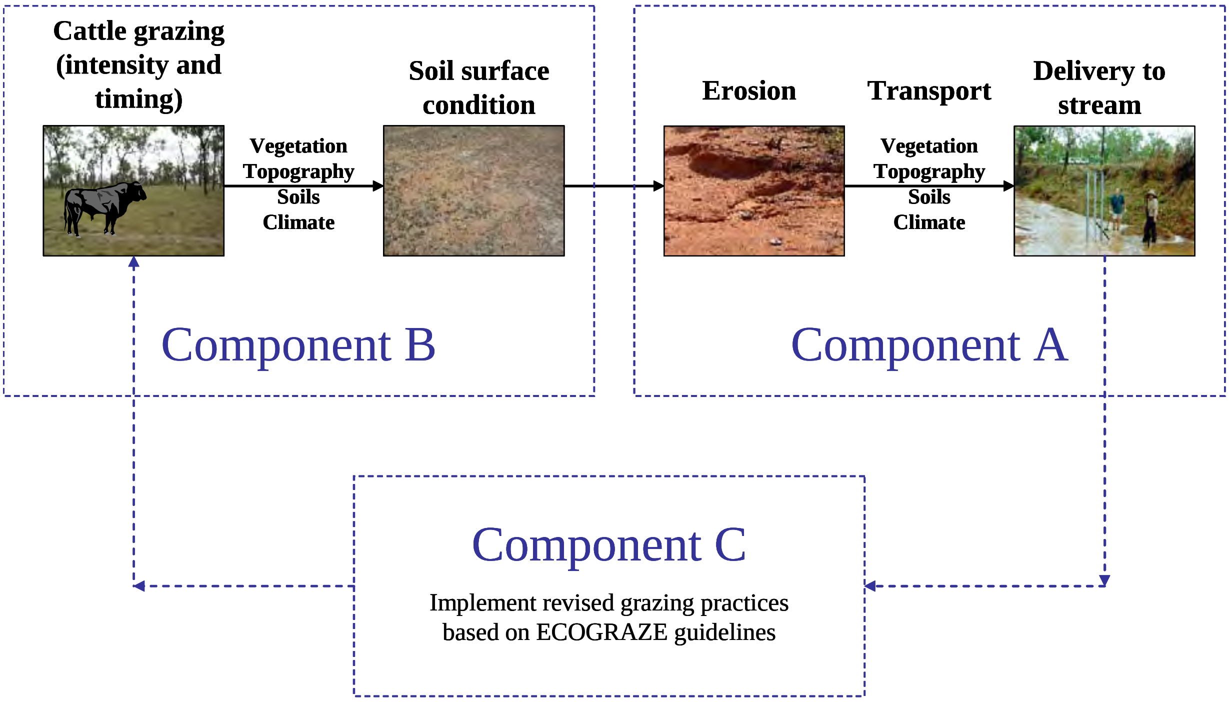


Figure 1: Overall structure of the project

4.2 Research sites

This project is set entirely within the Burdekin catchment. Funding from this project contributes to the maintenance of 5 of the sites shown in **Figure 2**; Wheel, Weany, Blue Range, Station and Burdekin. The other sites are also maintained by CSIRO Land and Water but paid for by the Department of Defence and the Burdekin Dry Tropics NRM. Permission has been given from these agencies to make use of their data. Details of the monitoring at each of these sites is given in Section 7.4.2. In addition to these sites, aspects of component B grazing and patch dynamics studies were conducted at Wambiana Research site and selected commercial paddocks on

Hillgrove, Blue Range, Trafalgar, Cameron Downs and Kirkland Downs stations – all within the upper Burdekin catchment.

Within the Burdekin catchment, the vast majority of the research is being carried out on Virginia Park Station, and particularly in the catchment area drained by Weany Creek. The details of this monitoring are presented and discussed in Section 6.2 (pasture monitoring) and 7.3 (water quality monitoring).

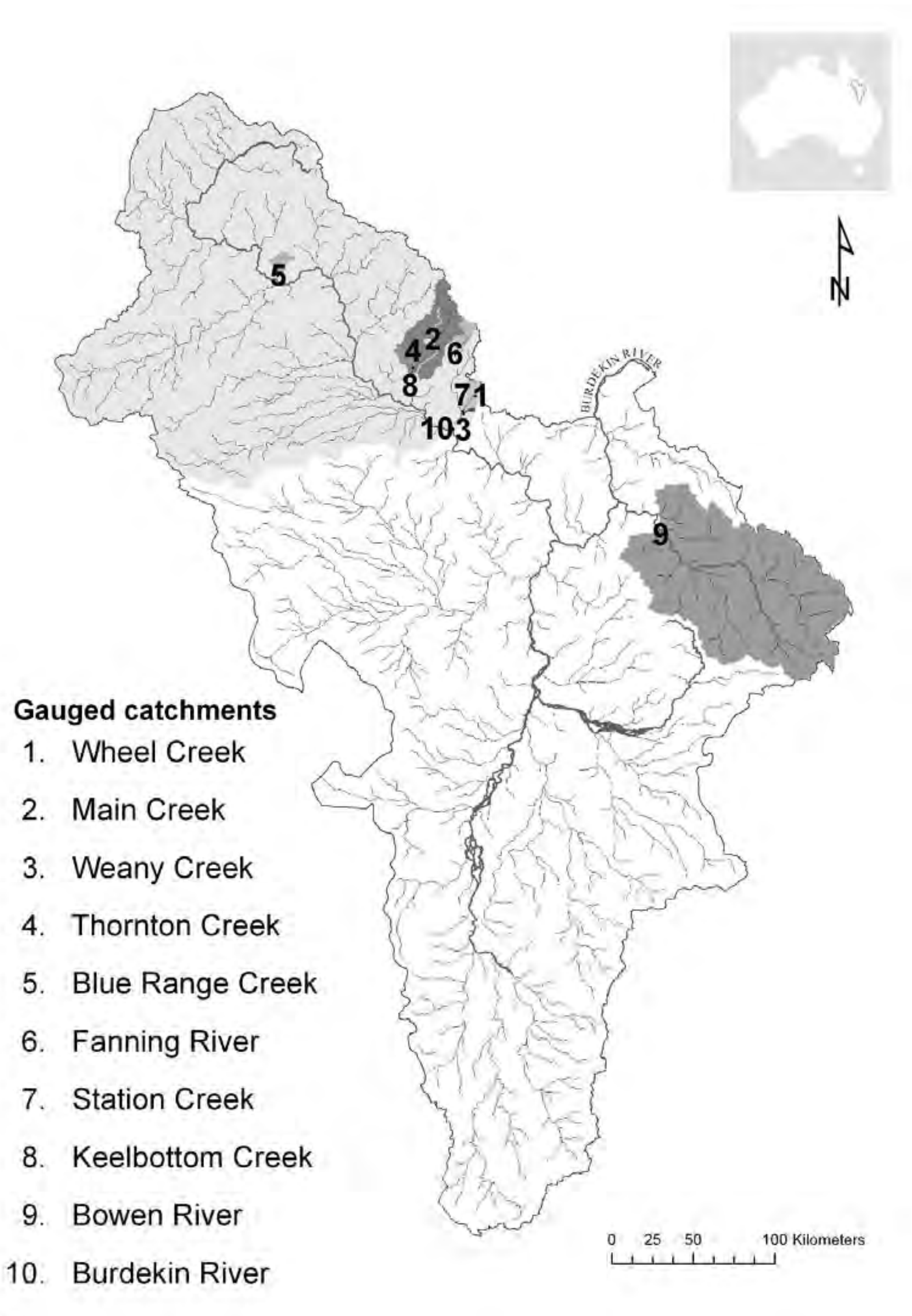


Figure 2: Location of gauged water quality sites in the Burdekin catchment. Catchments are listed in order of size.

5 Implementing grazing strategies to improve land condition

5.1 Key messages

This section of the report outlines the major findings relating to implementing grazing strategies to improve land condition at Virginia Park Station. This section contributes to the overall project objectives outlined in Section 3 of this report, in particular to objectives (2), (3) and (5). A demonstration site consisting of four paddocks was set-up to improve land condition and reduce runoff in the real world. The overall objective of Component C was to implement 'ECOGRAZE' strategies on a commercial property to improve land from C to B condition'. The key findings relating to implementation of wet season spelling strategies are outlined as follows:

- Utilisation rates are very difficult to implement in practice when used to set short-term carrying capacities.
- Utilisation rates are best used to calculate long-term safe carrying capacities with land condition, tree density and land type pasture growth taken into consideration.
- The use of short-term carrying capacity tools (e.g. forage budgets) to achieve desired end of dry season yield and cover thresholds are practical and can achieve the desired outcome (i.e. land condition improvement through appropriate pasture use).
- Grazing systems that incorporate rest need to be designed with animal production and land management goals in mind to simplify implementation.
- To recover land in poor (C) condition requires the removal of all grazing animals over the full length of the wet season. Full wet season rest for two successive years is likely to speed the recovery process.
- Longer and more frequent wet season spells, especially in the early years of recovery are the key to shifting C condition couch dominant goldfields paddocks back towards B condition and improving long term carrying capacity.
- Management strategies to optimise recovery of C condition areas will need to be flexible and responsive to the rate and patterns of recovery, which will in turn be influenced by season, land type and topographic variability. Observing key indicators of land condition trend at patch scale will be important in managing for recovery.
- It is important to retain adequate end of dry season residual cover and biomass levels to provide protection of the soil surface, slow run-off and provide the litter resource essential to improving hydrological and landscape function (see section 6).
- To optimise recovery to B condition avoid premature return to long term stocking rates after achieving an improvement in land condition.
- Recovering land into B condition makes good economic sense.

5.2 Introduction

This section of the report presents findings relating to the application of ECOGRAZE sustainable grazing strategies on study paddocks at Virginia Park Station from 2002 to 2006. A demonstration site consisting of four paddocks was set-up to test the effectiveness of ECOGRAZE recommendations on improving land condition in the real world. The overall objective was to 'implement 'ECOGRAZE' strategies on a commercial property to improve land from C to B condition'. Specifically this section contributes to objectives (2), (3) and (5) of the project.

Virginia Park Station

The Virginia Park grazing enterprise is owned by Rob and Sue Bennetto and runs high-grade Brahman breeders with young male progeny sold for live-export or agisted within the region for heavier turnoff to the meat works. The property is 8050 hectares in size, which is average for the Mingela and Ravenswood districts. A property of this size, run as a cattle station only, would be considered sub-viable. Enterprises that have diversified their business, such as Virginia Park (farm stays), can provide for a good living standard.

The land types of Virginia Park are typical of the 'Goldfields' country around Charters Towers. The dominant soil is a neutral red duplex and narrow-leaf ironbark (*Eucalyptus crebra*) and red bloodwood trees (*Corymbia erythrophloia*) are found on these undulating hills. Scattered within this landscape are patches of sodic soil with false sandalwood (*Eremophila mitchellii*) and currant bush (*Carissa ovata*) vegetation. Narrow alluvial soil bands frame the waterways within this Weany Creek catchment.

The stoloniferous grass Indian Couch (*Bothriochloa pertusa*) dominates these paddocks, which are predominantly in C condition. Native tussock grasses such as desert bluegrass (*Bothriochloa ewartiana*), Black spear grass (*Heteropogon contortus*) and Golden beard grass (*Chrysopogon fallax*) are present in small numbers within the pasture.

The average rainfall for the Mingela district is 650mm. From 2002 to 2006 the property received well below average rainfall, with the 2002 to 2005 seasons falling in the lowest 10 percent on record (**Figure 3**). These drought years provided additional challenges to the implementation of sustainable strategies.

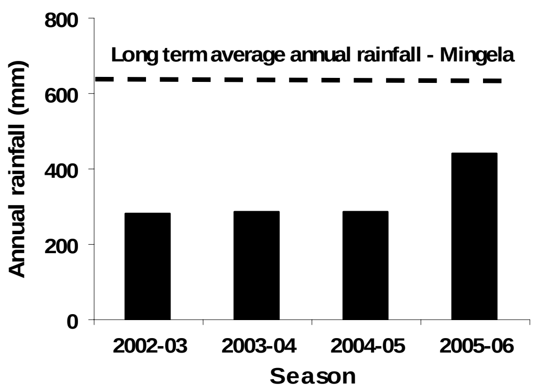


Figure 3: Seasonal rainfall at Virginia Park Station from 2002 to 2006 and long-term average annual rainfall for Mingela.

5.3 Methods

This section is divided into the following sub-headings:

- Grazing strategies
- The ECOGRAZE project
- Application of ECOGRAZE to Virginia Park Station
- Utilisation: a fundamental concept in grazing management
- Carrying capacity methodology

5.3.1 Grazing Strategies

A property planning process was used to determine the grazing strategies that would assist Virginia Park to improve land condition and achieve their animal production goals. The ECOGRAZE Project (Ash et al., 2001) recommendations were discussed and in January 2003 wet season spelling strategies with utilisation rates of 35%-50% were implemented on four paddocks; Top Aires, Bottom Aires, Blackfellas and Stud (**Figure 4**) using the long-term carrying capacity methodology (see 5.3.5). In July 2003 after being forced to de-stock all paddocks due to drought and army worm pasture devastation, the grazing strategies and the methodology for setting stocking rates was reassessed. As a result, from July 2003 short-term carrying capacity methodology (see 5.3.5) was applied to achieve end of dry season pasture yield and ground cover thresholds. Drought conditions (10 percentile) were experienced in the 2003, 2004 and 2005 seasons (**Figure 3**).

The following grazing strategies were proposed:

Top Aires, Bottom Aires and Blackfellas Paddocks: Full wet season spell every second year and stocked to ensure a minimum residual yield of 400 kg DM/ha at the end of the dry season and 40% ground cover (<35% use of standing dry matter).

Stud Paddock: Annual early wet season spell and stocked to ensure a minimum residual yield of 400 kg DM/ha at the end of the dry season and 40% ground cover (<50% use of standing dry matter).

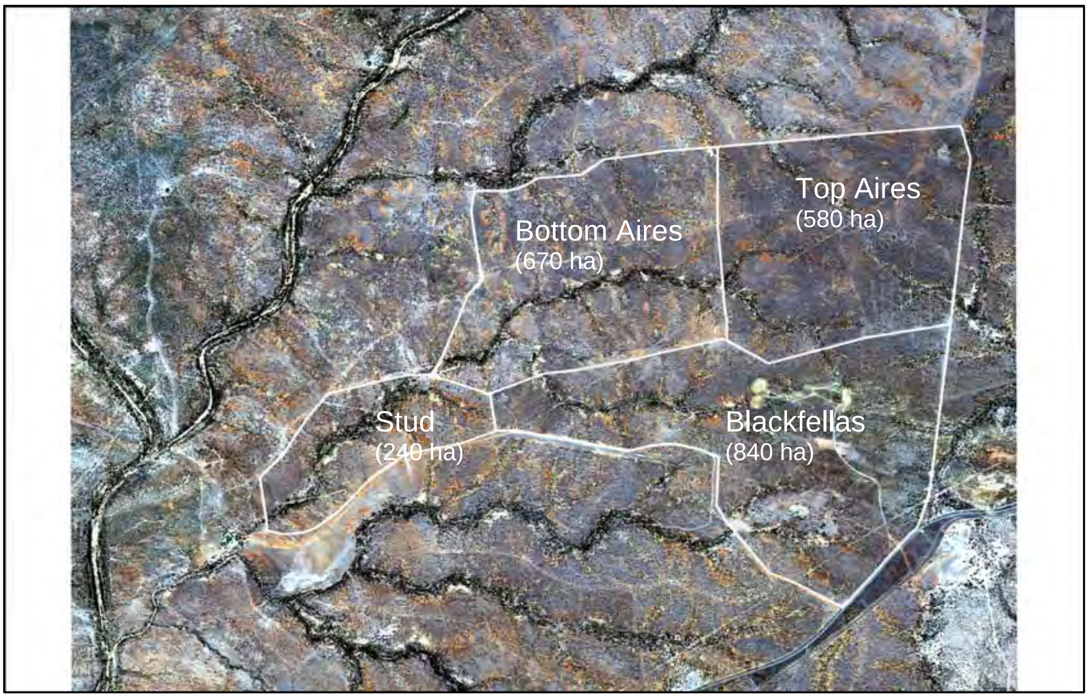


Figure 4: Four demonstration paddocks at Virginia Park Station

5.3.2 The ECOGRAZE Project

The ECOGRAZE project (Ash *et al*, 2001) was the first trial in the Dalrymple Shire and Burdekin catchment to formally look into sustainable grazing strategies and develop sustainable grazing management options for the region. The ECOGRAZE Project (1992-2000) examined how pastures in different condition states respond to a range of grazing utilisation, spelling and fire regimes over time. The land condition states were equivalent to the State 1 and State 2 condition states used in the state and transitions model of Ash *et al* (1996), with state 1 being equivalent to condition A and state II being equivalent to condition B/C of the DPI&F's ABCD land condition framework (Chilcott *et al*, 2003). Utilisation rates of 25% (low); 50% (medium) and 75% (high) were implemented, with or without other management treatments including the use of annual wet season spelling and dry season burning. The paddocks were one to five hectares in size allowing regular adjustment of animals to achieve the desired utilisation of pasture. The project was carried out from 1992/3 to the year 2000/01 (a period which included the drought years 1992-96) on three major land types: infertile red and yellow earths, moderate fertility red duplex (Goldfields) and fertile red basalt soils.

The ECOGRAZE project concluded that both conservative stocking with continuous grazing and a rotational system that includes regular wet season spelling could maintain 3P grasses in the pasture or help them to recover after degradation. Moreover, it concluded that wet season spelling may provide some opportunity for a modest increase in overall carrying capacity without negatively affecting land condition. The ECOGRAZE Project recommended the following strategies for implementation on commercial properties:

- Continuous stocking at 25% utilisation,
- Biennial wet season spelling regime with an average utilisation of 35% and,
- Annual early wet season spelling with up to 50% utilisation

5.3.3 Application of ECOGRAZE to Virginia Park Station

At Virginia Park Station the ECOGRAZE strategies were applied on land in a lower condition class (C) and dominated by the stoloniforous Indian Couch pasture. The demonstration site characteristics and strategies implemented were:

- Demonstration conducted 2003-2006 (with the period 03-05 in the lowest 10% rainfall years on record)
- 1 major land type: moderate fertility red duplex (Goldfields) land type
- C condition lands dominated by stoloniforous grass (> 85% Indian Couch)
- Stocking rates set to achieve end of dry season pasture yield and ground cover thresholds (pasture use rates not exceeded)
- Full wet season rest after first significant rains
- Paddocks 240 - 840 hectares

The major difference between the ECOGRAZE Project and the demonstration site at Virginia Park was that the ECOGRAZE research was carried out on State 1 and State 2 condition land dominated by tussock grasses, or A and B condition land. Virginia Park Station, although on essentially the same land type (Goldfields red duplex) is dominated by Indian couch pasture (*Bothriochloa pertusa*) which is stoloniforous and predominately in C condition. ECOGRAZE paddocks were also very small and animal numbers were adjusted regularly to achieve desired utilisation rates by estimating short-term carrying capacity and comparing what was being eaten with the pasture grown in pasture exclosures.

In commercial situations graziers seldom have pasture exclosures within paddocks to compare the level of pasture utilisation against the quantity of pasture grown in that season. As a result, forage budgets were used to calculate short-term carrying capacities for the four paddocks at Virginia Park Station. A description of the methodology used to calculate stock numbers follows.

5.3.4 Utilisation: a fundamental concept in grazing management

Sustainable grazing practice recommendations derived from research trials, such as ECOGRAZE are based on the concept of utilisation. Safe utilisation is the maximum rate of annual average use consistent with maintaining or encouraging good land condition. This safe level will vary with the land type, grazing strategy, and evenness of forage use across a paddock and from year to year. 25% utilisation of forage grown is considered safe for most land types in the Burdekin catchment. If paddocks are rested during part or the whole of the wet season the pasture can often withstand higher utilisation.

Although utilisation is clearly defined as the proportion of pasture growth consumed over a year; in practice, this is virtually impossible to implement on an annual basis. In commercial situations, the amount of pasture grown in a season is unknown, and the only way to assess available forage it to estimate the standing dry matter yield. Consequently, recommended utilisation rates are being applied by the grazing industry to standing forage rather than the amount of pasture grown (eg. Pigeon Hole, VRD).

When calculating short-term carrying capacities based on utilisation of standing dry matter, we need to ask the following questions:

- Do utilisation recommendations based on pasture growth hold true when based on standing forage?
    - The amount of pasture grown over the year (June-May) may yield considerably less than the standing feed which may have accumulated bulk over many seasons

- Will grazing pressure exceed the desired yield required to be left at the end of the grazing period?
    - This is particularly apparent in below average rainfall years where the forage yield may be very low at the end of the wet season.
- Are unpalatable pasture species, detachment and diet quality taken into consideration?
    - Selective over-grazing of the preferred species may occur and where land condition is poor, recovery of preferred grass species is paramount.
- Is the utilisation rate achievable and sustainable?
    - In drought years a utilisation rate of 25% may not even be achieved due to the need to retain sufficient residual pasture biomass to ensure minimum end of dry season cover thresholds are attained.

The use of the long–term carrying capacity equation is not recommended by Meat & Livestock Australia's Edge Grazing Land Management Workshop and the Department of Primary Industries and Fisheries to determine short-term stock numbers based on standing dry matter yield. A forage budget is the only correct way to determine stock numbers on a seasonal basis.

5.3.5 Carrying Capacity Methodology

The correct methodology for setting long-term carrying capacity and short-term carrying capacity are given below. These methods were applied on the Virginia Park Station demonstration paddocks.

Long-term carrying capacity

Long-term carrying capacity is the average number of animals that a paddock can be expected to support over a planning horizon (5-10 years) and is based on the mix of land types, the condition of the land types, climate, evenness of use by cattle, the grazing strategy and the goals for animal production and land condition.

Long-term carrying capacities are calculated using an equation involving the amount of forage grown, the amount a standardised animal will eat, and the amount of pasture that is consumed over a year at a set utilisation rate. This procedure provides a benchmark of 'where we are at now'. Long-term carrying capacity is not about recommending the number of animals that should be run at any specific time or for any particular run of years. The decision requires consideration of the short-term carrying capacity and assessment of trend in land condition.

GRASP models provide landholders with expected growth values for regional land types in a range of condition classes and tree densities. These pasture growth values are modelled using the median rainfall for climate stations across Queensland. The model uses an annual period from June to May to encompass seasonal growth.

Calculating long-term carrying capacity

Long-term carrying capacity is determined within the property planning process. An aerial photo mosaic or satellite image is printed and used as the basis for planning. Paddocks, infrastructure and land types are drawn onto clear plastic overlay. Paddock areas are calculated and the relative contribution of each land type within a paddock estimated. The condition of each land type within a paddock is also assessed, along with the estimated tree basal area. Using this information the pasture growth look-up tables derived from the GRASP model are used to determine the expected pasture growth for each land type and its respective condition and tree density with median rainfall. The long-term carrying capacity equation is:

Carrying Capacity = Forage Demand ÷ (Pasture Growth × Utilisation Rate)

This calculation is completed for each land type within the paddock and then the area of that land type is divided into the land type carrying capacity to give the number of Adult Equivalents for that land type. The number of Adult Equivalents for each land type is summed to give the paddock long-term carrying capacity.

Short-term carrying capacity

Short-term carrying capacity is the number of animals that a paddock can support for a week, a month, a season or a year. Short-term carrying capacity will deviate from long-term carrying capacity due to the variation in rainfall received. It is a function of pasture on hand (standing dry matter) and the minimum residue required to maintain the site. The premise here is that a certain minimum level of dry matter should always be present on a particular land type to maintain the soil, forage plant vigour, livestock diet quality and ecosystems function. Forage budgeting tools are used to determine short-term carrying capacity. A forage budget does not require a safe utilisation rate; it is a simple balance between available feed and animal demand.

The ***level of use*** can be back calculated from the proportion of dry matter consumed over the given period. The ***level of use*** and the ***rate of utilisation*** are discrete concepts, where the latter is based on pasture growth, rather than standing dry matter. The two are often confused and this poses a problem for researchers and extension staff. In the U.S.A. the term ***harvest efficiency*** has been used in forage budgets to reflect the ***level of use***.

Calculating Short-term carrying capacity

Forage budgeting is about balancing forage demand and forage supply for a given period of time. The forage budget calculates the number of cattle that can be run based on the area of the paddock, the number and class of cattle, the grazing days, the amount of useful available pasture, and the yield required to be standing at the end of the grazing period (residual yield).

The amount of useful pasture is determined by the amount of standing dry matter at the start of the grazing period, minus wastage yield from trampling and natural leaf detachment, minus the yield of unpalatable species, and minus the desired residual yield. Anticipated pasture growth during the grazing period is added to the useful pasture yield to give the total useable pasture yield.

The total pasture consumption per hectare for the grazing period is calculated by multiplying the number of grazing days by the dry matter intake and number of standardised cattle in the paddock. This value is then divided by the paddock area.

The number of days the useable feed will last with the current number of cattle in the paddock is determined by the total usable pasture for the paddock area divided by the dry matter intake for the number of cattle in the paddock. This calculation can be turned around to determine how many standardised animals can be run for the given period of time.

Another useful calculation is the level of pasture use and the amount of feed eaten as a proportion of palatable pasture. The level of pasture use provides you with a “surrogate” (technically incorrect) utilisation rate, and the proportion of palatable pasture eaten can be used as an indicator of diet quality and hence animal performance.

5.4 Results

5.4.1 Stocking history

From January 2003 to June 2006 Top Aires and Blackfellas paddocks received a full wet season spell every second year and was stocked to ensure a minimum residual yield of 400 kg DM/ha at the end of the dry season and 40% ground cover.

Bottom Aires Paddock received a full wet season spell two years in a row and was stocked to ensure a minimum residual yield of 500 kg DM/ha at the end of the dry season and 40% ground cover. Bottom Aires was given a sequential spell and a slightly higher end of dry biomass to speed recovery.

Stud Paddock was set up to receive annual wet season rest, however, due to the paddock being very small and located next to the house yards it was often used as a holding paddock and temporarily used during the wet. For these reasons the report focuses on Top and Bottom Aires and Blackfellas paddocks.

Table 1: Wet season spelling regimes of the demonstration paddocks

	2002-2003 season	2003-2004 season	2004-2005 season	2005-2006 season
Top Aires	wet spell		wet spell	
Bottom Aires		wet spell	wet spell	
Blackfellas		wet spell		wet spell

A simple analysis of the stocking rates over the demonstration paddocks indicates that historical stocking rates of 1:10 acres (1:4 ha) are not appropriate for C condition Goldfield's paddocks. From 2003 to 2006 the stocking rates averaged to 1:25 acres. Given that these were significant drought years, stocking rates of 1:15-20 acres (1:7-9 ha) is likely to be sustainable for C condition Indian Couch dominated Goldfields Country with frequent wet season rest. This is half the traditional stocking rate.

The actual stocking rates imposed and the estimated quantity of standing dry matter (pasture) at the end of the wet season are graphed below for the three large paddocks: Top Aires, Bottom Aires, and Blackfellas. **Table 2** outlines the strategies and wet season rest implemented.

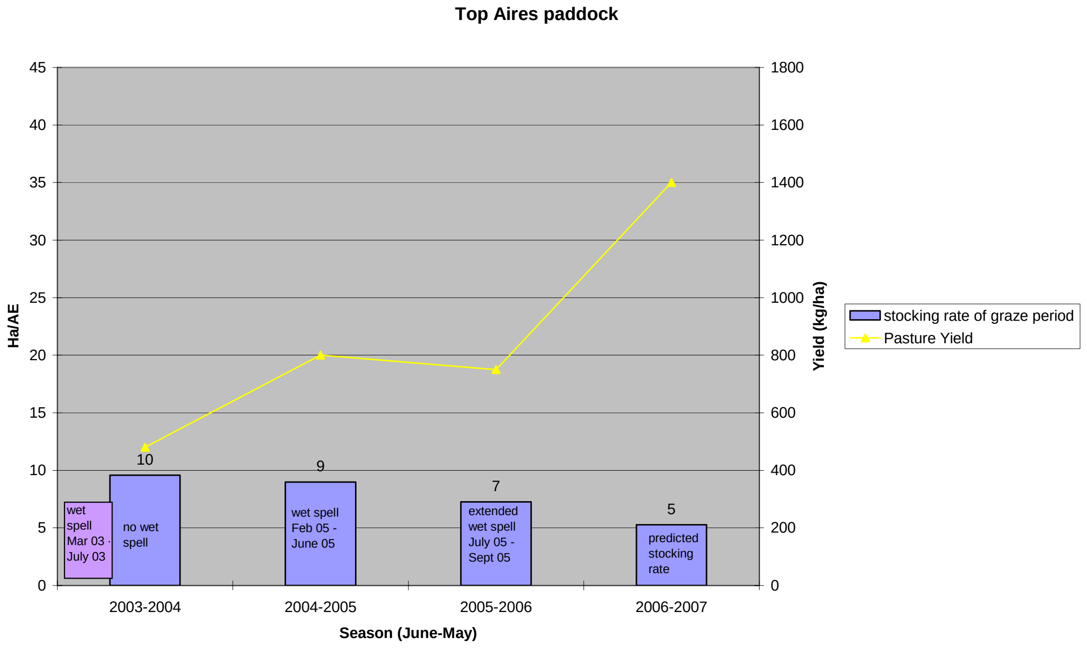


Figure 5: Top Aires Paddock stocking rates and end of wet dry matter yields 2003-2006. This paddock was full wet season spelled in the 2002-2003 and 2004-2005 wet seasons. The stocking rates are for the period when cattle grazed the paddock.

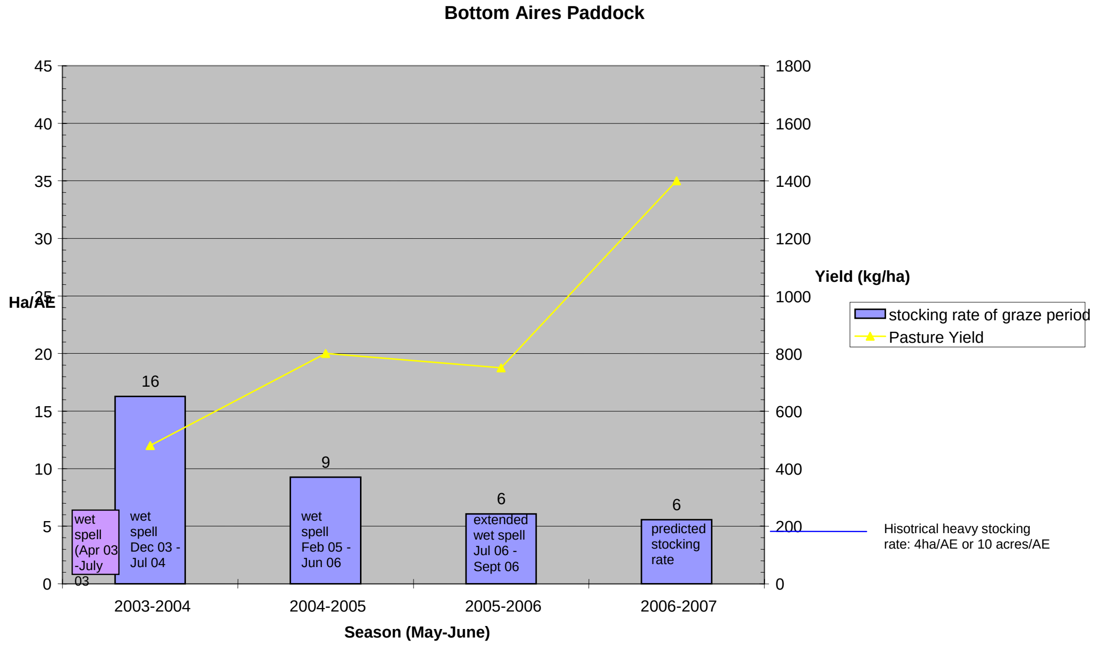


Figure 6: Bottom Aires Paddock stocking rates and end of wet dry matter yields 2003-2006. This paddock was full wet season spelled in the 2003-2004 and 2004-2005 wet seasons. The stocking rates are for the period when cattle grazed the paddock.

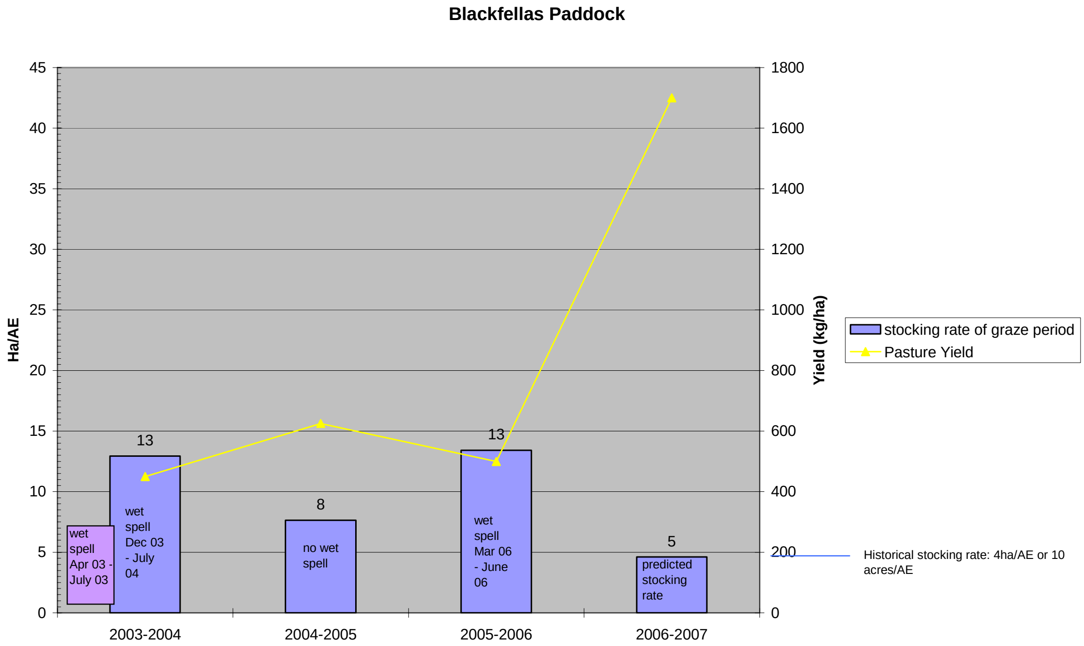


Figure 7: Blackfellas Paddock stocking rates and end of wet dry matter yields 2003-2006. This paddock was full wet season spelled in the 2003-2004 and 2005-2006 wet seasons. The stocking rates are for the period when cattle grazed the paddock.

5.4.2 Wet season rest

Due to the low rainfall conditions and the poor condition of the paddocks, inadequate pasture response was seen after 8 weeks of rest (early wet season spell) for all paddocks. It was obvious from the first wet season spell in 2003 right through to the wet season of 2006, that a full wet season rest was required to initiate a reasonable pasture recovery response in C condition Indian Couch dominated Goldfield's country. Cattle were returned to the rested paddocks once the pasture had seeded and growth had ceased.

Bottom Aires Paddock received its first full wet season rest in 2003-2004. Although visual improvements were seen from the rest, the response in 3P (perennial, palatable, productive) pasture species generation and bulk was small. It was decided that the paddock should be given another full wet season rest in 2004-2005 to stimulate recovery. The paddock responded well to the sequential rest (see Chapter 6).

Table 2: Stocking history of demonstration paddocks at Virginia Park Station

VIRGINIA PARK DEMONSTRATION 2003-2006 SUMMARY

	Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04
Top Aires	biennial early wet spell, 35% utilisation, 185 AE		SPELL	DESTOCK DUE TO DROUGHT			forage budget to achieve 25% use, 83 AE (gates open)					83 AE	83 AE					
Bottom Aires												WET SEASON SPELL EXTENDED UNTIL END OF GROWTH						
Blackfellas	biennial early wet spell, 35% utilisation, 130 AE						forage budget to achieve 25% use, 57 AE											
Stud	annual early wet spell, 50% utilisation, 50 AE		SPELL				forage budget to achieve 25% use, 18 AE											

	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Dec-05
Top Aires	Forage budget July 04 to Jan 05, 35% use, min 400kg/ha, 62 AE						62 AE	WET SEASON SPELL EXTENDED UNTIL END OF GROWTH							Forage budget September 05 to May 06, 35% use, min 400kg/ha, 80 AE			
Bottom Aires	Forage budget July 04 to Jan 05, 35% use, min 500kg/ha, 72AE						72 AE								Forage budget September 05 to May 06, 35% use, min 500kg/ha, 110 AE			
Blackfellas	Forage budget July 04 to May 05, 35% use, min 400kg/ha, 62 AE						62 AE					Forage Budget June 05 to Feb 06, 35% use, min 400kg/ha, 55 AE						
Stud	Forage budget July 04 to Feb 05, 25% use, min 400kg/ha, 25 AE						25 AE	WET SEASON SPELL EXTENDED UNTIL END OF GROWTH							Forage budget September 05 to May 06, 35% use, min 400kg/ha, 46 AE			

	Jan-06	Feb-06	Mar-06	Apr-06	May-06	Jun-06
Top Aires	80 AE					
Bottom Aires	110 AE					
Blackfellas	55 AE	WET SEASON SPELL				
Stud	46 AE					

5.4.3 Forage budgeting

The forage budgeting worked well despite such small dry matter yields. From 2003 to 2006 the minimum residual yield was set at 400kg DM/ha and 500 kg DM/ha. In these years there was as little as 600 kg DM/ha of standing feed at the end of the wet season. In May 2006 the dry matter yields increased to up to 1700kg DM/ha. Had the demonstration continued for another season the minimum residual yields would have been set to as high as 800kg DM/ha.

CSIRO conducted paddock yield assessments at the end of the wet season which increased the accuracy of the budgets. In most years we did not manage to achieve the desired use percentage of 35% on paper (forage budget) due to the very low available forage. The measured defoliation scores were quite high (~60%) though, and this could have been due to the dry conditions and the impact of trampling. It is difficult to know how the defoliation scores equated to pasture use.

The biophysical evidence shows that the trend in land condition is improving from C to B as a result of the wet season spelling and the conservative grazing regime. It would be fair to conclude that the stocking rates imposed (calculated using the forage budget) have contributed to the positive shift in land condition.

5.4.4 Implementation issues at the property scale

Resting the paddocks during the run of drought years was difficult due to the shortage of pasture across the entire property. This was exacerbated in 2003 when a plague of army worms stripped the pasture of leaf. The failure of Indian Couch to tolerate drought conditions resulted in an unplanned increase in grazing pressure and very low end of dry season forage yields and ground cover in 2003. Ironically, data indicates that the collapse of Indian Couch, coupled with wet season spelling and moderate utilisation rates has favoured the recovery of 3P grasses.

The requirement to spell the demonstration paddocks did put pressure on other paddocks within the property, despite placing 200 head on agistment. At this time, the stocking rate on the four paddocks was effectively reduced by two thirds. Additional agistment was found for a further 250 head in 2003-2004 for a period of 12 months. This was initiated when the project team decided to de-stock all four paddocks for a period of three months. The additional agistment eased pressure on the property.

Properties that are consistently over stocked and do not have a ‘spare’ paddock will have difficulty implementing wet season spelling strategies. Even intensive grazing systems require paddocks to be stocked to safe carrying capacity.

The provision of adequate water can also be a barrier to implementing wet season rest. Due to the dry conditions, surface water for cattle failed to last the whole season in Top Aires paddock in 2003 and 2004. As a result, the gate between Top and Bottom Aires paddocks was opened to allow cattle to water in Bottom Aires. The additional grazing pressure during the 2003 and 2004 dry season in Bottom Aires paddock may have contributed to the inadequate response from the wet season rest over the 2003/2004 wet. In 2005, an additional watering point was installed in Top Aires to overcome this problem.

Additional mustering was required to remove cattle from the paddocks as soon after the first rains as practical. The owners chose to do this over taking cattle out at the second round muster in October/November. Cattle were placed back into the paddocks in May at the first round muster.

Dry matter yield, pasture species assessment and forage budgeting was taught to the owners of the property. The owners learnt a lot from this; however professional rangeland technical officers assessed yield on a 200m grid basis using ATVs and motorbikes. The variability of pasture yield within paddocks was considerable. It may be difficult for graziers to capture this variation when assessing these yields at strategic places within a paddock using photo standards. Understanding the spatial and temporal variability of pasture yield and land condition recovery, and observing the key indicators of change are important for implementing appropriate management strategies for optimising recovery.

5.5 Implications for implementation in the real world

5.5.1 Planning wet season spelling systems

Improved grazing management can only occur by optimising land condition, evenness of use and diet quality. A successful grazing system will manage utilisation well, i.e. carrying capacity and the timing of spelling; reduce uneven grazing that is either wasteful or environmentally harmful; and will match stocking rate to the diet quality required for the animal production targets. Below are a set of steps to consider when developing a grazing strategy.

1. Inventory and analyse the current situation
   - Map land types, infrastructure, waters
   - Calculate paddock areas and land type contribution
   - Assess land condition on a land type basis for each paddock
   - Record current stocking rates and grazing systems
   - Estimate long-term carrying capacity for each paddock
   - Record natural resource and herd management issues (nutrition, genetics & health)

2. Identify opportunities to improve land condition, evenness of use and diet quality
   - Record ideas for improvement on a paddock basis
   - Refer to the inventory and analysis of the current situation

3. Select those options worthy of further evaluation
   - List all options and rate for ease and impact
   - Prioritise options
   - Select priority options for financial analysis

4. Assess the profitability and affordability of priority options
   - Simple cost-benefit analysis
   - Herd analysis using Breedcow & Dynama Software
   - Seek expert advice on positive and negative expected herd and environmental outcomes from options

5. Plan the implementation of the option
   - Grazing system design including animal movements, frequency and duration of rest, mustering, infrastructure, animal turn-off, markets, supplementation, breeder management, water supply, seasons and drought strategies.
   - Skills and tools required to successfully implement option: pasture yield photo standards, land condition assessment, forage budgets, phases of pasture growth, ground cover photo standards, key recovery and degradation indicators and a monitoring package.
   - Labour to run the system and family lifestyle

6. Establish a monitoring and recording system
    - Monitor to determine trend in land condition and animal production (using indicators of recovery and degradation as a guide)
    - Monitor to establish sustainable stocking rates for grazing system
    - Monitor to determine profitability of the system

7. Implementation
    - Consider timing of implementation
    - Flexibility and drought strategies

8. Revise Grazing Strategy
    - Assess monitoring results and revise system accordingly

5.5.2 Assessing the financial implications of recovering C condition land

To explore the financial implications of management attempts to recover poor condition land through regular wet season resting a typical property of the Goldfields area was modelled based on the experiences from the demonstration. The models were populated using data and expert opinion of DPI&F Beef Research and Extension staff and CSIRO Sustainable Ecosystems (**Table 3**). The model property is 28,000 hectares in size and turns off 18 -24 month old steers. The carrying capacity in B condition is 2500 AE. Approximately 50% of the breeder paddocks are assumed to have deteriorated to C+/C land condition.

A model scenario was created to represent an improvement from poor condition (C+/C) to fair condition (B) as a result of a wet season spelling strategy for the 50% of the land that was assumed to have degraded. Another scenario was created to represent a decline from poor condition (C+/C) to very poor (C-/D+) on this same set of paddocks. The model simulations were run over a twenty year period, and a range of economic measures recorded including total gross margins, gross margin per hectare and gross margin per adult equivalent. The full economic impact of the strategy is measured as the differences between the first model scenario (seek improvement) and the second model scenario (do nothing). The differences for each gross margin measure over the 20 year simulation runs have been converted to a net present value (NPV) by discounting using rates of 5% and 10%, respectively, to represent different cases where landholders' time preferences for returns may be less or more impacted by their circumstances.

The improving condition scenario is based on the wet season spelling system outlined in **Table 4**. This is a four paddock system, where three breeder paddocks and one spare paddock are brought into a rotation. The three paddocks represent 50% of the breeder paddocks on the property and are in C+/C condition. The spare paddock can be rotated within the remaining paddocks on the property. To allow this system to operate, breeders from spelled paddocks are relocated to steer paddocks for the relevant wet season and the steers form those paddocks are agisted for 180 days and sold direct ex-agistment. The agistment scenario involves 100 steers in each of the first six years only.

Each paddock receives two successive full wet season spells, is grazed through the following wet season, is given another two successive wet season spells, and is then rested every three years. A 33% recovery by year 8, 66% recovery by year 9 and 100% recovery by year 10 is expected. B condition is maintained from year 10 to 20. The model assumes that paddocks are stocked according to available dry matter, and this is reflected in the carrying capacities outlined in **Table 3**.

The wet season spelling system design is based on the results from the project's demonstration paddocks. It was deemed that two full wet season spells in a row resulted in a positive shift from C to B land condition. The actual stocking rates and wet season spelling frequency imposed on the demonstration paddocks can be found in **Figure 5**, **Figure 6**, and **Figure 7**.

The total gross margin (TGM) for the 28000 ha property at the start of the runs is estimated to be $171,352, while the corresponding estimates of gross margin per ha (GM/ha) and per adult equivalent (GM/AE) are $6.12 and $97.82. The 20 year profile of the TGM estimates for both the improving and deteriorating scenarios is presented in **Table 5**. Each row of the table is the estimate at the end of the particular run year. The TGM estimates indicate that it would take six years for the wet season spelling system to return a TGM that is higher than that of the starting state. However, because the pastures are also assumed to continue to deteriorate under the "do nothing" scenario, the spelling option would actually be outperforming the alternative "do nothing" strategy after only 2 years.

From this point the TGM continues to increase in each year until the full response of the wet season spelling system (B condition) is reached in year 10. From this point forward until year 20, the TGM is maintained. The net present value (NPV) of the spelling option which is measured as the cumulative 20 year differences in total gross margin of the improvement vs. declining scenario is $2,468,528 and $1,369,106 when the respective 5% and 10% discount rates are applied. The positive NPV at either discount rate suggests that the option is economically attractive.

The gross margin per hectare (GM/Ha) and gross margin per adult equivalent (GM/AE) estimates are presented in **Table 6** and **Table 7**. These estimates generally mirror the TGM values in **Table 3**, from which they are derived. The GM/Ha values for the wet season spelling strategy improves from the baseline value of $6.12 to $13.21 by year 10 when the system has stabilised at productivity levels consistent with land condition B. Over the same time period the declining condition or 'do nothing' scenario deteriorates to a very low value of $0.41. The NPV of the 20 year differences is $88.16 and $48.90 respectively at the 5% and 10% discount rates used to calculated these measures.

The GM/AE values also increase steadily over the 20 year simulation period for the wet season spelling strategy, from the base level of $97.82 to $146.04 by year 10. The "do nothing" scenario, on the other hand, continues to decline to $13.52 once the land condition has reached the less productive land condition C-/D+. While the difference in the TGM and GM/Ha estimates between the wet season spelling scenarios and the "do nothing" scenario has become positive by the end of the 3rd year of the simulation run, the GM/AE remains negative for one additional year. This result is due to rapid fall in estimated carrying capacity on the deteriorating C- land still offsetting the more modest gain in carrying capacity for improving land condition and its concurrent general improvement in animal performance. From the end of the 4th year on, difference in the GM/AE is positive in all years with an estimated NPV of $88.16 and $48.90 for the 5% and 10% discount rates respectively.

Table 3: Enterprise scenario data

Goldfield's Property	**Land condition**		
	B	**C+/C**	**C-/D+**
Property area (hectares)	28,000	28,000	28,000
Carrying capacity (AE)	2500	1800	900
Breeders (AE)	1400	1000	500
Av. breeder Mortality %	3	4	5
Bull/breeder ratio (%)	4	4	4
Age at first mating	1.5	1.5	1.5
Branding rate 1.5 years (%)	50	45	35
Branding rate 2.5 years (%)	55	50	45
Branding rate 3.5+ (%)	70	65	60
Av. steer mortality (%)	2	2	3
Months in herd -steers (months)	12	12	12
Selling prices ($/kg liveweight basis)			
Steers - export ox ($)	1.85	1.75	1.65
Steers - stores ($)	1.9	1.8	1.75
Weaner steers -stores ($)	1.9	1.8	1.75
Domestic cow -cull ($)	1.7	1.6	1.5
Domestic young heifer ($)	1.8	1.7	1.6
US cow beef - cows CFA ($)	1.6	1.5	1.4
US cow beef - cull ($)	1.6	1.5	1.4
US beef - bulls cull ($)	1.5	1.4	1.4
Weaning weights (kg liveweight basis)			
weaning weight - steers (kg liveweight)	150	130	120
weaning weight - young heifers (kg liveweight)	150	130	120
Sale weights (kg liveweight basis)			
sale weight -steers (kg liveweight)	320	270	250
sale weight -young heifers (kg liveweight)	280	260	240
sale weight -cows CFA (kg liveweight)	500	470	450
sale weight -cows cull (kg liveweight)	460	410	390
sale weight -bulls cull (kg liveweight)	700	675	665
Sale value ($)			
sale value -weaner steers	285	234	210
sale value -steers (export ox)	592	472.5	412.5
sale value -steers (stores)	608	486	437.5
sale value -young heifers	504	442	384
sale value -CFA cow	800	705	630
sale value -cull cow	736	615	546
sale value -dom cow	782	656	585
sale value -bulls cull	1050	945	931
bull purchase price (head)	2000	2000	2000

Supplements			
	B	**C+/C**	**C-/D+**
Ration 1 - M8U (days fed)			
Weaners	90	90	0
Breeders	120	120	210
Heifers	180	180	0
Ration 1 - M8U (kg/mix/day)			
Weaners	1	1	1
Breeders	2	2	3.5
Heifers	1.5	1.5	0
Ration 1 - M8U cost/head/day			
Weaners	0.15	0.15	0.15
Breeders	0.3	0.3	0.3
Heifers	0.23	0.23	0.23
Ration 2 - M3UP (days fed)			
Weaners	120	120	210
Heifers	0	0	180
Ration 2 - M3UP (kg/mix/day)			
Weaners	1	1	1
Heifers	0	0	4
Ration 2 - M3UP cost/head/day			
Weaners	0.16	0.16	0.16
Heifers	0	0	0.64
DRY LICK days fed (200g/day)			
steers	120	120	210
DRY LICK cost/head/year	8.4	8.4	14.7
steers			
Wet season P supplementation days fed (kynofos/salt 5:1)			
Steers	120	120	120
Weaners	120	120	120
Breeders	120	120	120
Heifers	120	120	120

Major assumptions

Land in C+/C and C-/D+ condition will have pasture available (approximately 500 kgDM/ha) in the late dry season due to a reduction in carrying capacity in line with the land condition state. Therefore, we have not invoked a substitute feeding program. Cattle grazing C-/D+ condition land have increased intake rates, a poorer quality diet, and increased feeding durations.

Cattle in C and D land are penalised by weight, price, fertility and mortality

Table 4: Wet season spelling scenario

		Paddock 1	Paddock 2	Paddock 3	Spare Paddock
Year 1	Wet season (Nov-Apr)	REST	GRAZE	GRAZE	GRAZE
Year 2	Wet season (Nov-Apr)	REST	REST	GRAZE	GRAZE
Year 3	Wet season (Nov-Apr)	GRAZE	REST	REST	GRAZE
Year 4	Wet season (Nov-Apr)	REST	GRAZE	REST	GRAZE
Year 5	Wet season (Nov-Apr)	REST	REST	GRAZE	GRAZE
Year 6	Wet season (Nov-Apr)	GRAZE	REST	REST	GRAZE
Year 7	Wet season (Nov-Apr)	REST	GRAZE	REST	GRAZE
Year 8	Wet season (Nov-Apr)	GRAZE	REST	GRAZE	GRAZE
Year 9	Wet season (Nov-Apr)	GRAZE	GRAZE	REST	GRAZE
Year 10	Wet season (Nov-Apr)	REST	GRAZE	GRAZE	GRAZE
Year 11	Wet season (Nov-Apr)	GRAZE	REST	GRAZE	GRAZE
Year 12	Wet season (Nov-Apr)	GRAZE	GRAZE	REST	GRAZE
Year 13	Wet season (Nov-Apr)	GRAZE	GRAZE	GRAZE	SPARE
Year 14	Wet season (Nov-Apr)	REST	GRAZE	GRAZE	GRAZE
Year 15	Wet season (Nov-Apr)	GRAZE	REST	GRAZE	GRAZE
Year 16	Wet season (Nov-Apr)	GRAZE	GRAZE	REST	GRAZE
Year 17	Wet season (Nov-Apr)	GRAZE	GRAZE	GRAZE	SPARE
Year 18	Wet season (Nov-Apr)	REST	GRAZE	GRAZE	GRAZE
Year 19	Wet season (Nov-Apr)	GRAZE	REST	GRAZE	GRAZE
Year 20	Wet season (Nov-Apr)	GRAZE	GRAZE	REST	GRAZE

Table 5: Total gross margin (TGM)

TGM ($)		Improving	Deteriorating	Difference	NPV
		$127,943	$171,352		$2,468,528
	1	$127,943	$171,352	-$43,409	$1,369,106
	2	$134,978	$148,206	-$13,228	
	3	$142,815	$126,585	$16,229	
	4	$150,774	$106,778	$43,996	
	5	$159,309	$86,620	$72,689	
	6	$167,990	$69,145	$98,846	
	7	$218,976	$53,232	$165,743	
	8	$227,929	$37,070	$190,858	
	9	$293,949	$23,550	$270,399	
	10	$369,913	$11,391	$358,522	
	11	$369,913	$11,391	$358,522	
	12	$369,913	$11,391	$358,522	
	13	$369,913	$11,391	$358,522	
	14	$369,913	$11,391	$358,522	
	15	$369,913	$11,391	$358,522	
	16	$369,913	$11,391	$358,522	
	17	$369,913	$11,391	$358,522	
	18	$369,913	$11,391	$358,522	
	19	$369,913	$11,391	$358,522	
	20	$369,913	$11,391	$358,522	

Table 6: Total gross margin per hectare (TGM/ha)

TGM/HA		Improving	Deteriorating	Difference	NPV
		$4.57	$6.12		$88.16
	1	$4.57	$6.12	-$1.55	$48.90
	2	$4.82	$5.29	-$0.47	
	3	$5.10	$4.52	$0.58	
	4	$5.38	$3.81	$1.57	
	5	$5.69	$3.09	$2.60	
	6	$6.00	$2.47	$3.53	
	7	$7.82	$1.90	$5.92	
	8	$8.14	$1.32	$6.82	
	9	$10.50	$0.84	$9.66	
	10	$13.21	$0.41	$12.80	
	11	$13.21	$0.41	$12.80	
	12	$13.21	$0.41	$12.80	
	13	$13.21	$0.41	$12.80	
	14	$13.21	$0.41	$12.80	
	15	$13.21	$0.41	$12.80	
	16	$13.21	$0.41	$12.80	
	17	$13.21	$0.41	$12.80	
	18	$13.21	$0.41	$12.80	
	19	$13.21	$0.41	$12.80	
	20	$13.21	$0.41	$12.80	

Table 7: Total gross margin per adult equivalent (TGM/AE)

TGM/AE		Improving	Deteriorating	Difference	NPV
		$73.04	$97.82		$879.49
	1	$73.04	$97.82	-$24.78	$475.70
	2	$75.50	$89.98	-$14.48	
	3	$78.30	$82.01	-$3.72	
	4	$81.05	$74.12	$6.93	
	5	$83.99	$64.70	$19.29	
	6	$86.89	$55.86	$31.03	
	7	$111.16	$46.79	$64.36	
	8	$113.58	$35.70	$77.88	
	9	$129.66	$25.05	$104.60	
	10	$146.04	$13.52	$132.52	
	11	$146.04	$13.52	$132.52	
	12	$146.04	$13.52	$132.52	
	13	$146.04	$13.52	$132.52	
	14	$146.04	$13.52	$132.52	
	15	$146.04	$13.52	$132.52	
	16	$146.04	$13.52	$132.52	
	17	$146.04	$13.52	$132.52	
	18	$146.04	$13.52	$132.52	
	19	$146.04	$13.52	$132.52	
	20	$146.04	$13.52	$132.52	

5.6 Discussion

Wet season rest is an essential part of any successful grazing system. Increasing the duration and frequency of wet season rest is the key to recovering land in poor condition. The actual implementation of wet season rest can be difficult for grazing enterprises and this seems to be particularly apparent for properties that are continually over-stocked or are small in size or are on the boundary of being a viable business.

The challenge for agencies, R&D corporations and industry bodies is to assist producers to make the first step toward a grazing system that incorporates rest. Education programmes provide understanding and justification for implementation; however, mechanisms are needed to assist producers to tailor these concepts into their own unique situation and in a holistic manner. Wet season rest improves the nutrition of the pasture, which is fundamental to improving reproduction rates, growth rates and death rates. A concerted effort is required to integrate R&D recommendations for beef businesses.

5.7 Recommendations

- Determine the best ways to incorporate wet and dry season rest into commercial enterprises to improve land condition and animal performance.
- Design and/or improve current grazing systems to fully integrate cattle and land management recommended practices (increase the ease of implementation).
- Identify end of dry season cover and pasture yield thresholds for all major land types and condition classes.
- Continue testing wet season spelling strategies on commercial properties to determine the length of time to recover land between condition classes.
- Support an extension program to teach graziers how to assess forage yield and calculate forage budgets.

6 Impact of grazing strategies on land condition, patchiness and landscape function

6.1 Key Messages

This section of the report outlines some of major research findings relating to the drivers of spatial grazing patterns and relationship between grazing preference, impacts, land condition and landscape function. In doing so it contributes to the overall project objectives outlined in Section 3 of this report, in particular to objective (3), but also to objective (1), (4) and (5). The overall objective of component B (as outlined in the original contract document) was to *develop quantitative linkages between processes that determine the location, magnitude, and consequences of grazing impacts on landscape function, by conducting measurements of relevant landscape attributes, across a range of scales at selected locations*. Some of the key findings relating to these objectives are outlined under the following headings:

Monitoring the impact of ECOGRAZE strategies at Virginia Park – the interaction of land condition, grazing preference, utilisation and spelling on recovery trends and patterns.

- Results from the Virginia Park paddock study show that discernable recovery can be achieved on C condition Indian couch dominant goldfields land, even through a drought period. This compliments the findings of the earlier ECOGRAZE project and further supports the contention of Ash *et al* (2001) that management, rather than climate, is the key driver of long term land condition.

- However, recovery of C-condition Indian couch-dominant land is likely to be slower and patchier than that achieved in the ECOGRAZE study, mainly due to the lower levels of 3P grass basal area and root reserves, stored soil organic matter and nutrients, all of which influence rainfall infiltration and plant growth.

- Topographic location, land type and landscape position all contribute to small scale variability in spatial and temporal response patterns to grazing management strategies. Ground cover is generally higher closer to drainage lines, tree canopies and down-slope areas (except for lower slope sodic land types), with the common driver being the ability to trap and retain resources.

- In recovering paddocks, cattle have a strong selection preference for C and some D condition patches, with C condition patches being twice as likely to be heavily grazed, than adjacent B condition areas. Continued selection preference for C condition patches, especially those with remnant 3P grass populations, exacerbates within-patch variability and soil surface instability which further impedes patch recovery and restoration of connectivity between patches.

- When these factors coincide with identified seasonal selective use of vulnerable landscapes such as lower slope sodic or frontage areas, significant localised degradation can continue even when average paddock condition is improving.

- Whilst lower utilisation rates will contribute to increased biomass and cover levels, wet season spelling is essential to protect recovering 3P grass plants in C condition patches from selective wet season grazing. Experience from Virginia Park indicates that whole of wet season spells are required to stimulate recovery of 3P grasses in couch dominated pastures, with consecutive spells being beneficial in early years of recovery.

- Infiltration and soil biological activity are strongly influenced by the level of ground cover and the proportion of litter contribution present. The amount and distribution of cover is also a critical determinant of run-off, sediment and nutrient movement within and from hillslopes. Retention of adequate end of dry season cover and standing dry pasture will protect soil surface from early storms, improve infiltration, slow run-off and provide the litter resources necessary to improve soil biological function and nutrient cycling. This will encourage recovery of 3P grasses – an essential step in improving land condition.

- To help shift land from C to B condition aim for end of dry ground cover and standing dry pasture retention thresholds approaching those normally associated with B condition for that land type. For Indian couch dominated goldfields and sedimentary country this translates to at least 60% ground cover and 800kg/ha standing dry pasture at the end of the dry season. Experience at Virginia Park suggests that such targets might not be achievable on C condition Indian couch paddocks in the early in the early stages of recovery, especially following drought. However they should form part of long term recovery management objectives and strategies.

- Spatial and temporal variability in recovery patterns and processes in C condition Indian couch dominant landscapes requires management strategies which are flexible and take account of within-paddock variability in land condition response. To optimise paddock recovery, managing for the proportion of C condition land present in a paddock is preferable to managing for “average” paddock condition.

- Recovering paddocks remain fragile and vulnerable to renewed decline in land condition for some time, even though “average” cover and biomass may have improved significantly. This is because of the often uneven distribution of plant cover and associated reserves of nutrients and organic matter. Premature return to higher stocking rates risks re-exposing leakiness pathways, leading to renewed loss of sediment and nutrients.

- Managing to optimise sustainable recovery and productivity in C condition paddocks may also require more complex management strategies to balance utilisation targets, end of dry cover and pasture reserve targets and wet season spelling requirements and protection of vulnerable land types to optimise recovery and productivity. Increased hands-on knowledge of the key patch scale indicators of land condition decline and recovery trends and the use of forage budgeting will aid this process. An alternative approach might be to opt for an even more conservative set of utilisation, spelling and end of dry cover and pasture retention strategies to optimise recovery, than that recommended in this report.

Establishing quantitative links between key descriptors of land condition and measured attributes of landscape and hydrological function at a range of scales.

- Robust relationships between patch structure and function were developed for a range of key patch condition classes on the crusting soil types of the upper Burdekin, using the PATCHKEY framework. These have been used to provide underpinning values for ABCD land condition classes and help develop or refine predictive models such as the LISEM hillslope delivery model (Kinsey-Henderson *et al*., 2006), Savanna AU model (Bartley et, al, 2005, Liedloff *et al*., 2005) and .the landscape leakiness (LI) index calculator (Ludwig *et al*, 2005).
- PATCHKEY has also provided a spatially relevant means of quantifying ABCD land condition categories in terms of the size and distribution of key patch types. This provides a useful tool for ground based monitoring of condition trends, which can also link well with and assist refinement of existing remote sensed cover and landscape leakiness classification systems.

6.2 Introduction

This section of the report presents findings relating to the patterns and processes of recovery in land condition and landscape function in response to application of ECOGRAZE sustainable grazing strategies on study paddocks at Virginia Park Station from 2002 to 2006 and their implications for future management recommendations. It also outlines some of the major research findings relating to the drivers of spatial grazing patterns and relationship between grazing preference, impacts, land condition and landscape function at a range of scales from patch to paddock. In doing so, it contributes to the overall project objectives outlined in Section 3 of this report, in particular to objective (3), but also to objective (1), (4) and (5).

The overall objective of component B (as outlined in the original contract document) was to *develop quantitative linkages between processes that determine the location, magnitude, and consequences of grazing impacts on landscape function, by conducting measurements of relevant landscape attributes, across a range of scales at selected locations*. Specific objectives were to:-

1. Verify and refine our ability to forecast the spatial distribution of grazing impacts at paddock scales.
2. Develop a predictive understanding of patch formation and structure at hill-slope scale.
3. Describe small-scale attributes of grazing impacts on sites and in vegetation communities most important to generation of runoff, and link these attributes to hydrological function at the scale of rainfall simulations and runoff troughs.

Change in Component B objectives and milestones

Objectives, outputs and milestones relating to development of a predictive model linking paddock scale spatial grazing patterns with hydrological impacts were subsequently replaced with the following in December 2003, by agreement with MLA

Develop a conceptual model of the relationships between patch characteristics such as sediment run off and livestock preference at the paddock scale. This model will be a patch classification scheme based on vegetation cover and soil surface characteristics and linked to the QDPI&F ABCD land condition characterisation. The classification scheme will be field tested at the Wambiana and Virginia Park field sites to assess the relationship with water infiltration and run-off and animal grazing preference).

The main reasons for this change were:-

- The short term nature of the project which limited opportunities to monitor long term paddock scale impacts of contemporary grazing patterns at a range of sites, especially during a drought.
- The results of initial work on predictive grazing model development, which indicated poor or inconsistent relationships between observed contemporary grazing patterns and factors such as land type, topography or vegetation structure.
- Indications from initial studies that patch scale processes and interactions were the key drivers of land condition and hydrological function.

6.3 Methods

This section is divided into the following sub-headings which address both the overall project objectives 3, 1, 4 and 5 and the revised component objectives:

- Measuring the response to ECOGRAZE strategies implemented at Virginia Park
- Understanding and predicting relationships between grazing patterns, drivers and impacts
- Linking land condition to landscape function for prediction of hydrological impacts

6.3.1 Measuring responses to ECOGRAZE strategies at Virginia Park

The four paddocks involved in the sustainable grazing management study (see section 5 above) at Virginia Park Station were surveyed twice yearly to monitor spatial and temporal responses to ECOGRAZE derived strategies (including wet season spelling and conservative utilisation rates) in terms of key pasture and land condition metrics. A full description of the paddock layout, stocking history, and sustainable grazing strategies implemented can be found section 5 of this report.

Paddock scale surveys were conducted at end of wet (EOW) and end of dry (EOD) season on a regular 400m *100m grid in each study paddock, with pasture and soil condition data derived from a 2m*2m virtual quadrat located and recorded by GPS each time. In the first year, only Top and Bottom Aires and Blackfellas paddocks were included with Stud paddock being added in 2004, once it was included in the sustainable management study for Virginia Park. Pasture condition metrics such as main species and/or functional group composition, biomass, ground cover, basal area class, defoliation level and key soil surface condition (SSC) metrics such as erosion/deposition status, litter contribution and soil hardness were recorded using relevant BOTANAL (Tothill *et al*, 1978), Landscape Function Analysis (LFA) (Tongway and Hindley, 1996) and related visual estimation techniques. Information on vegetation/land type, landscape location, tree canopy cover was also recorded within a 10m radius from each sampling point.

Data from these monitoring surveys was used to assess both initial whole of paddock and within-paddock (land type/ location) land condition status and track land condition and grazing utilisation responses to imposed management regimes over the lifetime of the study. The use of a GPS located grid also provided the opportunity to explore spatially explicit patterns of response and to link ground based data to high resolution satellite imagery for refinement of landscape leakiness and other emerging remote sensed applications.

In addition to paddock scale monitoring, the hillslopes associated with the three flume catchments were monitored at the end of each dry season to provide detailed, spatially explicit data on land condition and landscape function to link with whole of flume catchment hydrological responses measured over the following wet season. A notional 4m*4m grid was established over the whole of each flume catchment, with data collected from within a 1m quadrat at each grid point. An adaptive sampling method was used, whereby additional quadrats were also sampled at patch boundaries to help define patches. This grid was later reduced to 8m*4m following initial data analysis, though data on patch boundaries was still recorded. Similar pasture condition, soil condition and vegetation/land type metrics were recorded to those at paddock scale, for the initial and final surveys, while a subset of these metrics, specifically ground cover, litter cover, biomass and patch condition were recorded at end of dry season surveys in intervening years.

Data from these hillslope grid surveys was used to track whole of hillslope and within-hillslope responses to imposed management regimes at a much finer scale and relate this to hydrological responses measured on each flume. This fine scale grid data also provided opportunities to map changes in size and distribution of key patches over time and relate this to both overall land condition and hydrological function.

The need to identify and classify key patch types within these hillslopes for the purpose of mapping and tracking small-scale patterns of land condition and linking this to hydrological function, led to the development of the PATCHKEY conceptual patch classification framework (see sections 6.2.2 and 6.3 of this report)

Within the main flume catchment (flume 1, see section 7), a series of Landscape Function Analysis (LFA) transects was also established, at various hillslope locations, at the commencement of the study, to monitor the response of key patch types and associated transition zones to imposed grazing management regimes over the lifetime of the study. LFA transects ranged in length from 10 to 30m depending on patch size. A full array of LFA measurements (Tongway and Hindley, 1995) were recorded at the end of each dry season (EOD) to monitor changes in size of patches and within-patch land and soil surface condition and landscape function. These transects were also used to calibrate PATCHKEY patch classification (see below for a description of the development of the PATCHKEY framework) data recorded from hillslope and paddock grid surveys.

A full description of sampling design, techniques and measurements used to monitor paddock and hillslope responses to imposed ECOGRAZE grazing management strategies can be found in appendix 14 of this report.

6.3.2 Understanding and predicting relationships between grazing patterns, drivers and impacts

Paddock scale grazing distribution studies from the previous MLA supported Burdekin Catchment project *Reducing sediment export from the Burdekin catchment project NAP3.224* (Roth *et al*, 2003) indicated, that whilst there was some association between land type and grazing preference in some seasons, by far the most consistent paddock scale drivers of grazing patterns were distance from water and fences and recent burning history, with the distance from water impacts being limited to <300m from water points. Despite the significant loss of spatial modelling skills with the departure of Dr. John Gross in mid 2003, his prototype grazing distribution model was subsequently field tested on a range of commercial paddocks in the upper Burdekin catchment through 2004 and 2005 in fulfilment of the original component B objectives. The aim was to test and verify the original model predictions and explore in more detail the interactions between some of the edaphic and non-edaphic factors which might influence seasonal grazing patterns and preferences at a range of scales. A total of 10 paddocks were involved in the grazing distribution study, comprising 6 commercial paddocks from 5 properties plus the 4 paddocks already involved in the Virginia Park ECOGRAZE study. **Table 8** provides details of the properties and paddocks surveyed.

Table 8: Details of paddocks used for grazing distribution study 2004-05

Property	Paddock	Land Type	Size (ha)	Long-term utilisation	ABCD Condition
Hillgrove	Plain	Basalt	2066	low	A-/B+
Hillgrove	Halers	sedimentary	2658	low-medium	B
Blue Range	Springs	sedimentary	3690	low-medium	B+
Trafalgar	Rocky	Canazoic	1273	medium	C+
Cameron Downs	Spring Creek	grano-diorite	1793	Medium-high	C+
Kirkland Downs	Boon Boon	Canazoic/sedim	1584	high	C-
Virginia Park	Top Aires	grano-diorite	580	high	C
Virginia Park	Bottom Aires	grano-diorite	667	high	C-
Virginia Park	Blackfellas	grano-diorite		medium-high	C+
Virginia Park	Stud	grano-diorite	506	medium-high	C+

Both randomly located paddock non-aligned transects with fixed quadrat positions and specific distance from water transects with variable sampling point distances were used to explore relationships between elements such as land type, soil type, vegetation community, tree/shrub density and canopy cover, distance from water and fences; land condition elements such as pasture composition and biomass, ground cover, erosion status; and grazing intensity / preference / distribution, using contemporary defoliation ratings (Andrew, 1986) as the main indicator.

Development and application of the PATCHKEY patch classification system

Re-examination of land condition data from grazing distribution, preference and impacts studies conducted during *NAP3.224* (Roth *et al*, 2003) using the relative selectivity method of Jacobs (1974) indicated that there was a strong relationship between pre-existing erosion status and contemporary grazing preference (**Figure 8**).

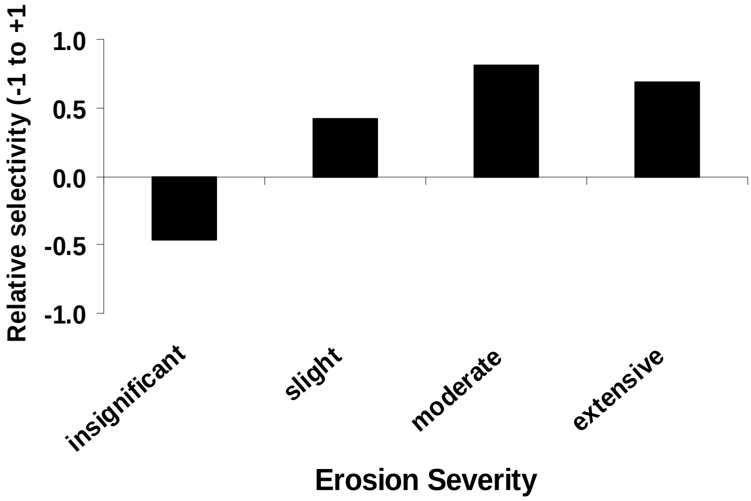


Figure 8: Relationship between erosion status and relative grazing selection preference, derived from NAP3.224 grazing distribution study paddock data collected at Virginia Park, Fanning River and Fletchervale stations, 1999-2001. Relative selectivity is expressed on a scale of -1 to +1 with positive values indicating relative selection in a higher proportion that relative abundance and negative values indicating relative selection in a lower proportion than relative abundance.

Previous work by Andrew (1986) also indicated that grazing selectivity begins at the patch scale and that, in the absence of fire impacts, stock will continue to re-graze already established grazed patches, hastening localised degradation and soil surface erosion in those patches. As bare ground and erosion status are key indicators of land condition within the DPI&F's ABCD land condition framework (Chilcott et al, 2003) the patch classification framework PATCHKEY, linking key structural descriptors of the ABCD land condition framework with key drivers of landscape and hydrological function, was devised to explore the relationship between land condition, grazing preference and landscape function at patch scale and relate this to impacts across a range of scales. A full description of the rationale for and development of PATCHKEY can be found in appendix 13 of this report. Poster and proceedings papers on PATCHKEY development (Corfield and Abbott, 2006) and application (Abbott and Corfield 2006) were presented at the 2006 Australian Rangelands Conference in Renmark, S.A. A schematic representation of the basic structure of the original PATCHKEY conceptual framework can be seen in **Figure 9**.

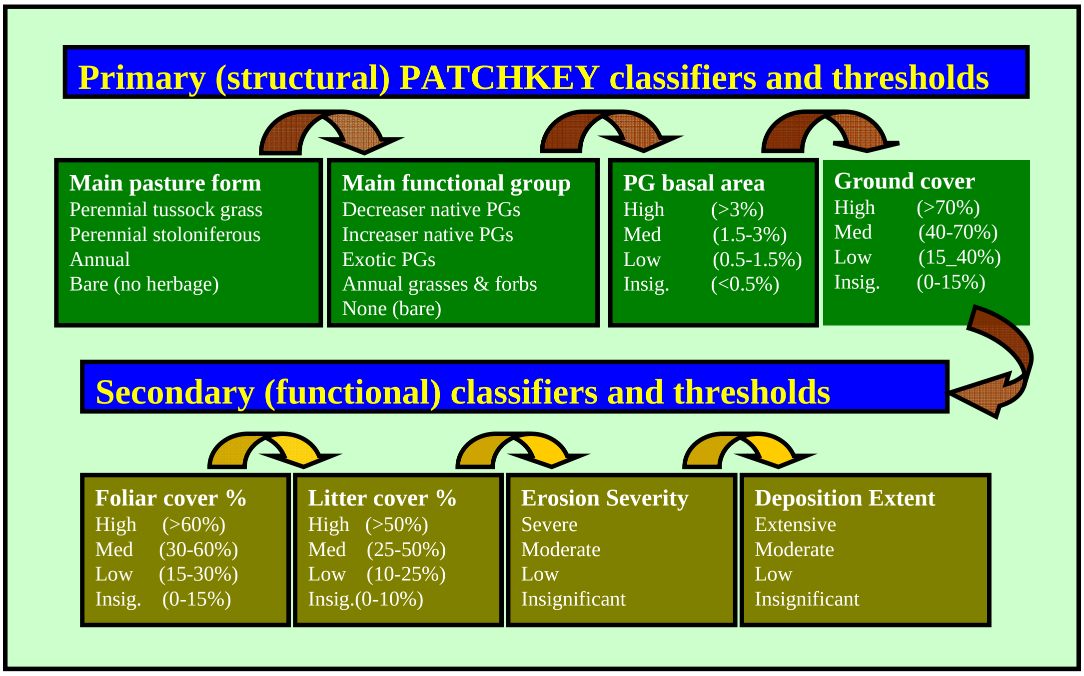


Figure 9: Schematic diagram of the original PATCHKEY conceptual framework

The original PATCHKEY conceptual framework comprised some 30 patch types spanning the ABCD range from good to very poor condition. Patches were represented by a binary classification code incorporating the primary (structural) ABCD category and a secondary (functional) classifier representing particular combinations and permutations of foliar and litter contribution, erosion / deposition status within each ABCD land condition level (**Table 9**).

PATCHKEY is still very much a work in progress, with extensive and detailed field testing being used to refine the conceptual framework into a robust and repeatable research tool capable of application to a range of land types and locations. While most of the PATCHKEY development has been focussed at the whole patch scale and above, dominant PATCHKEY classifications have also been recorded as part of the quadrat based surveys undertaken within both the Virginia Park hillslope and paddock studies and the broader grazing distribution surveys described above. This has facilitated exploration of the relationships between land condition and grazing preference at the patch scale across all of these study sites, yielding important insights. Multivariate analyses of the associated vegetation and soil surface condition data from these surveys has in turn assisted in refining the conceptual PATCHKEY framework in terms of identifying more robust classification indicators and thresholds.

Table 9: Original PATCHKEY conceptual framework

Primary (ABCD land condition)				Secondary (SSC) classifiers				Identifiers	
Pasture Form	**Dominant functional Group**	**Basal area**	**Total cover**	**Foliar contrib**	**Litter contrib**	**Erosion extent**	**Deposition extent**	**PATCHKEY ID**	**PATCHKEY functional group**
Tussock	3P	H	H	H	M-H	N	N	A1	3P-A
Tussock	3P	H	H	M	L-M	N	N	A2	3P-A
Tussock	3p+opg	Med	H	M	M-H	N	N	B1	3P-B
Tussock	3p+opg	Med	M	M	L-M	L	L	B2	3P-B
Stolon	Exotic pg	H	H	H	M-H	N	N	B3	couch_B
Stolon	Exotic pg	H	H	M	M-H	N	N	B4	couch_B
Stolon	Exotic pg	M	M	M	M	L	L	B5	couch_B
Stolon	Exotic pg	M	M	M	L	L	L	B6	couch_B
Tussock	ipg+3p	L	H	L	H	L	L	C1	ipg-C
Tussock	ipg+3p	L	M	L	M	L	L	C2	ipg-C
Tussock	ipg+3p	L	L	L	L	H	M	C3	ipg-C
Stolon	Exotic pg	L	H	L	H	M	H	C4	couch-C
Stolon	Exotic pg	L	M	L	M	M	M	C5	couch-C
Stolon	Exotic pg	L	L	L	L	H	M	C6	couch-C
Annual	ann+pg	L	H	M	M	M	M	C7	mixed_C
Annual	ann+pg	L	M	M	L	M	M	C8	mixed_C
Annual	ann+pg	L	H	L	H	M	M	C9	mixed_C
Annual	ann+pg	L	M	L	M	M	M	C10	mixed_C
Annual	ann+pg	L	L	L	L	H	L	C11	mixed_C
Annual	Anns	N	H	M	H	L	H	D1	anns-C
Annual	anns	N	M	L	M	M	M	D2	anns-C
Annual	Anns	N	L	L	L	H	M	D3	anns-C
Nil	Nosp	N	N	N	H	M	H	D4	nosp-C
Nil	Nosp	N	N	N	M	H	H	D5	nosp-C
Nil	Nosp	N	N	N	N	H	H	D6	nosp-C
Nil	Nosp	N	N	N	N	H	L	D7	nosp-C
Carissa	3P/ opgs	M	H	M	H	N	N	D8	shrub-pg-H
Carissa	3P/ opgs	L	M	L	M	N	N	D9	shrub-pg- L
Carissa	Nosp	N	H	N	H	L	L	D10	shrub-nosp-H
Carissa	Nosp	N	M	N	M	L	L	D11	shrub nosp-L

Codes: H=high, M=medium, L=low; 3P = palatable, perennial productive grasses, opg=other perennial grasses, ipg=increaser perennial grasses, pg=perennial grasses, anns=annual grasses and forbs, nosp=no pasture species, couch=Indian couch, shrub=shrub dominated (usually *Carissa*)

6.3.3 Linking land condition to landscape function for prediction of hydrological impacts

An important rationale for the initial development and testing of the PATCHKEY framework was to explore the relationship between land condition and landscape function at the patch scale and to link this with independent measures of hydrological function (infiltration/ run-off, landscape leakiness) and landscape health (soil respiration, nutrient cycling etc.) Once robust predictive relationships were developed at patch scale, we were able to apply these to hillslope and paddock scale to explore the impact of different arrangements of patch type, size and location on predicted hydrological function and sediment movement, using the measured flume hillslope outputs and detailed land condition spatial data as calibration. Results of predictive modelling work associated with these studies are reported in section 7 of this report and in Bartley *et al* (2006).

A range of patch-scale studies were conducted at several sites in the upper Burdekin during the period 2003-05. **Table 10** provides summary details of locations involved and relationships investigated. Appendix 14 of this report provides more details of measurements and methods employed in each study, many of which were collaborative efforts between CSIRO SE and LW to meet aspects of all 5 project objectives.

Table 10: Summary details of patch condition / patch function studies 2003-05

Site	Soil type/land type	Study objectives	Timing
Virginia Park Station – Bottom Aires paddock	Grano-diorite (goldfields)	Develop relationships between patch condition, infiltration, soil respiration and LFA SSC metrics for key patch types.	Aug 2003 Dec 2004
Blue Range Station - Pressland exclosure site	Sedimentary	Develop relationships between patch condition, infiltration, soil respiration and LFA SSC metrics for key patch types.	May 2005
Wambiana research site, various study paddocks	Canazoic – three land types (box, brigalow and silver leaf ironbark)	Develop relationships between patch condition, soil respiration, soil physical and chemical status, LFA SSC metrics for key patch types.	August 2003 July and Nov 2004 July and Nov 2005

The studies involved three main phases, at all three sites:

(i) Detailed land condition and LFA SSC measurements of the range of patch types originally identified via the PATCHKEY conceptual framework.

(ii) Identification and selection of key patch types and thresholds from this data for more detailed testing using independent empirical measurements of landscape and hydrological function.

(iii) Development, testing and application of relationships between key drivers of patch condition and measured landscape function identified through this process e.g. ground cover/infiltration, litter contribution / soil respiration.

While it is to expected that there would be significant auto-correlation between PATCHKEY conceptual classes and LFA SSC values, due to the fact that PATCHKEY uses key SSC elements such as cover, litter contribution and erosion/deposition status in its secondary classification, it was important to independently test these conceptual PATCHKEY types against the full array of SSC metrics to ensure the elements included were significant and robust indicators.

For the major patch function studies at Virginia and Blue Range in 2004-05, a range of patch types representing key thresholds identified in (ii) were selected across the hillslopes to provide a response surface for testing derived relationships. Detailed pasture condition and LFA SSC measurements were collected from a contiguous set of 1m^2 quadrats located in a belt transect running downslope across each patch. Infiltration was measured by two methods – ring infiltrometer and hood permeameter at around 3 sites per patch (see section 7 for full description of methods). Soil respiration was measured using the method of Hartigan (1980) with between 3-6 measurements taken per patch, depending on the study site and number of patches involved. In some cases, soil penetrometer measurements and soil physical and chemical samples for determination of bulk density, particle size and nutrient status were also taken by CSIRO LW colleagues for further analysis. Additional details can be found in section 7 of this report.

In a preliminary study at Virginia Park, in February 2004, replicated sub-patch sample sites were established on a range of key patch types located in upslope, mid-slope and lower slope locations adjacent to flume 3 to explore relationships between landscape location, patch condition and measured landscape function metrics. Again, comprehensive pasture condition (species composition, biomass, basal area, cover, litter cover, defoliation) and SSC measurements were taken for each sub-patch site and compared with measured metrics such as soil respiration, LFA SSC and soil physical and chemical properties.

The final phase of this work (iii) involved the application of relationships derived from these studies to whole of hillslope and whole of paddock scales for the sites and land types studied. In the case of Virginia Park this provided the opportunity to test predicted hydrological outcomes against measured flume outputs. This involved direct application of these relationships to spatially explicit flume and paddock grid survey data to produce kriged (ESRI, 2004) maps of likely infiltration, soil respiration, landscape leakiness patterns and also the use of such derived relationships in predictive modelling of likely infiltration and sediment movement outcomes from various configurations of hillslope cover, patch size and distribution (see section 7 results or details).

6.4 Results and discussion

6.4.1 Impact of ECOGRAZE strategies at Virginia Park

Whole of paddock responses and trends

Below-average rainfall conditions were experienced at Virginia Park for all three years of this study, with 2003 recording the most severe drought conditions for over 100 years (see **Figure 13**). This significantly affected the imposition and maintenance of planned grazing management strategies (see section 5 of this report) and also the number and magnitude of run-off events recorded in the flume catchments (see section 7 or this report). Onset of severe drought during the 2002-03 wet season and subsequent collapse of the dominant Indian couch (*Bothriochloa pertusa*) pasture, resulted in a 50% reduction in dry season ground cover (from around 70% to 35%) and perennial grass basal cover (from around 1.5% to 0.7%) and five fold reduction in available pasture biomass (from around 600kg/ha dry matter to <100kg/ha D.M.) between December 2002 and November 2003. This was despite the imposition of sustainable grazing strategies (wet season spelling and 25% utilisation) and subsequent complete de-stocking of study paddocks during 2003. Despite this, a slow but steady improvement in land condition was recorded over the lifetime of this study, once the initial setbacks of the 2003 drought were overcome.

Whole paddock response trends to imposed ECOGRAZE sustainable grazing management strategies were captured in terms of pasture composition and biomass, total ground cover and litter contribution and soil surface metrics such as erosion/deposition status and soil hardness (surface crusting) for study paddocks in twice-yearly grid surveys between end of dry (EOD) 2002 and end of wet (EOW) 2006. Exceptions were EOW 2003 when a late (end of February 2003) start to the wet season closely followed by severe drought, collapse of Indian couch and de-stocking rendered of wet season surveys largely irrelevant. Stud paddock was not surveyed until end of dry season 2003, when it was first included in the study paddock group. **Figure 10** shows seasonal trends in functional group component yields for Aires Top and Bottom paddocks, the paddocks which received the most intensive management in terms of wet season spelling during this study period.

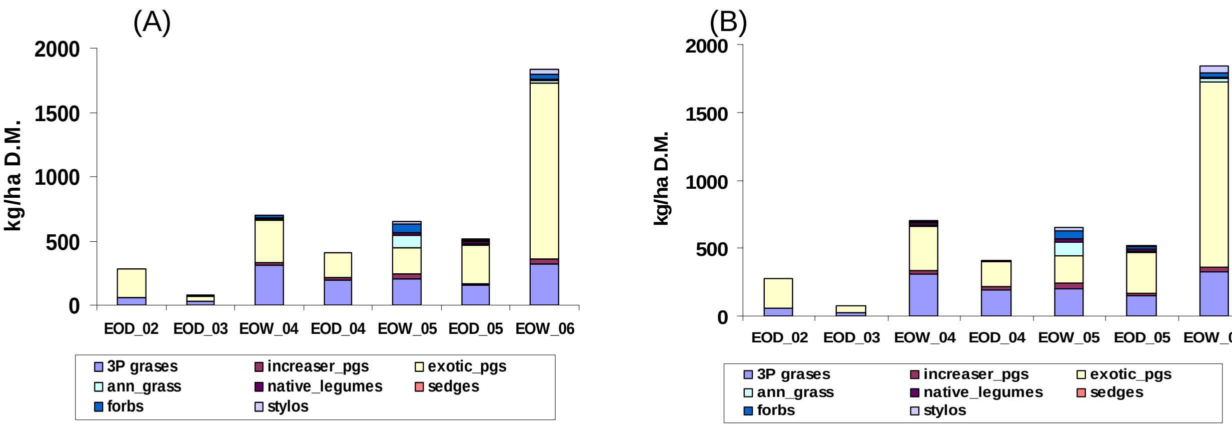


Figure 10: Seasonal trends in functional group component biomass yields for Virginia Park study paddocks - 2002 to 2006 for (A) Aires Bottom and (B) Aires Top paddock

Figure 10 shows a slow but discernable improvement in percentage of 3P grasses contribution since the 2003 intense drought; even though 3P grass frequency has remained similar or even fallen over time (**Figure 11**b). This was accompanied by a gradual improvement in perennial grass basal area from the 2003 low of around 0.7% back to around 1.2% overall by end of dry season 2005.
Likewise, **Figure 11** indicates a gradual improvement in mean paddock ground cover for the same paddocks over this period, again following the setback of the 2003 drought and allowing for the impact of dry season grazing.

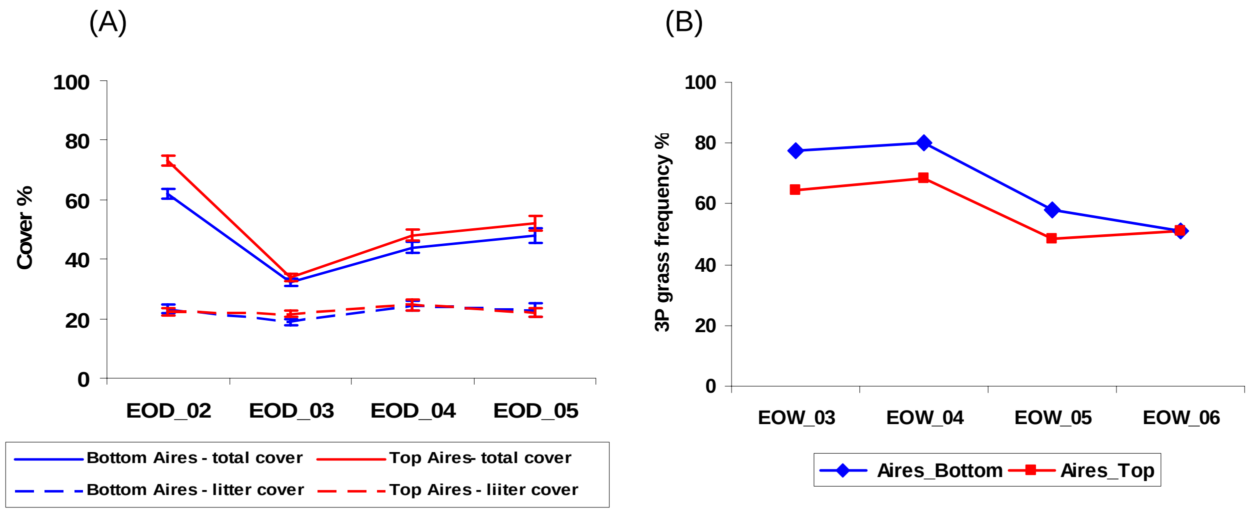


Figure 11: Seasonal trends in (A) total end of dry season (EOD) ground cover and litter cover and (B) 3P grass frequency of occurrence for Top and Bottom Aires paddocks Virginia

Perhaps the most dramatic indication of this change in paddock scale land condition can be seen in the high resolution *Quickbird* image shown in **Figure 12**. This image of Virginia Park and surrounding properties, enhanced to represent the relative change in cover between late dry 2003 and late dry 2005 clearly indicates the cumulative impact of lower utilisation and wet season resting on ground cover, within Aires paddock in particular, relative to trends in adjacent paddocks. It also demonstrates the positive response to application by Sue and Rob Bennetto of similar wet season resting strategies to other Virginia Park paddocks since the commencement of this project.

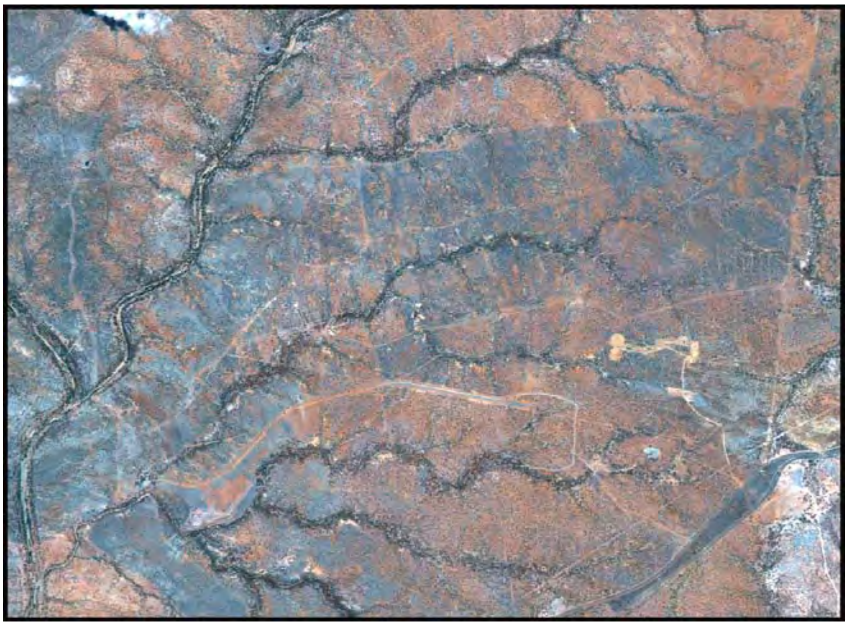
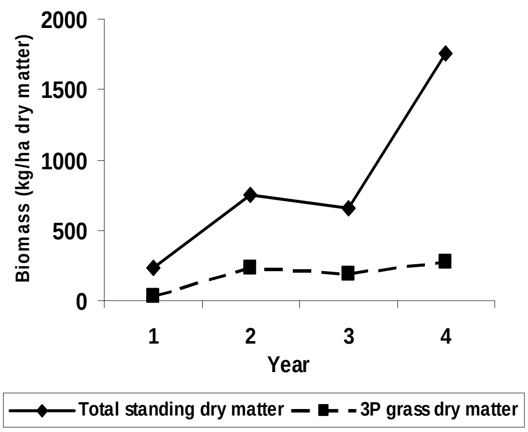


Figure 12: *Quickbird* high resolution satellite image of Virginia Park study site and surrounding paddocks and properties. The image has been adjusted to show the relative change in ground cover between late 2003 and late 2005, with darker areas representing increased cover and lighter areas indicating reduced cover over time. The Aires paddocks clearly stand out from surrounding areas in terms of improved cover, as do adjacent paddocks which the owners of Virginia Park have also spelled during the life of this project

It is useful here to compare recovery trends over the first four years at both Virginia Park and the ECOGRAZE Cardigan state II recovery sites (Ash *et al*, 2001) for paddocks of similar land type, land condition and imposed grazing regimes. Both studies were conducted during a similar period of below average rainfall over the first four years of recovery. Total biomass and component 3P biomass trends for the combined Virginia Park Aires paddock data are shown in **Figure 13**A while the prevailing seasonal rainfall trends for the period 2002-2005 are shown in **Figure 13**B. For comparisons sake, total and 3P biomass trends and rainfall data are shown for the equivalent ECOGRAZE Cardigan paddocks (25% utilisation, biennial wet season spelling) first 4 years of recovery (**Figure 14**A and **Figure 14**B).

(A) (B)



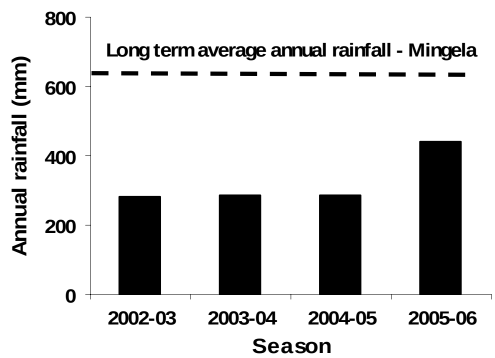


Figure 13: (A) Total biomass and component 3P biomass trends over the first 4 years of recovery on Aires paddocks Virginia Park (C to C+ or poor condition) following application of sustainable grazing treatments (25% utilisation, wet season spelling). (B) Seasonal rainfall patterns for the same 4 years at Virginia Park.

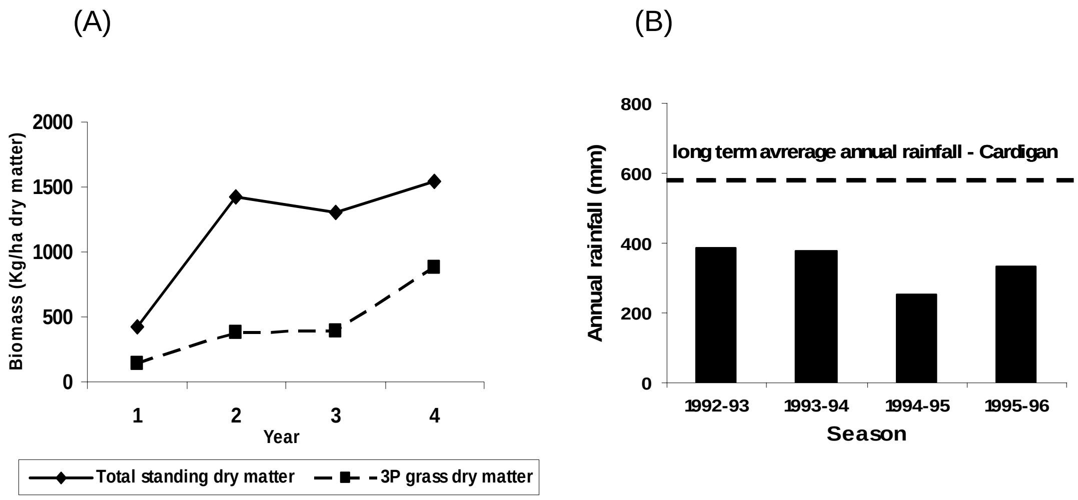


Figure 14: (A) Total biomass and component 3P biomass trends over the first 4 years of recovery on ECOGRAZE Cardigan state II (B- or fair condition) paddocks, following application of sustainable grazing treatments, including 25% utilisation and biennial wet season spelling. (B) Seasonal rainfall patterns for the same 4 years at the Cardigan state II site.

Importantly, Virginia Park paddocks were in relatively poorer starting condition (C to C+ or poor condition) (Chilcott *et al*, 2003) with <13% palatable, perennial and productive (3P) native tussock grasses and > 85% Indian couch) in Aires paddock compared to equivalent Cardigan recovery site paddocks (B- (fair) condition, which started with at >30% 3P grasses still present and less than 10% *Bothriochloa pertusa* (Indian couch). Even so, similar recovery trends can be seen, though 3P recovery is slower at Virginia Park, starting off from a lower base. Importantly, Virginia Park results support the ECOGRAZE contention that management, not climate, is the key driver of land condition in grazed landscapes (Ash *et al*, 2001), as both studies have achieved significant recovery in land condition and pasture productivity, through drought periods.

While both sites had relatively high mean starting 3P frequency percentages (>75% for Cardigan and >65% for Virginia Park Aires Paddocks) individual 3P plants at Virginia Park were much smaller than their Cardigan equivalents and largely swamped by Indian couch in the early years of recovery. This may have a significant bearing on the rate of recovery of 3Ps at Virginia Park.

Experience from the original ECOGRAZE study suggests that 3P tussock grass patches provide more permanent architecture for trapping and retaining resources such as litter. Being deeper rooted, 3P tussock grasses also provide better pathways for rainfall infiltration to the sub-soil compared to shallower rooted, stoloniferous species such as Indian couch, while their crowns and associated root mass are also important stores of nutrients (Northup *et al*, 1999).

Studies at Virginia Park have shown that Indian couch cover is also highly dynamic and ephemeral in response to seasonal conditions. **Figure 15** compares the ground cover trends at both Virginia Park Aires paddocks and the equivalent Cardigan ECOGRAZE paddocks over the first four years of recovery. While Virginia Park started with much higher ground cover, this fell by almost 50% during the 2003 severe drought, before slowly recovering to pre-study levels by 2005. By contrast Cardigan, with far less Indian couch and a higher percentage of tussock grasses, maintained relatively lower, but more stable ground cover under similar rainfall conditions during the first four years of recovery.

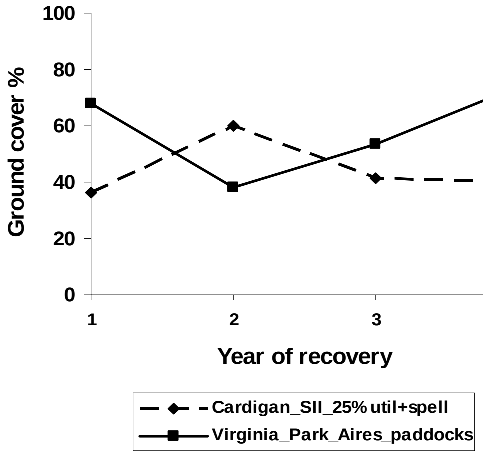


Figure 15: End of wet season ground cover trend comparison between Cardigan state II (B- or fair condition (mostly 3Ps + annuals) low utilisation + biennial spell and Virginia Park Aires paddocks (C or poor condition – mostly Indian couch) over first four years of recovery.

Note that Aires paddocks started with far higher ground cover, which was reduced by almost 50% during the 2003 severe drought, then recovered to 2002-03 levels by end of wet 2006. The bulk of Virginia Park end of wet season ground cover is contributed by Indian couch (*Bothriochloa pertusa*).

Where couch dominates, collapse of its stoloniferous architecture at the onset of drier conditions can result in rapid decline in ground cover as occurred in 2003, while extensive soil seed banks (when they exist) allow it to respond rapidly when better seasonal conditions return (**Figure 15**), often swamping recovery of 3Ps. This poses challenges for managing recovery of Indian couch dominated C condition landscapes on granodiorite and other surface crusting soil types. Interestingly, experience in both the ECOGRAZE project and the recent study at Virginia Park also suggests that recovering 3P grasses may in fact have a competitive advantage in the drier years when Indian couch cover and growth is reduced.

Impact of wet season spelling on 3P grass recovery within Virginia Park study paddocks

Previous studies (Andrew, 1986, Ash et al, 2001) have shown the value of wet season resting (spelling) in protecting 3P grasses from excessive defoliation at their most vulnerable growth stage in the early wet season and promoting recovery of 3P grasses in degraded pastures. Results from Virginia Park also demonstrate the early benefits of strategic wet season resting in encouraging 3P recovery.

Figure 16 shows the mean end of wet season trends in 3P biomass for Aires Top and Bottom study paddocks, which were the main recipients of wet season spells within the suite of study paddocks at Virginia Park over the lifetime of the project. Whilst yields of 3P grasses remain relatively small, there is an identifiable response to wet season spelling in both paddocks, which was most evident in the year following the spell. There is also some evidence from Aires bottom paddock results, that consecutive wet season spells may help consolidate this recovery, though more extensive and longer term data is required to confirm this observation.

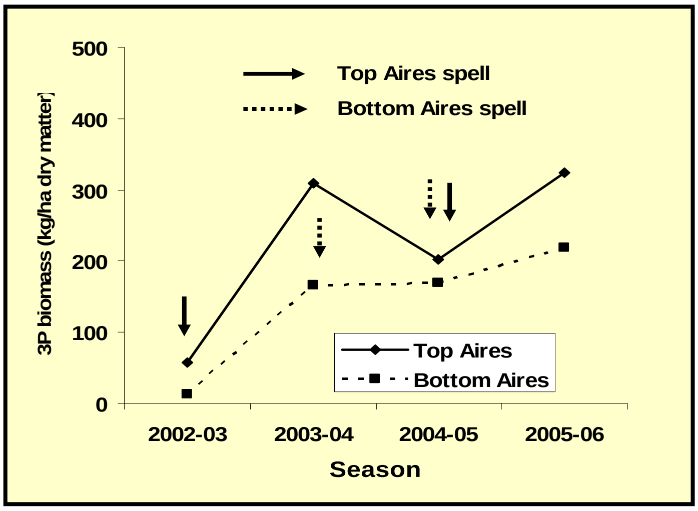


Figure 16: Trends in 3P grass production in response to wet season spells during the period 2003 to 2006. Downward arrows refer to timing of spells.

Note the initial wet season spell in Top Aires paddock in 2002-03 was followed by complete de-stocking of both Top and Bottom Aires paddocks, due to the onset of severe drought conditions from 2003, slowing recovery, especially in Bottom Aires paddock, where existing 3P grass contribution was very low. As a result Bottom Aires paddock received consecutive spells in 2003-04 and 2004-05 wet seasons, as part of an adaptive management strategy to encourage recovery. Response to spells can be seen in differential end of wet season 3P biomass trends for Bottom and Top Aires paddocks in 2004 and 2005.

Hillslope scale recovery trends at Virginia Park flume catchment sites

Observed paddock scale trends in biomass and ground cover were also reflected in mean hillslope trends recorded within the flume catchments monitored in Bottom Aires paddock over the same period. **Figure 17** indicates the relative trends in mean ground cover for the three flume hillslopes in Bottom Aires paddock, where the flumes are located and the paddock as a whole over the same period.

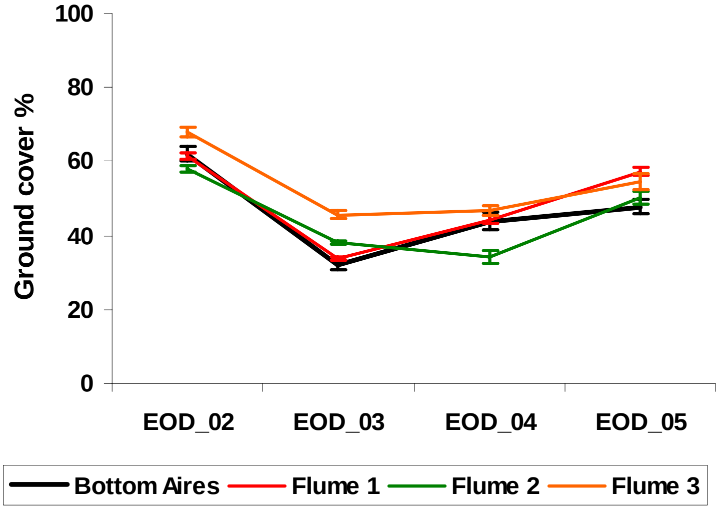


Figure 17: Comparison of end of dry season (EOD) ground cover trends between the three flume hillslopes in Bottom Aires paddock, Virginia Park, and the paddock as a whole - 2002-05 (means and standard errors).

As with Bottom Aires paddock as a whole, the flume hillslopes suffered a 50% loss of cover during the intense drought period of 2003, before slowly recovering to pre-2002 ground cover levels in response to reduced grazing pressure and the benefits of wet season resting in both 2003-04 and 2004-05. Lower rainfall resulted in fewer and less intense recorded run-off events with which to relate observed land condition responses to measured sediment movement off the flume hillslopes.

As noted in section 7 of this report and also in Bartley *et al* (2006) all three flume hillslopes started with similar average ground cover at the commencement of monitoring in late 2002, though the distribution of that cover varied significantly between hillslopes (**Figure 18**). The implications of this will be considered in the following paragraphs and also in section 7 of this report.

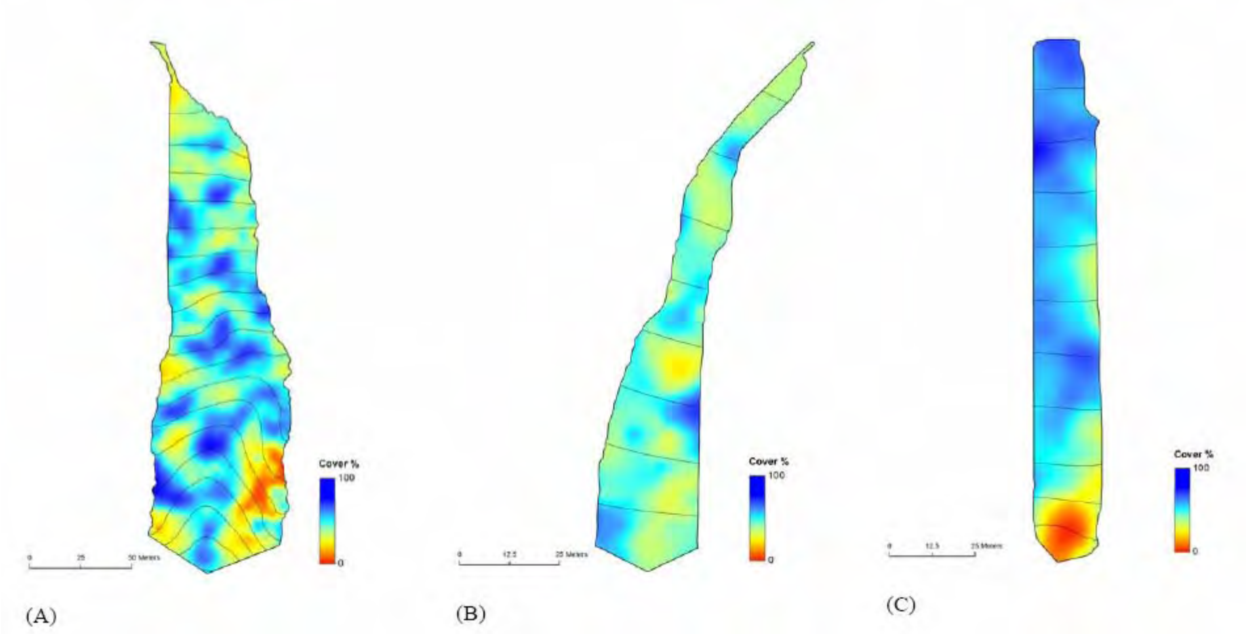


Figure 18: Distribution of ground cover on the three flume hillslope catchments at Virginia Park at end of dry season 2002 (A) main (whole of hillslope) flume 1 (B) upslope flume 2 and (C) scald flume 3. Dark blue = >75% cover, light blue= 50-75% cover, yellow= 25-50% cover, red=<25% cover. Flumes not to scale.

Spatial patterns of recovery within Virginia Park study paddocks

Whilst both paddock and hillslope scale responses to implementation of sustainable grazing management strategies were observed in Virginia Park study paddocks, the grid based survey data revealed considerable spatial and temporal variability in the pattern and rate of recovery in key land condition metrics at both scales. Kriged (ESRI, 2004) maps of Aires Top and bottom paddock grid survey data for key land condition metrics such as total ground cover **Figure 19**) and 3P biomass (**Figure 20**) demonstrate these variable response patterns across the landscape. While some areas and locations respond quickly in terms of improved cover and 3P biomass, significant areas have remained static over time, while some areas have actually gone backwards in land condition, despite reduced stocking and implementation of wet season resting.

Some of this variation is associated with location, with down slope and drainage line areas often responding more quickly than ridges or upslope areas due to differences in rainfall infiltration and/or run-off capture, accumulation or loss of litter and sediment. Other sources of variation are associated with the relative resilience of different land types or vegetation units. Overlaid upon this is the impact and interaction of grazing patterns and relative selection preference for both location, land type and land condition, all of which can affect the rate of recovery.

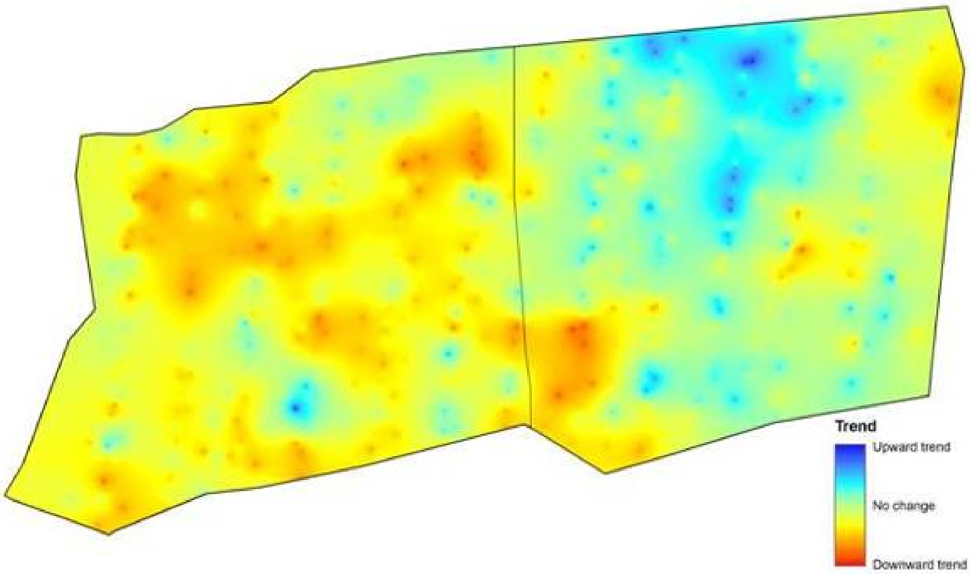


Figure 19: Kriged maps end of dry season ground cover data from Aires paddocks, Virginia Park showing patterns of change from 2003 to 2005. Light to dark blue colours indicate improving areas, light green indicates little change, while yellow to red colours indicate areas remaining static or still degrading**.**

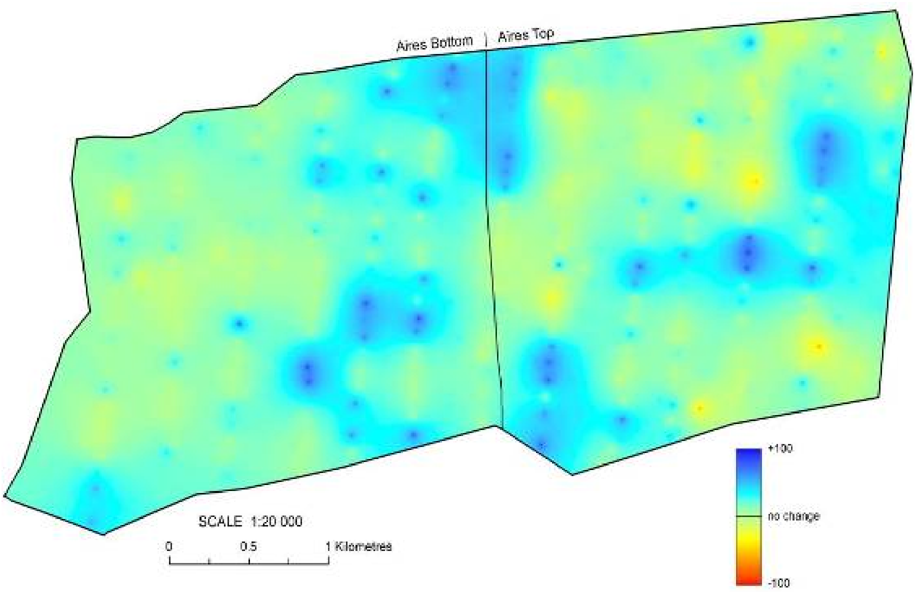


Figure 20: Kriged maps end of wet season 3P grass biomass from Aires paddocks, Virginia Park showing patterns of change from 2004 to 2006. Light to dark blue colours indicate improving areas, light green indicates little change, while yellow to red colours indicate areas remaining static or still degrading.

The scale of this variability can be seen by observing the spatial and temporal patterns of response within flume hillslopes over the same period, using the same approach on the finer scale flume hillslope survey data. **Figure** 21 shows Kriged (ESRI, 2004) maps of the relative change in end of dry season total ground cover between seasons for the main flume (flume 1) hillslope over the period 2002 to 2005.

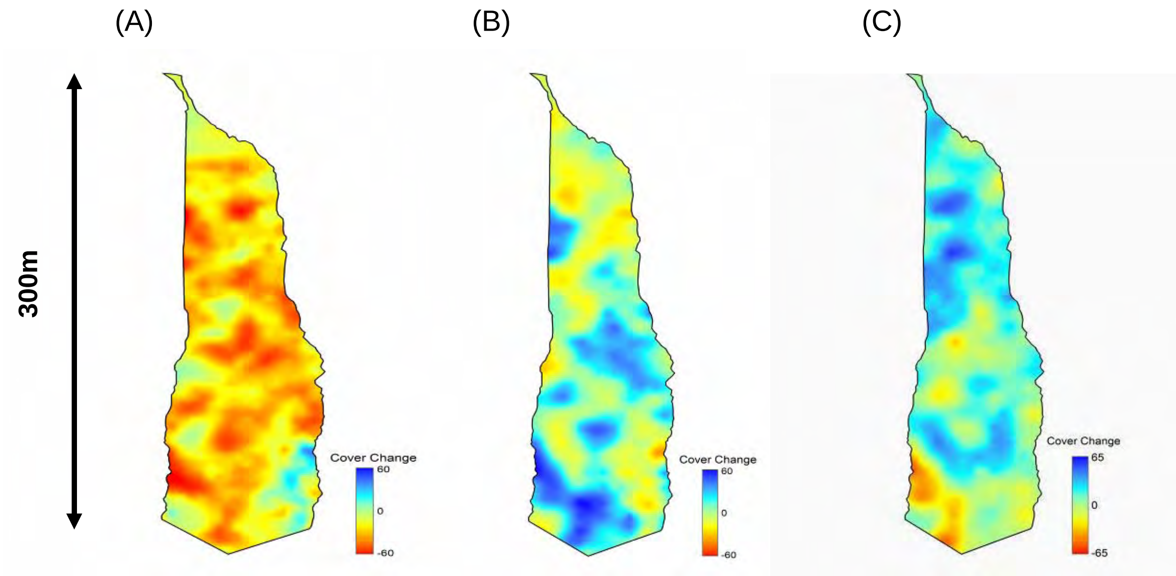


Figure 21: Kriged maps of the main flume hillslope, Bottom Aires paddock, Virginia Park showing spatial patterns of relative change in end of dry season ground cover between (A) 2002-03, (B) 2003-04 and (C) 2004-05. Dark blue=moderate-strong improvement, light blue=slight improvement green=static, yellow=slight decline, red=moderate-high decline.

The **Figure** 21 main flume hillslope maps indicate that the there can be considerable spatial and temporal patchiness in the patterns of response to changed climatic and management conditions and that much of this patchiness occurs at the scale of tens of meters and below - in other words at the grazed patch scale. Much of this variability in response is associated with micro habitat differences in patch condition, location land type/vegetation unit within the hillslope catena, which influence rates of infiltration/run-off and accumulation/loss of resources such as litter, sediments and nutrients. It also confirms paddock-scale findings that even when overall land condition is improving, significant areas may remain static or even decline in condition. Further, the trajectory of individual patch scale responses can vary considerably over time. This may be due to the influence of edaphic factors such as location and land type, the accumulated effects of past impacts and the on-going impacts of contemporary grazing patterns and selection preferences – or all three.

The influence of land type and location on spatial and temporal recovery patterns

Figure 22 compares end of dry season ABCD land condition trends (Chilcott *et al*, 2003) over time (in terms of framework categories, using PATCHKEY) for the dominant Ironbark/bloodwood land type in Aires paddock, with those for lower slope sodic soil land types dominated by *Carissa/Eremophila* in the same paddocks. While both land types show some increase in D condition over time and a marked decrease in B condition during the intense drought of 2003, the subsequent responses to reduced utilisation and wet season spelling varied significantly. The ironbark/bloodwood land type shows a slow but steady shift back toward B condition, while the sodic soil areas continue the slide to C and D condition.

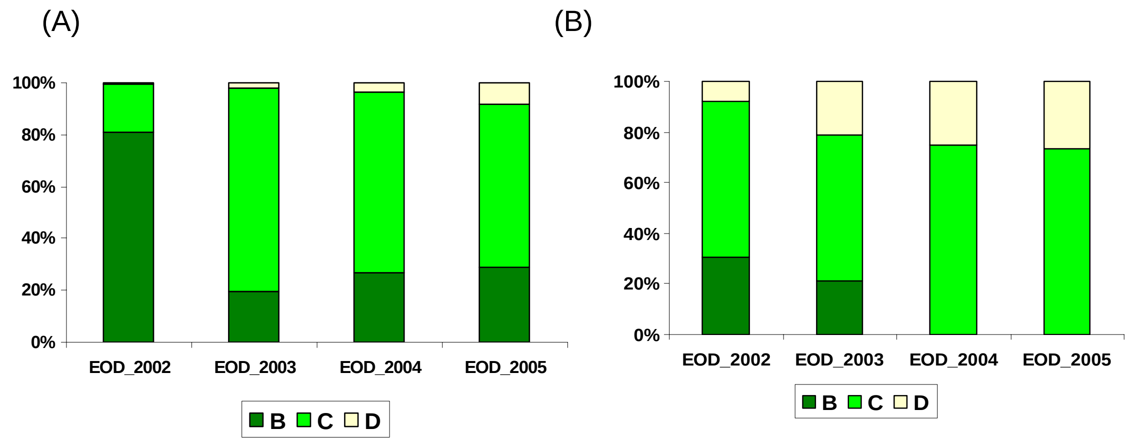


Figure 22: Comparison of trends in proportions of ABCD land condition (2002-05) in Aires paddocks Virginia Park between (A) the dominant ironbark-bloodwood vegetation type and (B) minority sodic soil areas dominated by *Eremophila mitchellii, Carissa ovata* and *Eucalyptus brownii* (box) species.

A similar trend is also evident from the main flume (flume 1) hillslope grid survey data (**Figure 23**). Comparison of end of dry season ground cover trends, a major driver of land condition, show a strongly significant (p<0.001) difference in mean cover levels between the dominant ironbark/bloodwood and minority lower slope sodic land types in all but the 2003 intense drought year. **Figure 23** also shows a steady increase in cover levels for the ironbark/bloodwood land type following the 2003 drought induced collapse of Indian couch, whereas cover trends for the lower slope sodic areas remain basically static over the same period. Sodic soil communities also show high small-scale spatial variability in cover distribution (as evidenced by ground cover coefficient of variation) but this variability is less dynamic from year to year, compared with the Indian couch dominated ironbark/bloodwood community (**Figure 23**B)

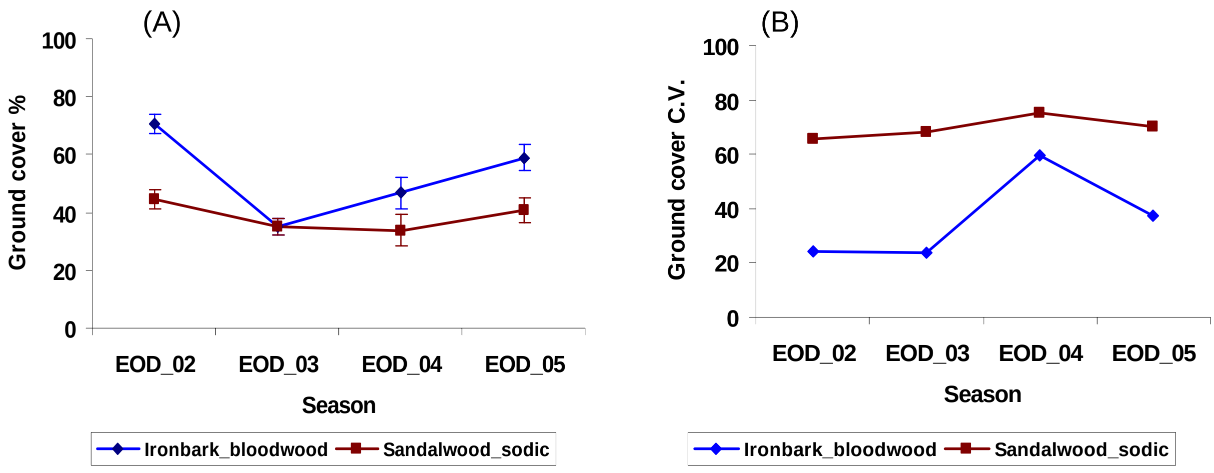


Figure 23: Time trend relationships between vegetation type and ground cover on the main Virginia Park flume site (flume 1) from end of dry season 2002 to end of dry season 2005. (A) Ground cover means and standard errors and (B) trends in coefficient of variation (C.V.) of ground cover.

Similar variability can be seen in the spatial and temporal patterns of ground cover response for different topographic locations and landscape positions within the flume hillslopes. For instance, there were strongly significant (P<0.001) ground cover differences associated with distance from the central drainage line (**Figure 24**) and from tree canopy (**Figure 25**) respectively and also strong year and year * distance interactions, within the main flume (flume 1) hillslope.

(A) (B)

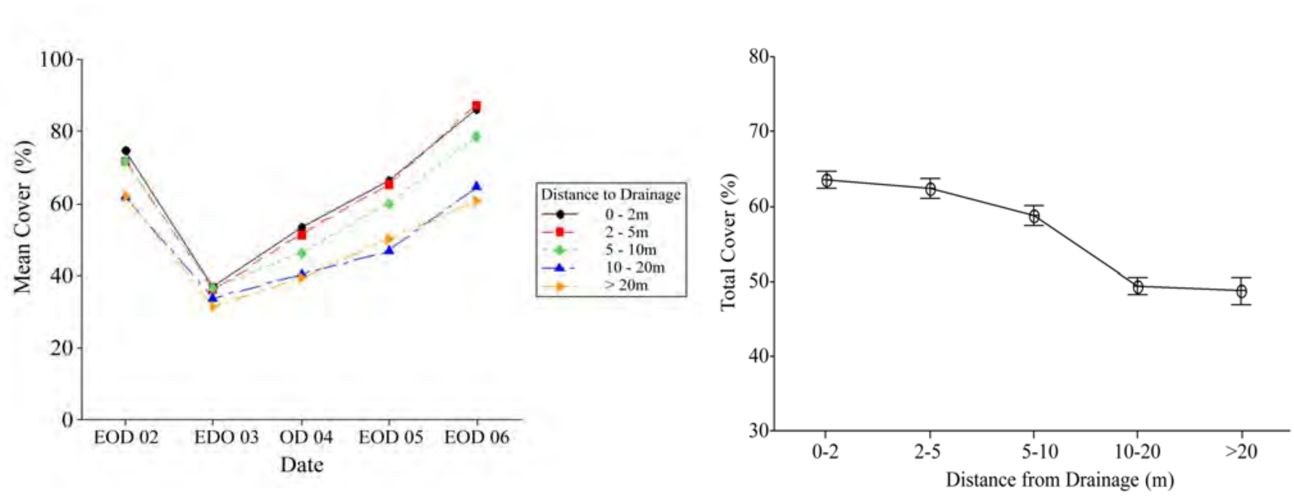


Figure 24: Time trend relationships between patch ground cover and distance from the central drainage line of the main Virginia Park flume (flume 1) hillsope. (A) Mean cover trends (2002-2006) for distance classes 0-2m (black) 2-5m (red), 5-10m (green), 10-20 (blue) and >20m (orange) from drainage line. (B) Effect of distance from central drainage line, averaged across years.

(A) (B)

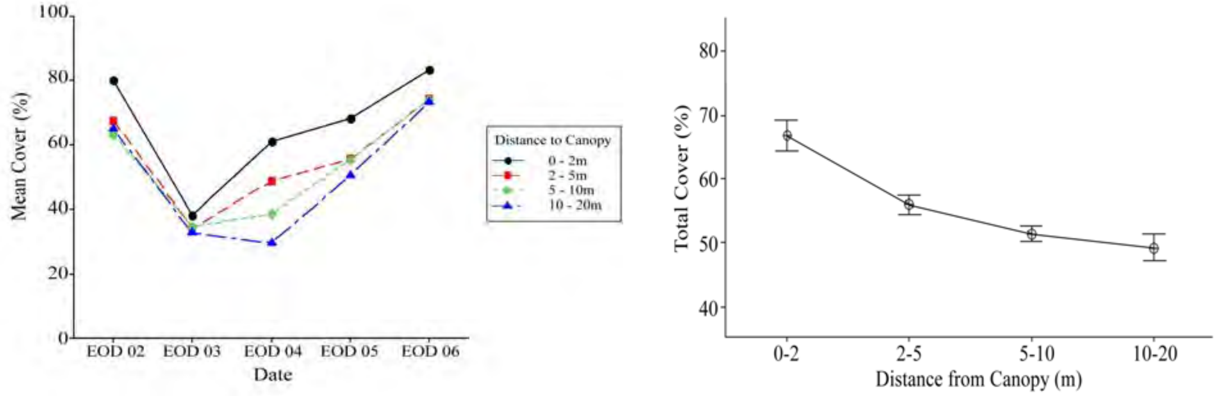


Figure 25: Time trend relationships between patch ground cover and distance from tree canopy on the main Virginia Park Flume. (A) Mean cover trends (2002-2006) for distance classes 0-2m (black) 2-5m (red), 5-10m (green), 10-20m (blue) from tree canopy. (B) Effect of distance from tree canopy, averaged across years.

Ground cover declines significantly at distances >5m from the central drainage line in all years but the severe drought year of 2003, when ground cover declined by >50% across the entire paddock. In the case of tree canopy the greatest effect is between 2-5 m in most years, which represents the mean canopy diameter. The greatest effect was recorded in 2004, in the first full year of recovery following spelling in this paddock. This may be a due to greater litter rain and/or a growth response to higher nutrient cycling and infiltration under trees at a time of continued low rainfall.

Landscape position within the hillslope can also affect spatial and temporal patterns of recovery, with run-on or accumulation areas more likely to be located within middle to lower slope locations than in up-slope and ridgeline areas. However, this can be confounded by the interaction of land condition, land type and localised grazing patterns and preference, all of which influence recovery. **Figure 26**A shows the trends in end of dry season (EOD) ground cover between 2002 and 2005 for up-slope, mid-slope and lower slope landscape positions within the main flume hillslope at Virginia Park.

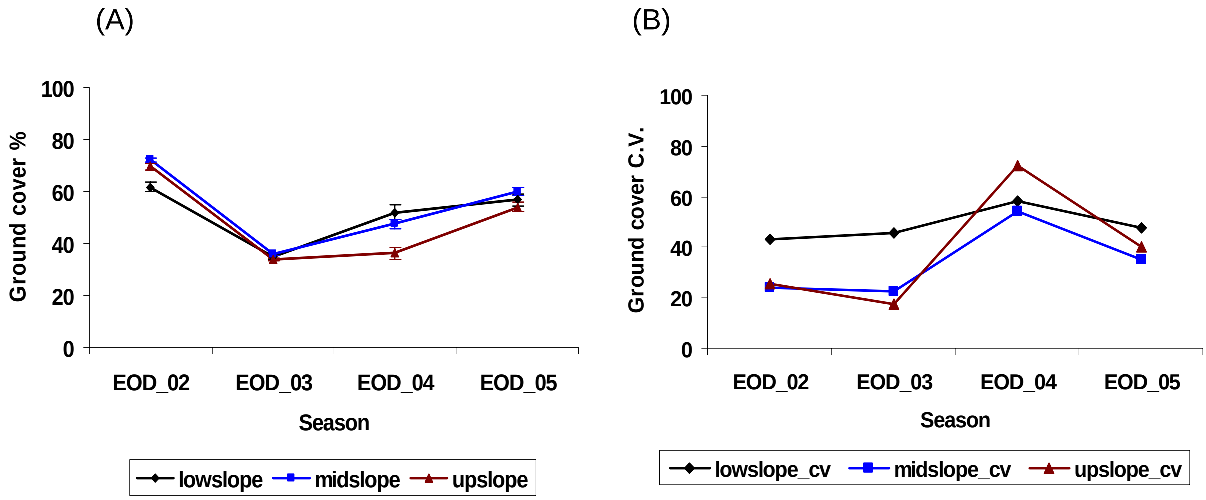


Figure 26: Time trend relationships between hillslope position and ground cover on the main Virginia Park flume site from end of dry season 2002 to end of dry season 2005. (A) ground cover means and standard errors and (B) trends in coefficient of variation (C.V.) of ground cover from end of dry season 2002 to end of dry season 2005.

The relationship between ground cover and hillslope position (**Figure 26**A) is only significant for 2004, following the first wet season spell of 2003-04, with upslope areas having significantly ($p<0.001$) lower ground cover. This may indicate a higher capacity of lower and mid-slope areas to respond to spelling in drier years, perhaps because resources have shifted down slope following the collapse in Indian couch cover across the hillslope in 2003.

The ground cover coefficient of variation (C.V.) data (**Figure 26**B) indicates that upslope and mid-slope C+ and B- condition areas dominated by Indian couch were initially fairly uniform in cover but became much more dynamic from year to year in response to the interaction of spelling and drought, during recovery. This may have also been influenced by selection preferences within recovering C condition patches during the early recovery period. By contrast, lower slope areas, which contain significant areas of *Eremophila/Carissa* sodic soils, had higher spatial variability in cover, though this variability was less dynamic from year to year, as seen in the land type data presented in **Figure 23**.

A common driver in both topographic location and landscape position response variability is the ability of these locations to accumulate resources through either sediment and nutrient transport and deposition (**Figure 23**) or litter rain, in the case of trees (**Figure 24**). This accumulation significantly improves soil organic matter and infiltration, facilitating increased growth and recovery of pasture biomass and ground cover (see soil physical and chemical analysis results in section 7 and component A appendices of this report).

The influence of hillslope position is confounded by the location of particular land types or vegetation units such as sodic soil areas on the lower slopes, as is the case with the main flume hillslope at Virginia Park. Separating these two factors shows that for the non-sodic soil areas, the ground cover responses to sustainable grazing management strategies are generally higher and less spatially variable than those from up-slope and mid-slope areas.

For lower slope sodic areas, the spatial and temporal trajectory of recovery is further confounded by the observed grazing selection preference for these land types, especially during the wet season. The highly mobile sodic B horizon soils are especially vulnerable to the impacts of this selective grazing pressure, reducing its capacity to respond to paddock scale sustainable grazing management strategies such as reduced utilisation. This goes some way to explaining the trends shown in **Figure 22**B. The influence of grazing patterns and preference on small scale response patterns and the implications of variable recovery for paddock scale management of recovery will be discussed in the following sections 6.4.2 and 6.4.3 respectively.

6.4.2 Drivers of selective use – impacts and interaction with land condition

Whilst the previous section examined the various edaphic factors influencing the observed spatial and temporal patterns of response to imposed management strategies at Virginia Park, there is one important factor overlaying all of this – the impact of grazing preference. Livestock graze patchily (Andrew, 1986) and selective use can occur at a range of scales from small patches to whole land or vegetation units, specific topographic locations or landscape positions within paddocks. The localised biophysical impacts of grazing selectivity can in turn be influenced by overall stocking rate and land condition, which can determine availability and distribution of forage and also by management actions such as location of waters and fences within a paddock.

Teasing out the relative influence and interaction of all these factors and relating them to likely hydrological impacts was a ground survey and modelling task initiated under the previous NAP3.224 project by Dr John Gross and followed through in the original component B objectives of NBP.314. Despite the loss of Dr. Gross' modelling skills, with his departure in mid 2003, his prototype predictive grazing distribution model was subsequently tested on a range of commercial paddocks of differing size, land type mix, stocking history and land condition in the upper Burdekin region during 2004-05, once the main de-stocking impacts of the intense 2003 drought had passed.

Results, from these surveys confirmed the previous NAP3.224 findings that:

- While there can be a significant grazing gradient impact out from water points, this is largely confined to <300m on all the land types studied (**Figure 27**)
- Recent burning history was a strong driver of grazing distribution at paddock scale (**Figure 28**) on the one site where recent burning had occurred.
- Whilst there were identifiable preferences for vegetation types in certain seasons on some land types, this was inconsistency between seasons and land type preferences in paddocks studied (**Figure 29**).
- The exception to this was a more consistent preference for riparian, frontage areas and lower slope sodic soil areas dominated by Eremophila mitchellii and Carissa ovata on grano-diorite and sedimentary land types, especially during the wet season (Figure 30)

For Figure 25 and Figure 26 the method used to calculate relative selectivity is after Jacobs (1974) as previously described in section 6.3.2 of this report.

(A) (B)

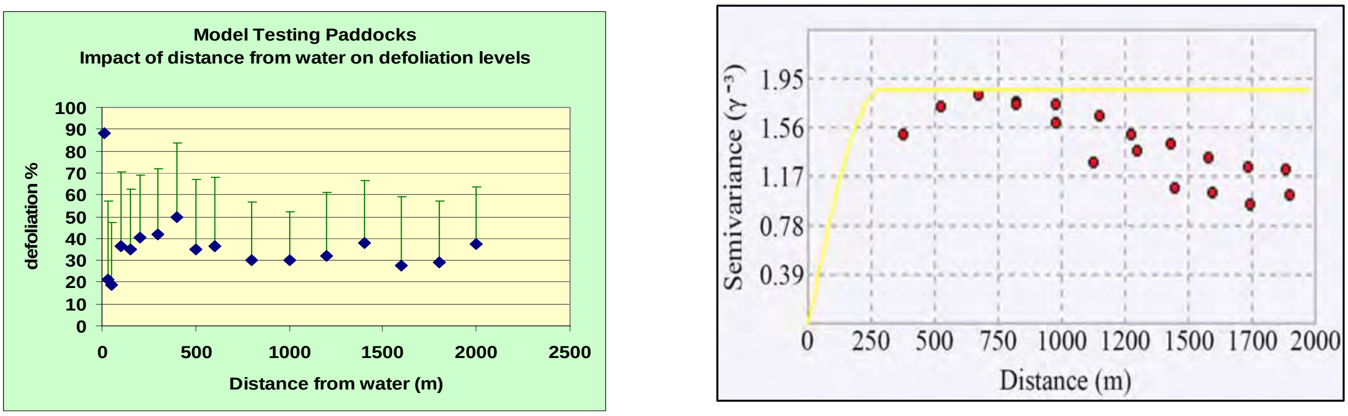


Figure 27: Impact of distance from water points on grazing intensity as measured by relative defoliation ratings. (A) defoliation means and standard deviations; (B) semi-variogram of defoliation ratings with distance (meters) from water point, showing increasing variance up to 250m then stabilisation beyond that. Data is a composite of all grazing distribution study paddock distance from water surveys 2004-05**.**

(A) (B)

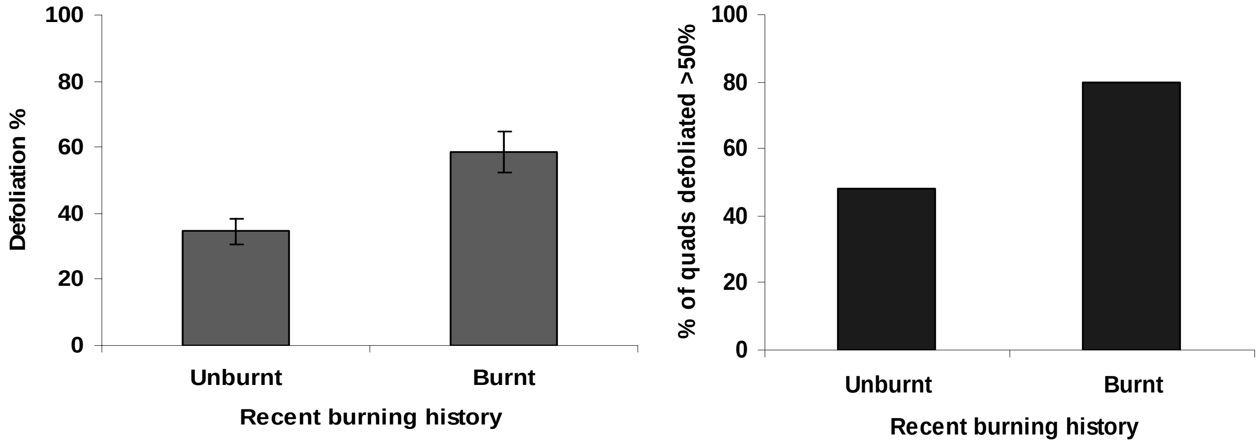


Figure 28: Impact of recent burning on grazing selective preference – Haler paddock, Hillgrove station, dry season 2005. (A) mean % defoliation and (B) proportion of quadrats >50% defoliated.

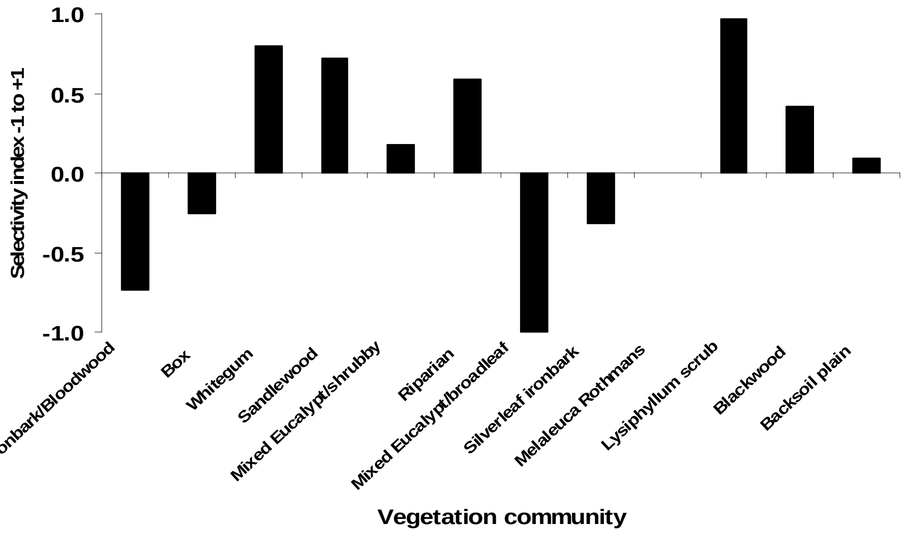


Figure 29: Relative selection preference for land type across all grazing distribution study paddocks surveyed during 2004-05 (data adjusted to remove for small scale distance from water effect). Data are relative selective index scores after Jacobs (1974) where negative scores indicate selection preference less than relative abundance and positive scores indicate selection preference greater than relative abundance.

(A) (B)

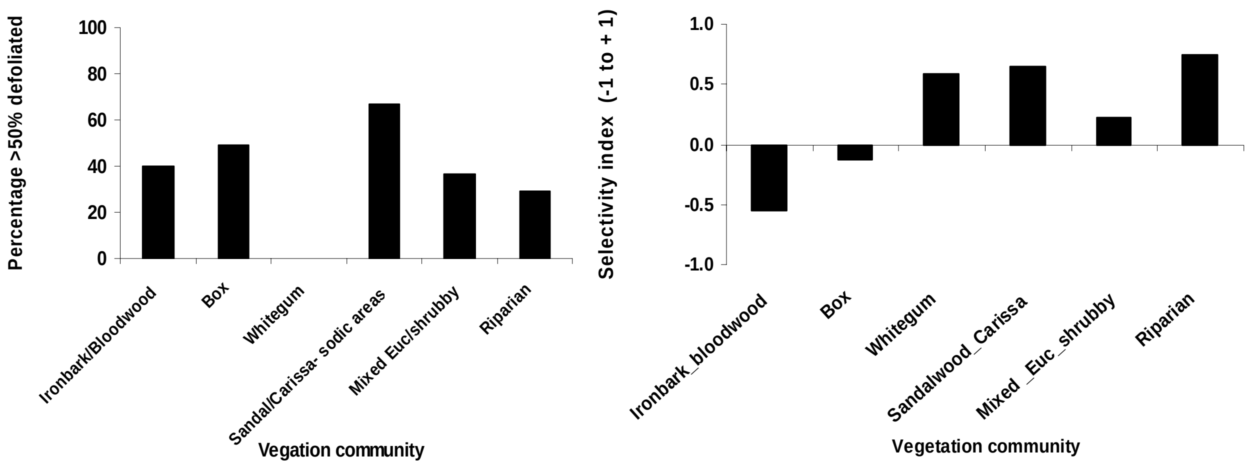


Figure 30: Vegetation community wet season selection preference on goldfield and sedimentary country (A) proportion of survey quadrats >50% defoliated. (B) Relative selectivity index scores (after Jacobs, 1974)

Other potential factors such as vegetation over-story cover and structure, topography and aspect were less consistent indicators of grazing distribution and preference across the range of land types and paddock conditions studied during the survey period.

Grazing selectivity and patch condition

Inclusion of PATCHKEY classifications in these paddock scale grazing surveys also demonstrated that pre-existing patch condition was perhaps the strongest driver of contemporary grazing preference and that this grazing selectivity begins at the patch scale. These results accord with findings of Andrew (1986a, b) that, in the absence of fire impacts, stock will continue to re-graze already established grazed patches.

PATCHKEY classification data from these surveys shows for paddocks in overall good (A) to fair (B) condition with low to moderate long term stocking histories there is a strong grazing selection preference for patch types of pre-existing C and D condition, as indicated by contemporary defoliation ratings. For both grano-diorite (goldfields) and sedimentary paddocks studied, C and D condition patches were twice as likely to be heavily grazed (>50% defoliated) than B condition patches and five times more likely than A condition patches within the same land type (**Figure 31**).This may be related to findings of Ash and McIvor (1995) that such degraded patches had higher plant N, P and macro-nutrient levels.

(A) (B)

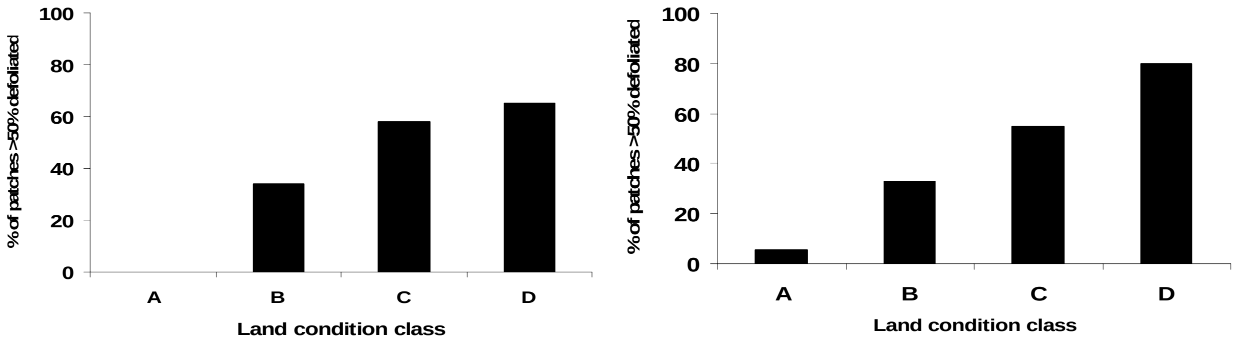


Figure 31: Proportion of each ABCD land condition patch class heavily grazed (>50% defoliated) by end of dry season 2004 (A) Grano-diorite (goldfields) land type - Virginia Park (all study paddocks); (B) Sedimentary land type – combined Blue Range (Springs) and Hillgrove (Haler) paddocks data.

This selection preference can better explored using the selectivity index method of Jacobs (1974) which scales relative abundance against relative defoliation for each PATCHKEY type recorded. **Figure 32** compares relative patch selection preference in two paddocks of sedimentary land type - a long term moderately stocked paddock (Haler paddock, Hillgrove station) and a long term high stocked paddock (Boon Boon paddock, Kirkland Downs station).

(A) (B)

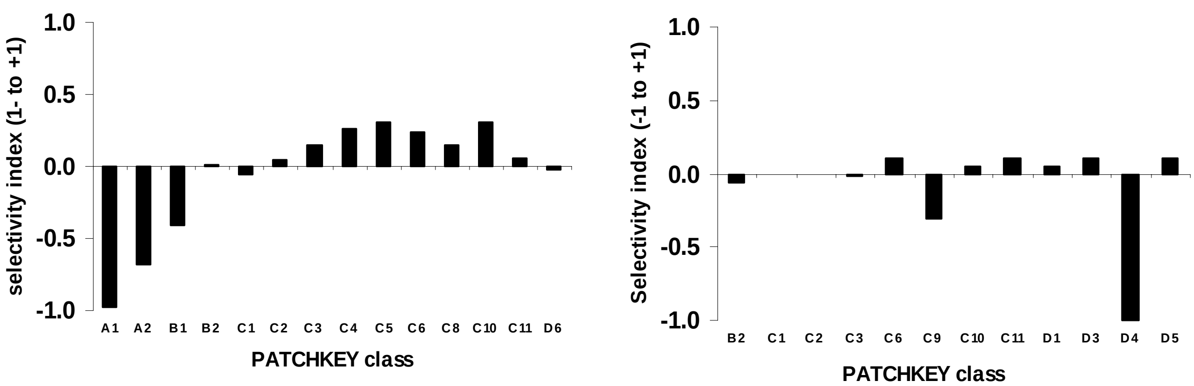


Figure 32: End of dry season 2004 grazing selectivity preferences for (A) Haler paddock, Hillgrove station - a long term moderately stocked B condition paddock and (B) Boon Boon paddock, Kirkland Downs station - a long term high stocked C– condition paddock both on sedimentary land types. PATCHKEY classes span the ABCD land condition class range.

Figure 32A clearly demonstrates the selection preference for C condition patches within the moderately stocked B condition paddock. By contrast, in long term high stocked C paddock, grazing selectivity is more evenly distributed across the paddock in response to shortage of overall forage resources and thus most patch types are grazed in proportion to their abundance as grazing pressure increases.

Interaction of patch condition and land type with selection preference

Where C and D condition patches coincide with more vulnerable riparian and lower slope sodic soil land types, there is considerable risk of continued degradation, even at the low paddock utilisation rates recommended by the ECOGRAZE project publication (Ash *et al*., 2001). **Figure 33** shows the proportions of ABCD land types (derived from PATCHKEY survey data) recorded for the main land/vegetation types in moderately stocked study paddocks on sedimentary soils in the upper Burdekin during the 2004-05 survey period. Note that the land types with the highest combined C and D condition patch proportions coincide with the land types preferentially grazed, especially during the wet season (**Figure 30**). This suggests that the negative feedback process described by Andrew (1986) whereby pre-existing C condition patches are continually re-grazed, and thus further degraded, is occurring here.

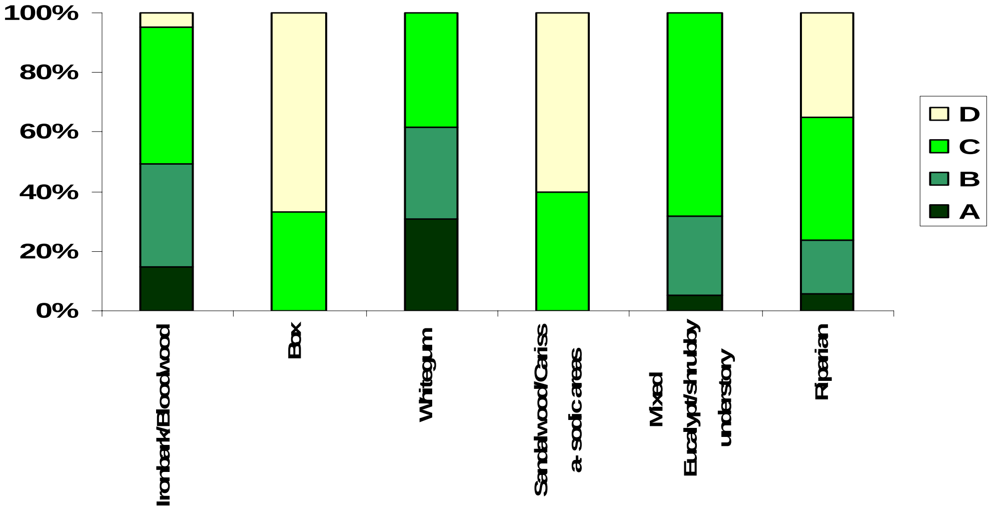


Figure 33: ABCD condition proportions for major vegetation communities on low to moderately stocked sedimentary country (Haler paddock, Hillgrove and Springs paddock, Blue Range station) Note that vegetation communities with the highest proportion of D condition land coincide with those preferentially grazed by stock, especially in the wet season.

Heterogeneity - the interaction of land condition, patchiness and grazing patterns

The interaction of stocking rate, land condition and selection preference described previously can influence the spatial distribution of patchiness across the landscape. Paddocks in fair to good (B-A) overall condition provide a greater range of selection choices for stock and this often translates into a greater diversity of patch condition types (**Figure 34**A), irrespective of the range of land types represented in the paddock. This in turn can be manifested in greater heterogeneity of grazing effort across the paddock (**Figure 35**A).

By contrast paddocks with a history of long term high stocking rates show far less diversity in patch condition (**Figure 34**B) and corresponding grazing selectivity (**Figure 35**B), due to overall high grazing pressure and shortage of available forage.

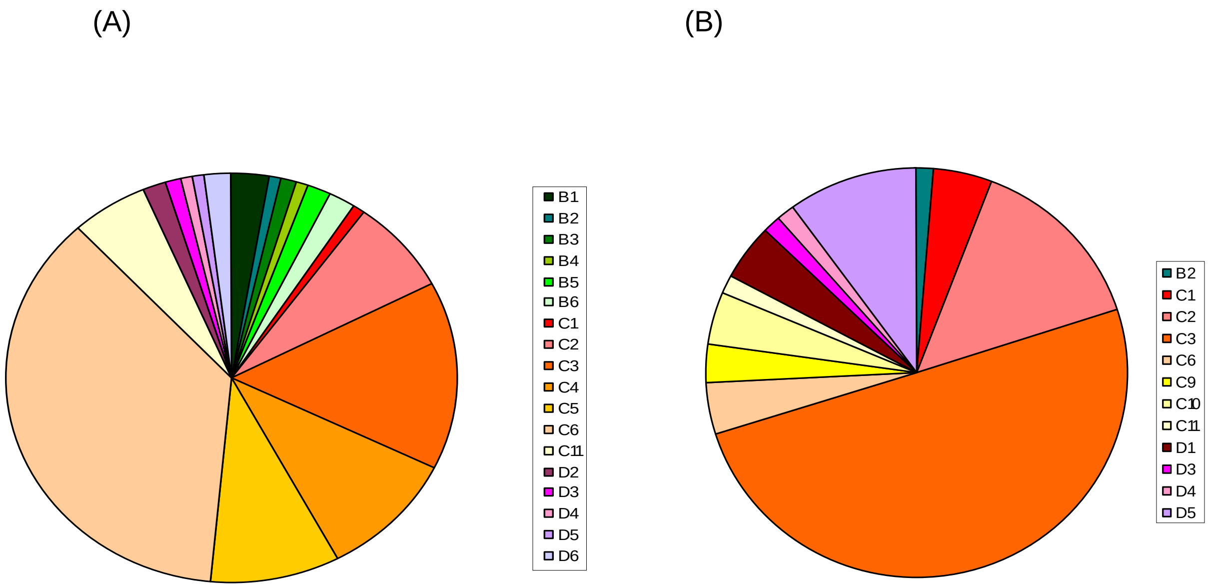


Figure 34: Patch/land condition proportions for (A) Spring Creek paddock Cameron Downs and (B Boon Boon paddock Kirkland Downs station) Dry season 2004, using the PATCHKEY framework. Note the higher proportion of B and higher C condition patches in Spring Creek paddock and also the greater diversity of patch types (18) compared to Boon Boon paddock (12).

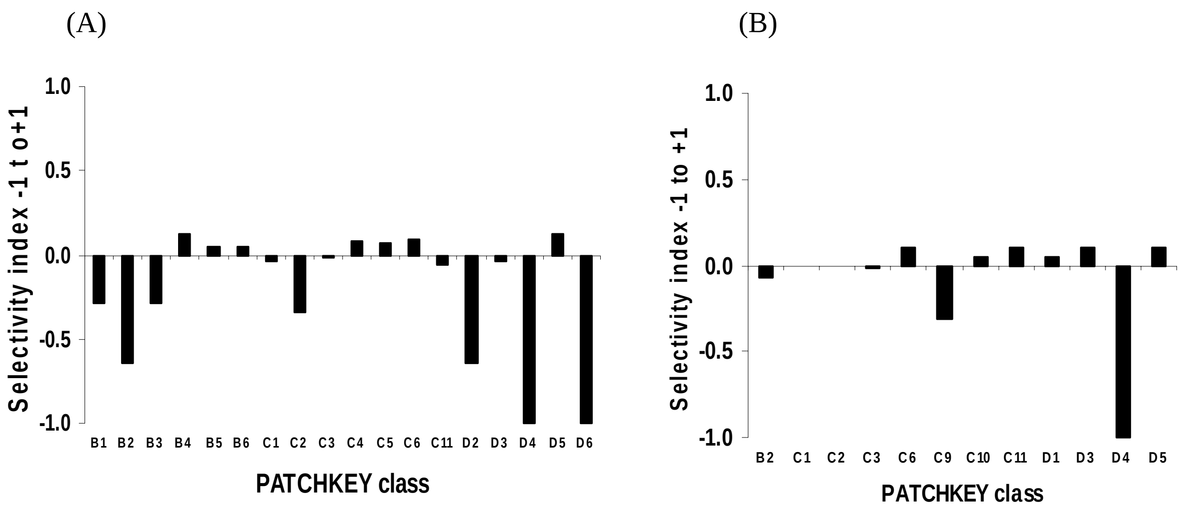


Figure 35: Relative selectivity Jacobs (1974) for PATCHKEY types at (A) Spring Creek paddock Cameron Downs – a C+/B- paddock and (B) Boon Boon paddock Kirkland Downs station – a C-/D+ paddock - dry season 2004 Relative selectivity index .

Where corresponding near infra-red spectrophotometry (NIRS) dung sampling data exists for some of these same study paddocks it indicates a difference in seasonal diet quality between the moderately stocked, fair condition, more patch-diverse paddock (**Figure 36**A)and the high stocked, less patch-diverse poor condition paddock (**Figure 36**B). NIRS results for the latter paddocks indicates that selected diet quality seldom exceeds maintenance requirements during the year, but especially through the dry season, increasing the need for protein and energy supplementation.

(A) (B)

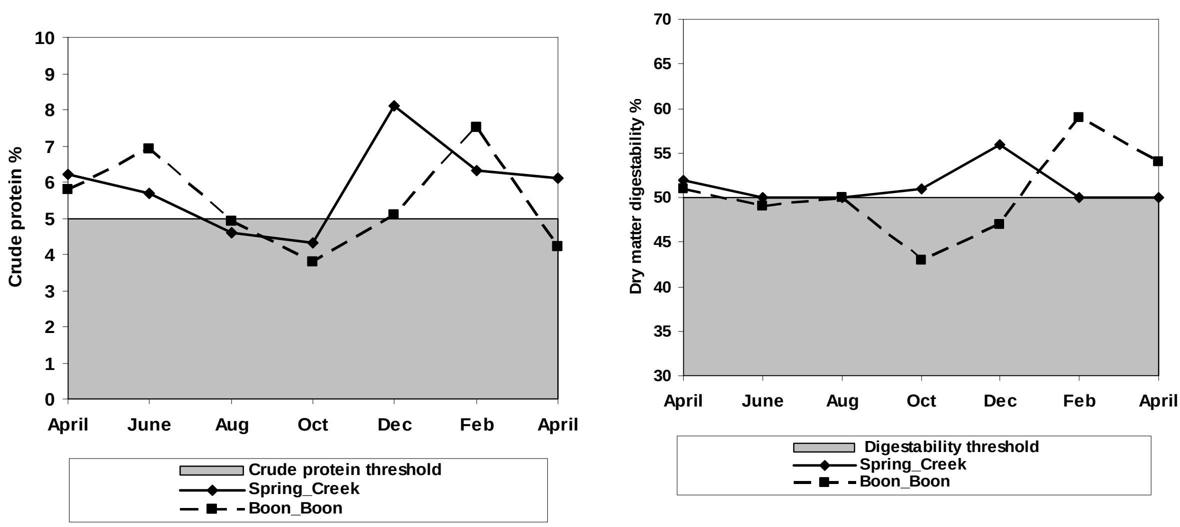


Figure 36: NIRS crude protein (A) and dry matter digestibility (B) trends over a 12 month period at two grano-diorite (goldfields) study paddocks. Spring Creek paddock, Cameron Downs was in B/C condition, long term moderately stocked, whilst Boon Boon paddock, Kirkland Downs was a C/D condition long term high stocked paddock. Boon Boon paddock cattle experienced longer and more severe dietary protein and dry matter digestibility deficits than Spring Creek during the dry season for the period surveyed.

While there is an obvious correlation between land condition, grazing pressure and diet quality, which can also be influenced by paddock size and land type diversity, the above data may suggest an interaction between patch diversity (or land condition heterogeneity) and diet quality, brought about in part by differences in available selection choices. This is difficult to test in anything but controlled experimental conditions, because long term stocking rate and contemporary land condition are usually confounded in commercial paddock situations.

The role of heterogeneity in paddock scale land condition recovery

Paddock scale studies at Virginia Park indicate that as paddocks recover, increasing heterogeneity in the range of available patch types (**Figure 37**A) is matched by increasing heterogeneity in the distribution and intensity of grazing effort across the paddock, as indicated by an increasing coefficient of variation in defoliation scores (**Figure 37**B). This is occurring during a period when average paddock utilisation (defoliation) is declining steadily in response to more sustainable grazing management practices.

Figure 37A also indicates a gradual shift toward higher C (blue patch types) and B land condition (green patch types) reflecting some improvement in land condition, but also a small increase in D condition (yellow-red-purple patch types). This is consistent with the findings for the dominant ironbark/bloodwood land type discussed in section 6.4.1.

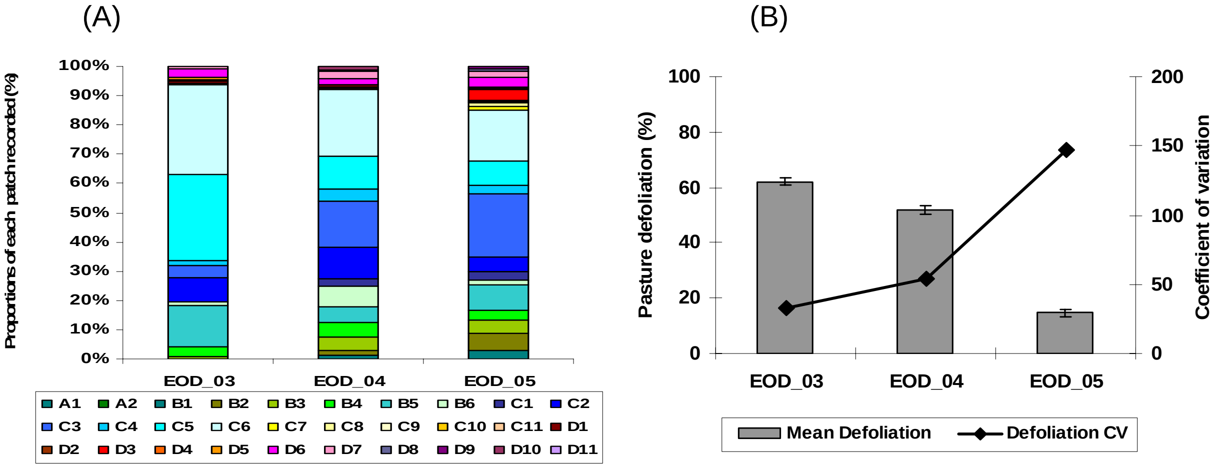


Figure 37: (A) Trends in patch diversity and grazing responses for combined Aires paddock survey data showing a gradual increase in the diversity of PATCHKEY patch types recorded at end of dry season 003, 2004 and 2005 (EOD_03, EOD_04, EOD_05). (B) Mean paddock defoliation and trends in defoliation coefficient of variation (CV) over the same period. Detailed descriptions of PATCHKEY patch types can be found in Table 9.

As overall forage supply and land condition improve and average defoliation decreases due to lower stocking rates (**Figure 37**B), opportunities for selective grazing increase (**Figure 38**). Note the increase in diversity of patch types from 2003 to 2005 (**Figure 37**A) and the corresponding increase in selection diversity and focus of grazing effort on C condition patches during recovery between 2003 and 2005 (**Figure 38**). This has important implications for understanding and managing the processes of recovery in degraded paddocks, especially those largely C condition paddocks dominated by Indian couch.

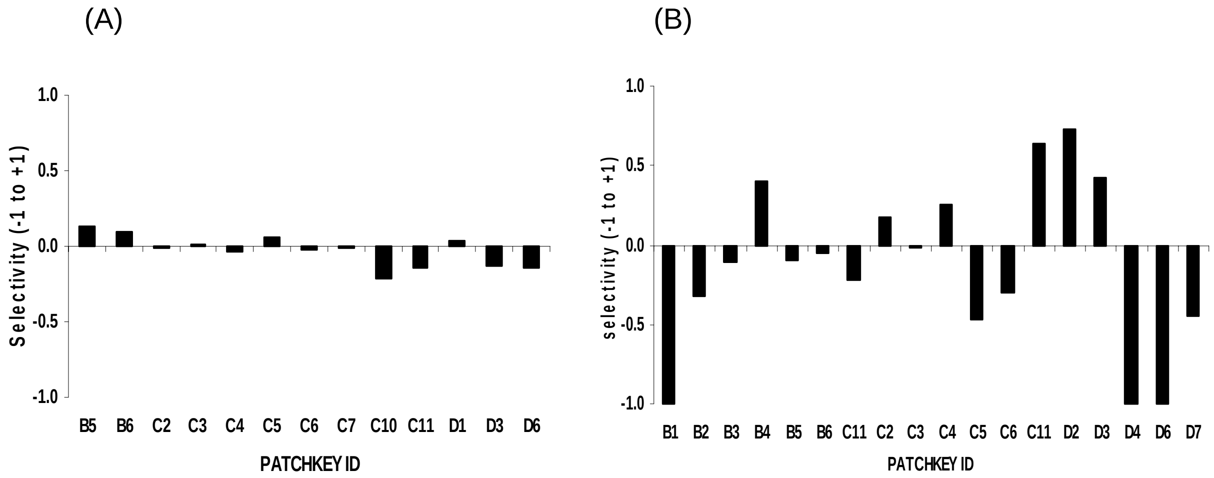


Figure 38: Comparison of patch selectivity patterns for Bottom Aires paddock Virginia Park between (A) 2003 dry season, prior to first wet season spell (which was also the start of a severe drought period) and (B) dry season 2005, following two wet season spells during that drought cycle. PATCHKEY classifications are used to identify individual patch types. See Table 9 for descriptions of PATCHKEY classes.

Implications for managing recovery of degraded C condition paddocks

The relationships between land condition, patchiness and grazing preference have important implications for managing recovery of degraded paddocks towards long term safe carrying capacity. Whilst implementation of lower stocking rates should lead to reduced overall utilisation and therefore relative increase in forage supply and selection choices, continued preferential grazing of C (poor) condition patches can have a significant impact upon the spatial and temporal patterns of recovery.

Results presented in section 6.4.1 indicate that recovery in C condition Indian couch dominated goldfields paddocks is a relatively slow and patchy process, influenced by edaphic features such as land type, topography and landscape position. When selective grazing preference for C and some D condition patches is overlaid, this interaction can further exacerbate spatial and temporal patchiness in recovery of land condition, with some patches remaining static or even further degrading despite an overall improvement in paddock condition. Continued preferential wet season re-grazing of C condition patches, especially those with recovering 3P grasses present, can severely impede the capacity of those plants to build up the root reserves and basal area needed for recovery and growth (Northup *et al*, 1999, 2003). 3P grasses provide both the semi-permanent architecture necessary to trap and retain litter, sediment and nutrients and also the deep infiltration pathways necessary to improve sub-soil moisture.

Thus, while reduction in overall pasture utilisation can improve ground cover and assist recovery, results from Virginia Park suggest that without wet season spelling, reducing utilisation alone may not be enough to optimise recovery, due to continued year round preferential selection of C condition patches. Wet season spelling can reduce selection pressure on these C condition patches when recovering 3P grasses are at their most vulnerable early wet season growth stage (Andrew, 1986) thus assisting their recovery. This is especially important for those vulnerable land types such as lower slope sodic and frontage areas which are already selectively grazed during the wet season.

Evidence from Bottom Aries paddock, Virginia Park, indicates that there may be a case for successive wet season spells to boost recovery of 3P grasses, especially during drier periods when they appear to have a competitive advantage over the more drought sensitive Indian couch. Further management implications and key messages relating to recovery of land condition and productivity in degraded grazed landscapes will be discussed in sections 6.4.5 and 6.4.6 of this report.

6.4.3 Land condition, leakiness and the importance of patchiness

The interaction and impacts of land condition and grazing preference on small scale patchiness in patterns of grazing distribution and recovery have been canvassed in the previous section. This has important consequences for recovery of landscape and hydrological function and control of sediment and nutrient movement across the landscape. Patch scale variability in land condition and grazing pressure leads to patchiness in distribution of ground cover and pasture biomass, which in turn influences the ability of landscapes to capture rainfall, trap and retain resources and control overland flow. As the size and frequency of C and D condition patches increases, under the impact of sustained overstocking and/or drought, landscapes become more "leaky" (Ludwig *et al*, 2005). Conversely, as recovery proceeds in response to lower utilisation and wet season spelling, recovering C condition patches, especially those containing remnant 3P grasses trap litter, moisture, soil and nutrients, join up via litter bridges and commence the shift back to B condition, improving patch infiltration and reducing landscape leakiness.

The processes of degradation and recovery often follow different or non-equilibrium spatial and temporal pathways. **Figure 39**A shows changes in mean number of patches per 10 metres and mean LFA infiltration scores for a range of permanent LFA transects established in late 2002 on the main flume (flume1) across key patch types and associated transition zones located within the flume hillslope. In LFA terms a "patch" is a resource accumulating zone (usually a zone of good plant foliar and/or litter cover, which traps and retains resources) whereas an "inter-patch" is a resource shedding zone (usually a zone of reduced plant and /or litter cover and some surface erosion) (Tongway and Hindley, 1995). The proportion and distribution of patches and inter-patches is a measure of landscape organisation and equates well with the relative leakiness of a landscape (Ludwig *et al*, 2002). Increase in number of patches and decrease in average inter-patch length often signifies break-up of existing patches during early degradation phases, though once degradation is advanced, the number of patches declines and the average inter-patch length increases as inter-patches join up to form large "fetches" (Tongway and Hindley, 1995).

During recovery, remnant micro-patches (grass tussocks, logs etc.) start the recovery process by trapping litter and sediment which improves localised infiltration, encourages herbage growth. These micro-patches expand upslope from their source and start re-connecting to form increasingly larger patches, subsuming many of the small inter-patches in the process. However, it is quite common during recovery for the larger, more surface eroded inter-patches to remain intact for some time – hence the often higher mean inter-patch length during recovery.

(A) (B)

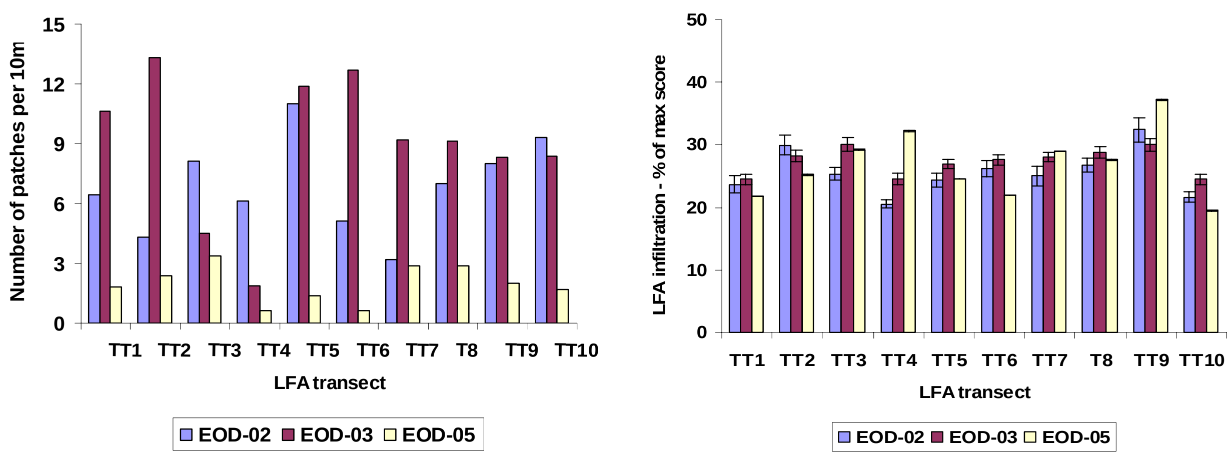


Figure 39: Comparison of (A) mean number of LFA patches per 10m and (B) LFA SSC infiltration scores for seasons 2002, 2003 and 2005 on main flume LFA fixed transects, Aires paddock, Virginia Park.

On the main flume transects, across all LFA transects mean number of patches per 10m went from 7 to 9 during the 2002-2003 drought period then declined to 2 by end of dry 2005 as recovery proceeded. At the same time mean inter-patch length went from 0.5m in 2002 to 0.6m in 2003 before increasing to 1.4m by late 2005.

Figure 39A also indicates that there was considerable variation in response between LFA transects, especially between 2002 and 2003. This reflects the influence of topographic location (run-on vs. run-off) and landscape position (up-slope, mid-slope, lower-slope) factors discussed in section 6.4.1. **Figure 39**B also indicates the same impact on SSC infiltration scores for these transects. For instance transects TT3 and TT4, located in lower slope sodic areas, show a decline in the number of patches as the 2002-03 drought proceeds, whereas transects TT1, TT2, TT6, TT7 and TT8 located in mid-slope show a marked increase for the same period. In the case of the sodic areas this indicates that degradation was already well advanced there and the few good patches remaining were under pressure and in decline. By contrast, the mid-slope transects started in C+ to B- land condition areas and so the increase in micro-patch frequency reflects early decline in LFA condition in response to the 2003 drought. Of the remaining transects TT9 and TT10, located in up-slope areas and TT5 in a lower slope, non-sodic area fall somewhere in between in terms of seasonal responses. .

The relationship between land type, patch condition and leakiness is especially critical where selective grazing coincides with the more vulnerable land types such as lower slope *Carissa/Eremophila* dominated sodic soil communities and frontage areas, which are adjacent to stream channels. Continued grazing-induced degradation of sodic soil areas can expose the highly dispersive sub-soils to rapid erosion, resulting in accelerated soil loss into the adjacent gullies and stream channels, especially during large rainfall events (Bartley *et al*, 2006, see also section 7 of this report). Once sodic sub-soils are exposed, the only practical way to reduce further erosion is to slow or divert overland flow onto these areas, either mechanically (by use of diversion banks) or through retention of increased cover and biomass upslope of such areas.

The relationship between patch condition, landscape and hydrological function

Patch scale studies at Wambiana research site, Virginia Park and Blue Range stations provided important insights into the relationship between patch condition, landscape and hydrological function, which feed into landscape leakiness. LFA soil surface condition (SSC) values were established for the full range of PATCHKEY classes at all three study sites. At Virginia Park and Blue Range studies also focussed on developing relationships between SSC, total ground cover and litter contribution and measured metrics such as infiltration, leakiness and soil respiration. A full description of the design and methods employed can be found in section 6.3 and appendix 13 of this report. Results comparing measured infiltration, ground cover and SSC scores are reported in section 7.3.2 of this report. The relationships reported here use whole of patch data, in order to accommodate the effect of within-patch variability and minimise the influences of immediate up-slope patch condition.

Figure 40 shows the strong relationships obtained between measured infiltration and total ground cover and litter cover respectively for the range of patches studied on the Virginia Park granodiorite (goldfields) study site in late 2004. Relationships derived from similar patch studies on the Blue Range sedimentary land type are also strong (**Figure 41**) though the amplitude of the infiltration response curves was shallower than for Virginia Park. This may reflect real differences in land type infiltration response, but it may also be due to land pre-existing condition features (e.g. soil surface hardness) which may be artefacts of previous land use history.

Earlier patch studies at Virginia Park in both 2003 and 2004 produced strong relationships between ground cover, LFA soil surface condition (SSC) measured ground based directional leakiness and soil respiration indices for a range of key patch types across the hillslope at the Aires paddock flume sites. Patch directional leakiness scores (**Figure 42**A) were derived from classified 4m*3m contiguous images captured by an ATV mounted digital camera, using the method of Ludwig *et al* (2002) modified for ground based use. Soil respiration (**Figure 42**B) was measured using the method of Hartigan (1980).

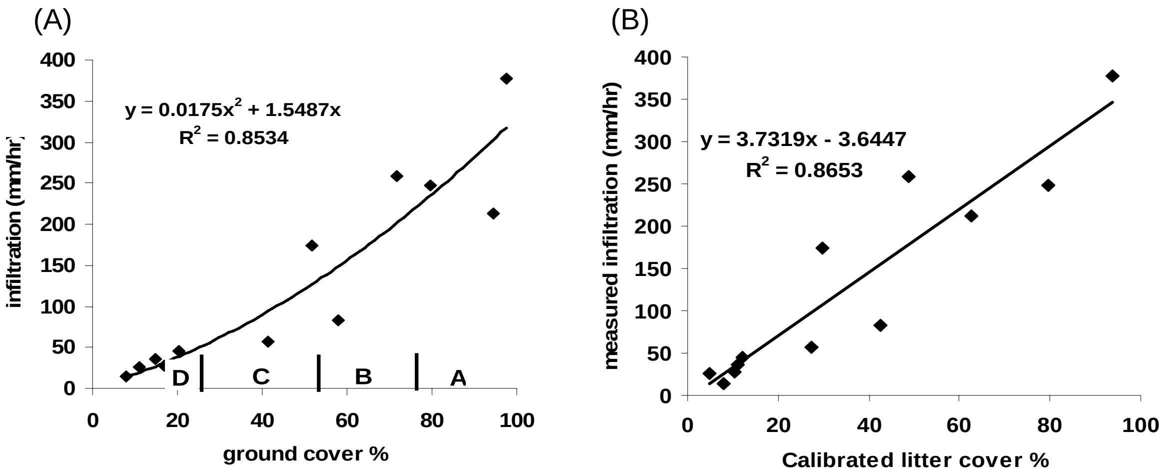


Figure 40: Relationships between (A) total ground cover and measured infiltration (in mm/hr) and (B) infiltration and litter contribution, from whole patch studies on grano-diorite (goldfields) land type at Virginia Park flume sites, 2003-05. A, B, C and D divisions in (A) indicate cover ranges and thresholds for each class measured in both patch and paddock surveys on this land type.

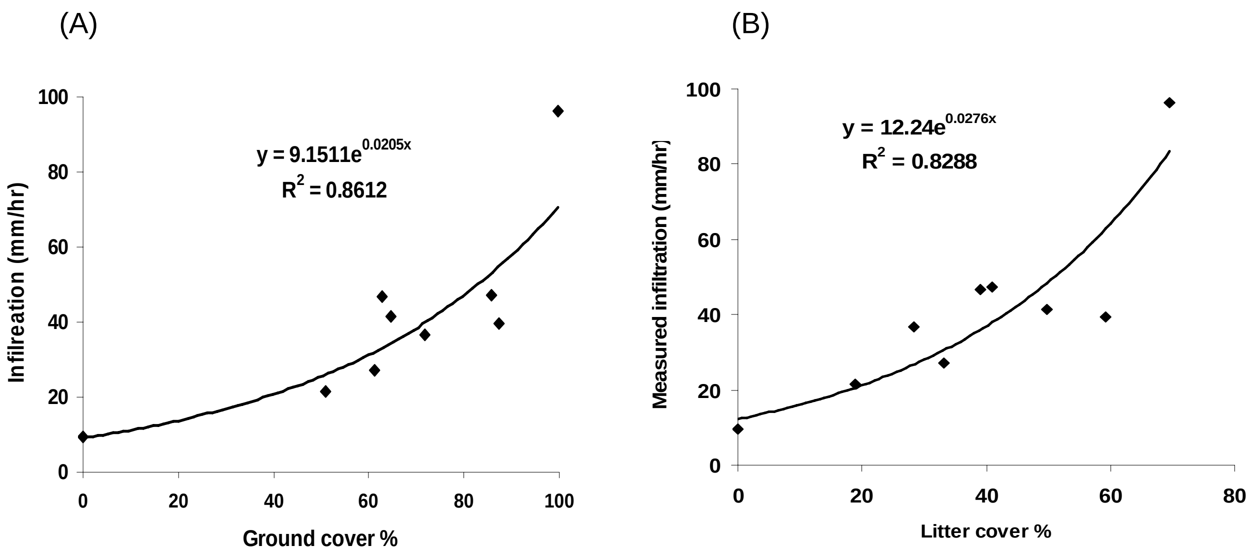


Figure 41: Relationships between (A) total ground cover and measured infiltration (in mm/hr) and (B) infiltration and litter contribution, from whole patch studies on sedimentary land type at Blue Range exclosure site May 2005. A, B, C and D divisions in (A) indicate cover ranges and thresholds for each class measured in both patch and paddock surveys on this land type.

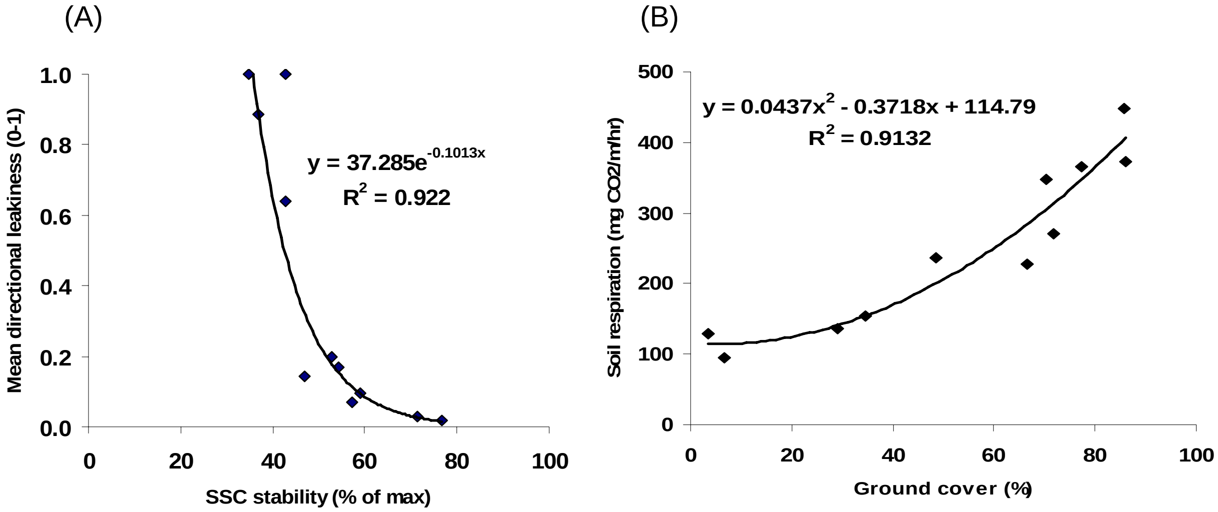


Figure 42: Relationships between (A) SSC stability and ground based directional leakiness and (B) SSC stability and soil respiration at Virginia Park 2004. Note that SSC scores are expressed as a percentage of maximum possible value for each SSC index.

The derived relationships were subsequently applied to hillslope and paddock scale patch, ground cover and patch SSC data to calculate predicted changes in mean hillslope and paddock infiltration, directional leakiness, SSC and soil respiration over time and also to examine the spatial patterning of these landscape function metrics. Whilst relationships between SSC indices and measured landscape and hydrological function metrics are also strong, the ground cover based relationships were preferred because of their applicability to readily available continuous cover data, compared to categorically derived LFA SSC scores and their direct relationship with landscape leakiness, which is derived from classified remote sensed ground cover data.

Table 11 shows the mean ground cover and the derived infiltration, directional leakiness and soil respiration scores for the main Aires study paddocks at Virginia Park between end of dry 2002 and 2005, while **Table 12** provides similar data summaries for the three flume hillslopes over the same period.

Table 11: End of dry season ground cover, infiltration, directional leakiness and soil respiration trends for Aires paddocks, Virginia Park, 2002-05

Variable	Unit of measure	Year	Bottom Aires	se	Top Aires	se
Ground cover	%	EOD_02	62.07	1.994	73.12	1.626
Ground cover	%	EOD_03	32.07	1.214	33.72	1.216
Ground cover	%	EOD_04	43.86	2.383	48.11	1.857
Ground cover	%	EOD_05	47.82	2.086	52.00	2.522
Predicted infiltration	mm/hr	EOD_02	144.01	5.941	113.37	6.513
Predicted infiltration	mm/hr	EOD_03	73.46	3.385	80.64	3.386
Predicted infiltration	mm/hr	EOD_04	92.59	7.182	116.65	5.860
Predicted infiltration	mm/hr	EOD_05	101.65	6.496	115.57	8.176
Directional leakiness	0-1 (non leaky-leaky)	EOD_02	0.20	0.019	0.22	0.022
Directional leakiness	0-1 (non leaky-leaky)	EOD_03	0.57	0.014	0.54	0.312
Directional leakiness	0-1 (non leaky-leaky)	EOD_04	0.50	0.028	0.41	0.022
Directional leakiness	0-1 (non leaky-leaky)	EOD_05	0.48	0.018	0.44	0.022
Soil respiration	mg CO2/m/hr	EOD_02	278.74	9.241	236.95	9.939
Soil respiration	mg CO2/m/hr	EOD_03	165.44	4.263	159.42	4.336
Soil respiration	mg CO2/m/hr	EOD_04	217.28	9.852	249.83	8.177
Soil respiration	mg CO2/m/hr	EOD_05	227.91	9.055	247.55	11.534

Table 12: End of dry season ground cover, infiltration, directional leakiness and soil respiration scores for Virginia Park flume hillslopes, 2002-05.

Variable	Unit of measure	Year	Main flume (1)	se	Up-slope flume (2)	se	Scald flume (3)	se
Ground cover	%	EOD_02	61.45	0.833	58.03	0.910	68.11	1.304
Ground cover	%	EOD_03	33.84	0.311	37.94	0.449	45.57	0.974
Ground cover	%	EOD_04	44.31	1.067	34.13	1.750	46.64	1.400
Ground cover	%	EOD_05	57.21	1.103	50.21	1.749	54.40	2.099
Predicted infiltration	mm/hr	EOD_02	186.91	2.335	176.53	3.329	182.55	3.443
Predicted infiltration	mm/hr	EOD_03	70.58	0.293	71.86	1.042	73.92	0.794
Predicted infiltration	mm/hr	EOD_04	116.43	3.344	88.53	4.794	85.68	2.764
Predicted infiltration	mm/hr	EOD_05	155.70	3.870	129.03	5.829	148.89	59.774
Directional leakiness	0-1 (non leaky-leaky)	EOD_02	0.30	0.004	0.30	0.005	0.31	0.010
Directional leakiness	0-1 (non leaky-leaky)	EOD_03	0.57	0.001	0.56	0.004	0.56	0.004
Directional leakiness	0-1 (non leaky-leaky)	EOD_04	0.50	0.008	0.55	0.013	0.57	0.009
Directional leakiness	0-1 (non leaky-leaky)	EOD_05	0.38	0.009	0.44	0.016	0.42	0.020
Soil respiration	mg CO2/m/hr	EOD_02	306.03	3.143	289.42	4.508	300.69	4.098
Soil respiration	mg CO2/m/hr	EOD_03	160.58	0.347	160.68	1.142	164.07	0.729
Soil respiration	mg CO2/m/hr	EOD_04	222.70	4.077	185.34	5.834	184.05	3.186
Soil respiration	mg CO2/m/hr	EOD_05	260.44	4.929	224.74	7.119	255.26	8.460

Figure 43 shows examples of Kriged maps of derived infiltration and directional leakiness at both paddock and hillslope scale. The derived spatial patterns of infiltration and directional leakiness can be compared with flume run-off and sediment data and landscape leakiness data derived from classified remote sensed imagery.

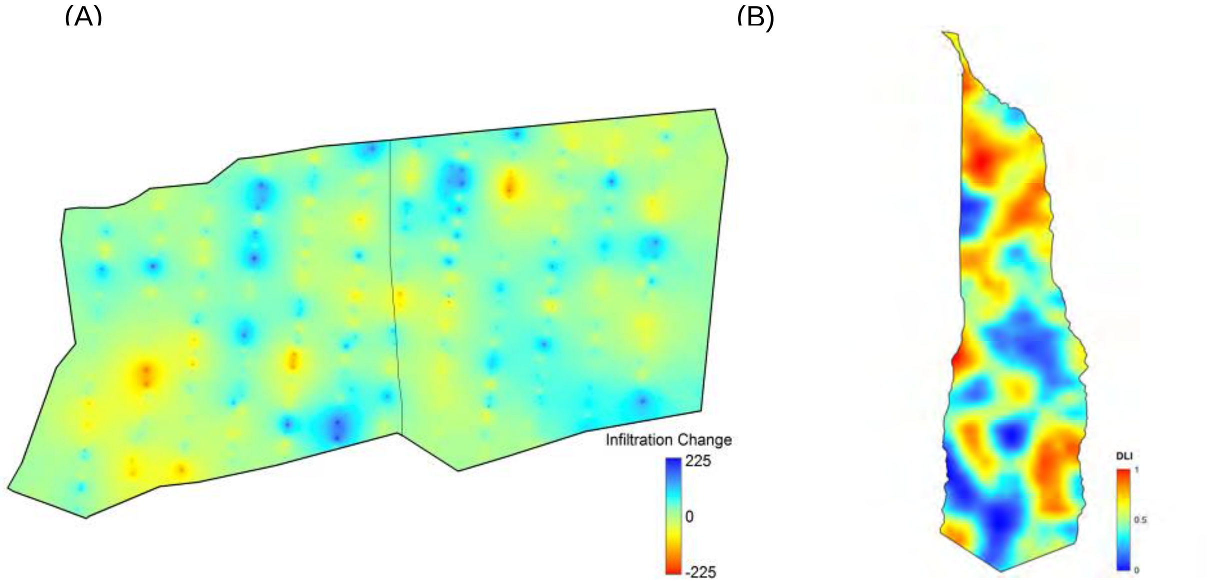


Figure 43: (A) Patterns of change in predicted EOD infiltration (mm/hr) in Aires paddocks Virginia Park from 2002 to 2005 and (B) directional leakiness (DLI) patterns on main flume 1 hillslope EOD 2004. DLI scale is between 0 and 1 with 0 being non-leaky and 1 being very leaky

These derived relationships were also employed in development of the development of predictive models such as the LISEM hillslope delivery model (Kinsey-Henderson *et al*., 2006) linking the distribution and quality of ground cover and key patch types with likely run-off, sediment and nutrients movement outcomes (Bartley *et al*, 2005) They are also being used to refine the landscape leakiness model and associated leakiness index (LI) calculator (Ludwig *et al*, 2005).

Small scale variability in patch condition – implications for stability and recovery

Detailed patch studies at Virginia Park and Blue Range have also shown that C condition and certain D condition patches are the most spatially and temporally dynamic of the ABCD condition classes. Erosion pin data from marked patches at Virginia Park and Blue Range show significant micro-scale movement of sediment within C condition patches (see section of 7 of this report) indicating a degree of soil surface instability, due to loss of perennial plant cover. Based on patch study observations, at least some of this instability can be attributed to the fact that C condition patches exhibit the greatest small scale (within-patch) spatial variability in key patch metrics such as plant cover, litter cover and soil surface condition, which drive hydrological and landscape function. This is in line with the findings of Northup (1999, 2004) in detailed patch dynamics studies at the Cardigan research site used for ECOGRAZE studies.

Figure 44 shows mean total ground cover and litter cover scores for a range of patch types at Virginia Park and compares these with the coefficient of variation for the same scores. They show that as mean cover and litter cover decline (indicating decline in patch condition) the small scale distribution of that cover across the patch becomes more variable. PATCHKEY classes have been grouped according to dominant plant functional group for the purpose of examining these relationships (see **Table 9** for details of PATCHKEY functional group classes). The implication here is that these small scale patch and inter-patch sequences, allow the development of leakiness pathways across and between patches, affecting soil surface stability.

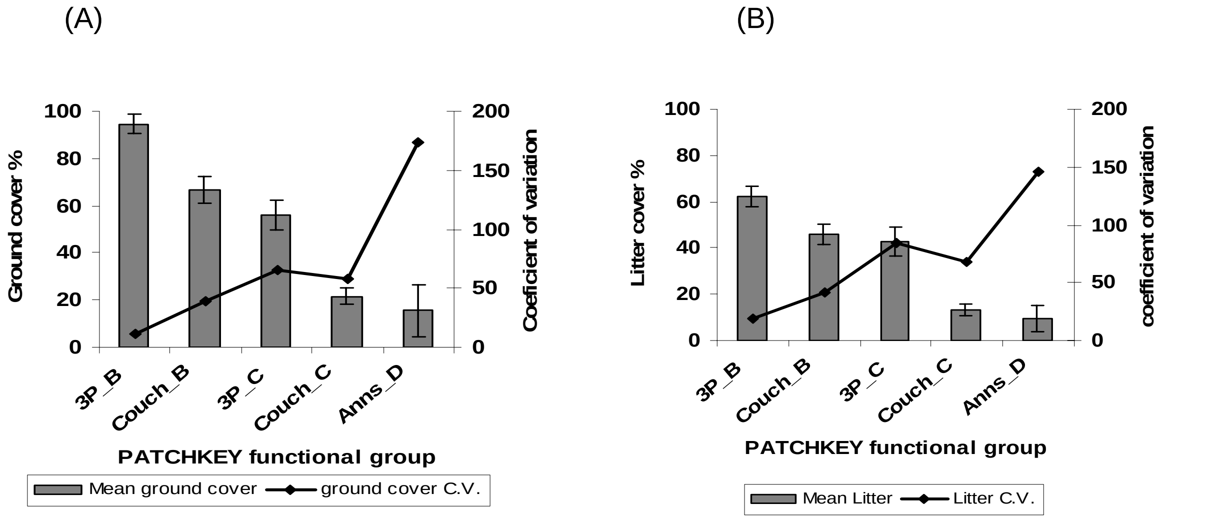


Figure 44: Comparison of means and coefficient of variation (C.V.) for (A) total ground cover and (B) litter cover measured at 1m intervals across patches of various land condition and functional group classes at Virginia Park study site in November 2004. PATCHKEY functional group descriptions are included in **Table 9**.

By contrast, C condition patches exhibit far less variability in terms of grazing preference, as evidenced high mean defoliation scores and lower coefficient of variation for defoliation scores on these patch types (**Figure 45**A). Similar patterns can be seen in paddock survey data from Virginia Park (Figure 43B). The combined impact of stronger grazing preference and small scale variability in resource distribution and soil surface condition leaves C condition patches particularly exposed to continued degradation, even under moderate grazing regimes, though this will vary with land type and location.

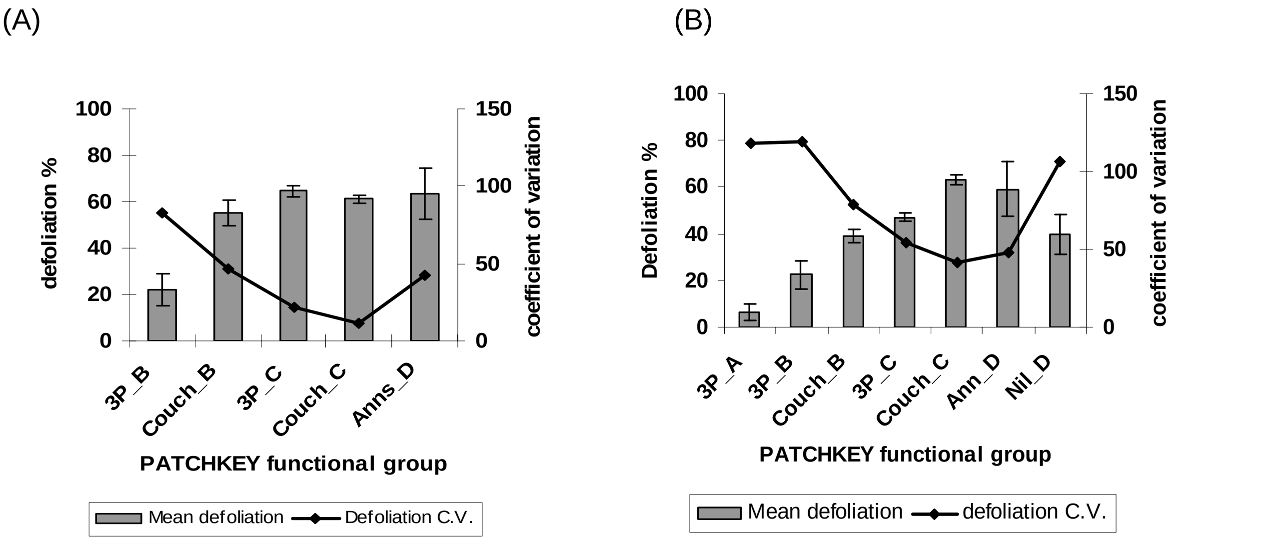


Figure 45: (A) Comparison of mean and coefficient of variation (C.V.) for defoliation (grazing) measured at 1m intervals across patches of various land condition and functional group classes at Virginia Park study site. (B) Comparison of mean and coefficient of variation (C.V.) for defoliation (grazing) measured in paddock surveys at Virginia Park study site. PATCHKEY functional group descriptions are included in Table 9.

Patch scale temporal variability

Figure 46 shows the trajectories of key patch types (as designated by cover class) between 2003 and 2005 on the main flume 1 hillslope at Virginia Park. It shows that for the 20-60% cover classes (the D-C-B condition transition) there is considerable volatility in both the magnitude and trajectory of year to year cover change. While most patches show improvement in cover% in response to better seasonal and management induced conditions, there is also some significant movement backwards for patches in the 40-60 % cover classes in particular and even some higher starting cover classes.

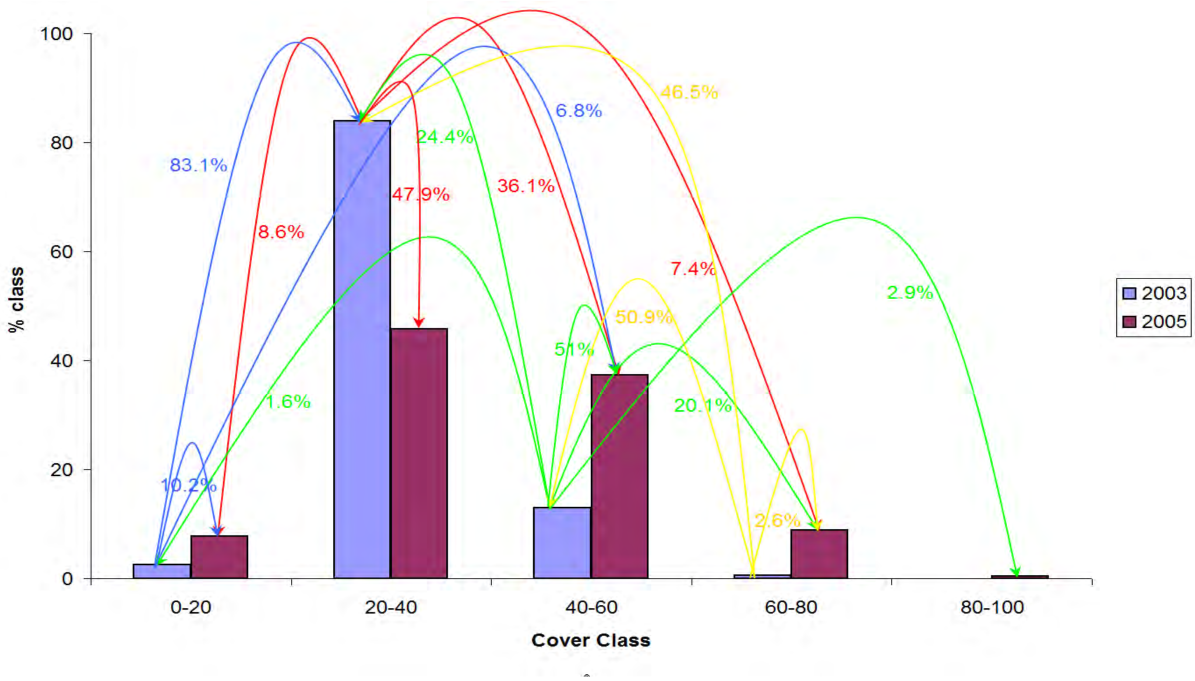


Figure 46: Patch change trajectories between 2003 and 2005 using end of dry 2003 ground cover class as a surrogate for patch type. End of dry 2003 covers are used as a starting baseline, because of the overriding impact of the 2003 drought. Whilst most of the cover trends are increasing, there is also movement backwards, significantly from some higher cover classes.

This temporal variability, together with the previously discussed small scale spatial variability within the dominant C condition patches, makes it difficult to predict the likely trajectory for individual patch types from starting patch condition data. The importance of this for assessing land condition at the hillslope or paddock scale is discussed in the following section.

6.4.4 Implications for assessing land condition

Figure 47 uses classified cover data from *Quickbird* high resolution satellite imagery to calculate the probability of land in the same locations within Aires Top and Bottom paddocks, Virginia Park, moving between A, B, C and D condition over a period of two years (2003-2005).

(A)

2005 State

2003 State	A	B	C	D
A	0.83	0.12	0.05	0.00
B	0.48	0.30	0.21	0.00
C	0.03	0.08	0.79	0.10
D	0.00	0.00	0.28	0.72

(B)

2005 State

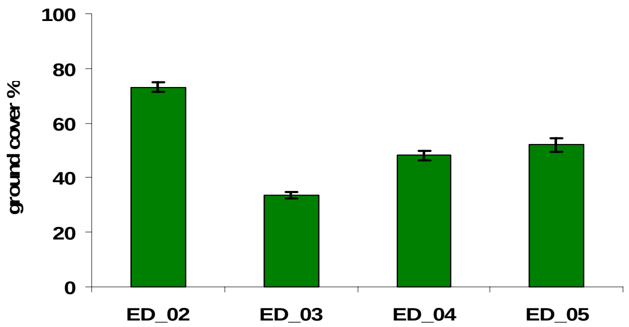
2003 State	A	B	C	D
A	0.72	0.16	0.12	0.00
B	0.44	0.30	0.26	0.00
C	0.03	0.07	0.82	0.08
D	0.00	0.00	0.32	0.68

Figure 47: Transition matrix illustrating the probability of patches moving from one ABCD land condition class (state) to another between 2003 and 2005 (A) Bottom Aires paddock; (B) Top Aires paddock.

These transition matrices indicate that at paddock scale, B condition land is probably the most dynamic in response to combined grazing and climatic impacts, in terms of short term movement between A, B and C condition in the goldfields landscapes of Virginia Park. This is not surprising when one considers that B condition, the equivalent of state II in the ECOGRAZE project, sits astride the state and transition model “management restoration threshold” (Ash *et al*, 1994, 2001), where grazing land management strategies (stocking rate, spelling, use of fire, placement of fences and waters etc.) can generate shifts in land condition between A and B (and some C) condition.

While C condition land appears to be the most stable in terms of the proportion remaining in that state between years, there was also a significant movement at the margins between C and adjacent B and D condition classes during the period from late 2003 and late 2005. This indicates that while land may slip from B to C, once it is in C condition and especially D condition, it is a much slower path back. This is consistent with the message of Ash *et al* in the paper titled *Falling over cliffs and climbing back slowly* (Ash *et al*, 1996). It also broadly reflects the patch scale trends recorded on the main flume hillslope (Figure 46) and the ground based paddock survey results in **Figure 48**B, in the period following the 2003 intense drought and crash in land condition.

(A)



(B)

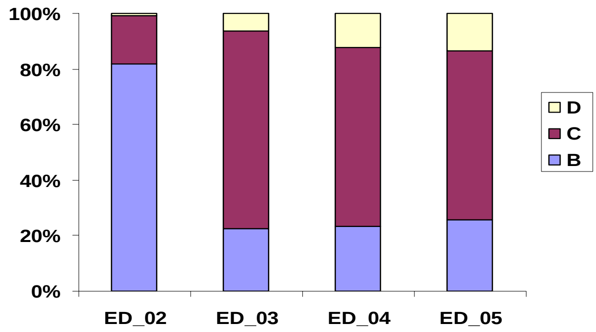


Figure 48: Comparison of end of dry season (ED) changes in (A) ground cover and (B) land condition proportions for Bottom Aires paddock, Virginia Park, 2002-2005.

While the 2003-05 shift from D to C recorded in the remote sensed data is slightly less evident in the ground based paddock data, this may be an artefact of the use of ground cover as a surrogate for land condition in **Figure 47**A. By contrast, the ground based data in **Figure 48**B uses the PATCHKEY framework to record land condition based on a full array of structural and functional elements. Paddock and hillslope scale studies at Virginia Park show that changes in the levels of ground cover were more volatile than changes in overall ABCD land condition class (**Figure 48**) except where severe drought conditions lead to a significant collapse in both Indian couch basal cover and overall ground cover, during the intense drought period of 2003. This might be expected, as land condition is made up of a range of pasture and soil condition elements in addition to cover, which itself can be more ephemeral in response to short term defoliation events, fire and drought.

Using ground cover as a surrogate for land condition is a common practice in remote sensing situations. While it works well in most situations, especially in tussock grass communities, studies using PATCHKEY in the Indian couch dominant Virginia Park paddocks and other sites has identified some issues that require consideration. For instance, while there is usually a strong nexus between foliar cover and land condition in tussock grass communities, reduced ground cover due to recent short term defoliation through grazing (or burning) does not necessarily imply a reduction in land condition, as the deep rooted perennial grass bases underpinning that land condition remain in tact.

By contrast, in Indian couch (*Bothriochloa pertusa*) pastures, high cover does not always mean high biomass, as pastures can be grazed as lawns but retain their stoloniferous cover. However, low couch cover often signifies reduced land condition, because it can signal a collapse of the matrix of shallow-rooted crowns and ephemeral stolons that hold the soil surface together. These are issues to take account of when assessing land condition and monitoring condition trends both on-ground and remotely, especially on Indian couch dominated landscapes.

Land condition changes at Virginia Park – lessons for assessment

These patterns of land condition trend observed from patch to paddock scale during 2003-05 were also evident in snapshot patchiness grid surveys conducted at hillslope and sub-catchment scale at Virginia Park, Blue Range and Wambiana study sites on various ABCD condition classes, during 2006. Again, they show that the proportion of C condition patches can remain relatively static for some time, while the proportions of both D and B shift according to which direction paddock is trending (**Figure 49**) (Abbott and Corfield, 2006).

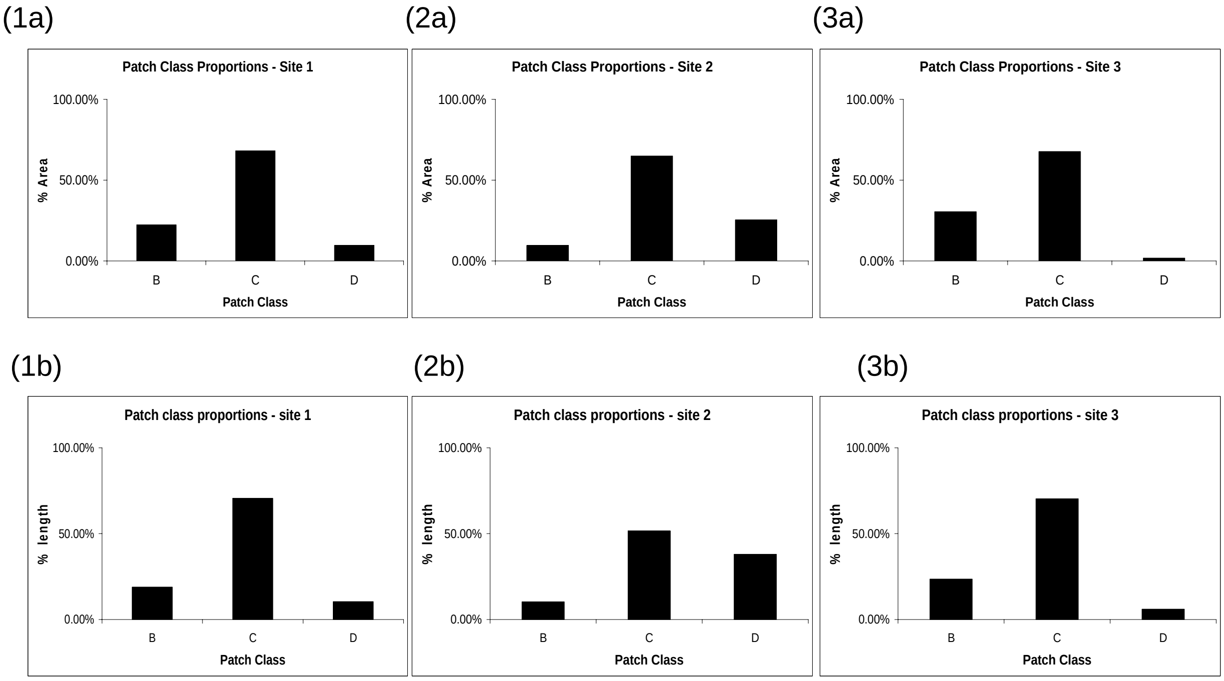


Figure 49: Analysis of PATCHKEY hillslope transect data representing 3 land condition classes straddling BCD range. Charts show ABCD patch type as a proportion of site for the classified image (% area) and transect samples (% of transect length). Site 1 is a mid -C condition hillslope with some B condition patches; site 2 is a C-D condition hillslope and site 3 is a C-B condition hillslope. Note the good agreement between classified QUICKBIRD satellite imagery (a) and ground-based PATCHKEY (b).

While B condition land sits astride the "management restoration threshold" which characterised the ECOGRAZE Cardigan state II recovery scenario, the landscapes shown in **Figure 49** all straddle the B-C-D continuum, just below that restoration threshold - as does much of the goldfields grazing lands in the upper Burdekin. Apart from site (e) the proportion of C condition land is much the same across all these sites, while the varying proportions of B and D characterize the overall land condition class.

So why do the proportions of land in C condition appear to remain relatively stable across a range of land condition situations either side of the B-C-D band, irrespective of land condition trend within these sites? Moreover, how does this reconcile with the evidence (see section 6.4.3) that C condition patch types are the most variable and volatile in terms plant and cover distribution, small scale soil movement and leakiness potential? Is the volatility observed at patch scale not reflected (or not captured) as we scale up? Does this suggest that the current ABCD thresholds and class ranges for C condition (e.g. bare ground >50% but <80%) are too broad to capture what is happening within this important condition class, which currently dominates the goldfields landscapes? And what can we do about it?

Issues of scale and resolution in land condition assessment

It is insightful here to compare the ABCD land condition and PATCHKEY class trends recorded on the main flume 1 hillslope at Virginia Park between end of dry 2002 and 2005 (**Figure 50**). Both data sets were derived from the same PATCHKEY data, with ABCD land condition categories making up the primary classifier of the binary PATCHKEY classes. As with the whole of paddock results, the shift back from C to B has been slow on the flume hillslopes, following the crash of 2003, with C condition proportions remaining largely the same between 2003 and 2005 (**Figure 50**A). Yet PATCHKEY data for the same surveys (**Figure 50**B) show considerable movement in the proportions of individual patch types identified on this site, with most of that movement occurring within the C condition range.

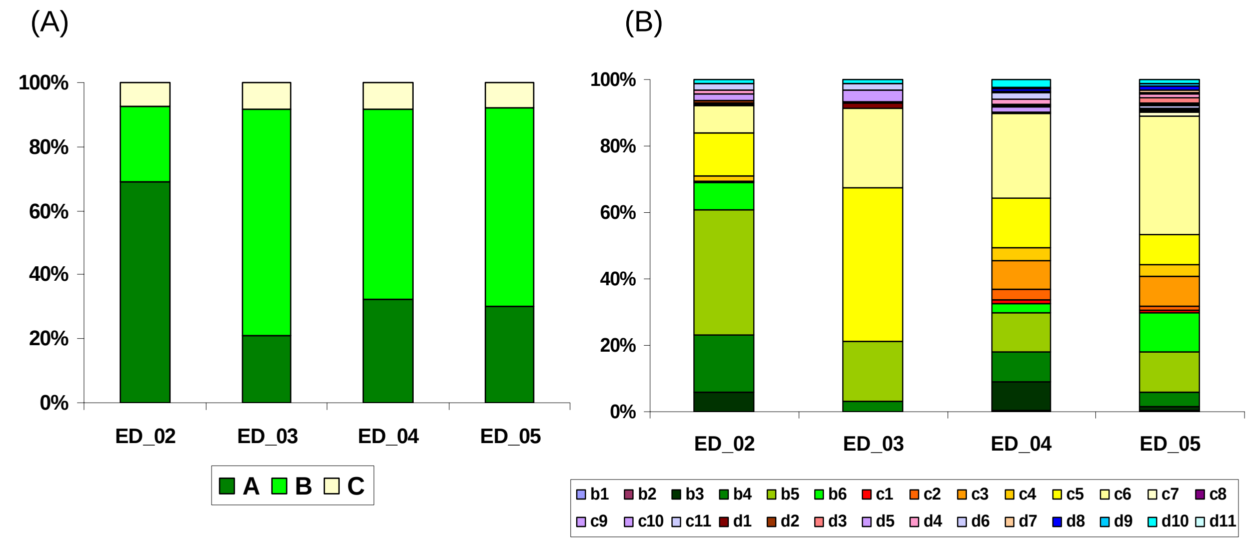


Figure 50: Trends in (A) ABCD land condition proportions and (B) PATCHKEY patch type proportions within the main flume hillslope in Bottom Aires paddock, Virginia Park, end of dry season 2002-05.

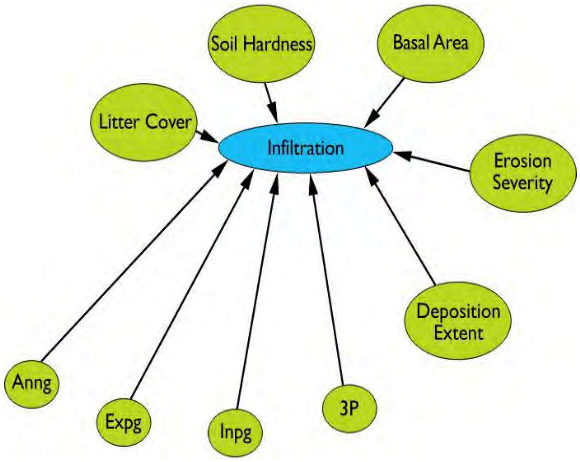
So, are these observed patch-scale spatial and temporal changes in C condition simply an artefact of the current PATCHKEY framework (i.e. the product of too many arbitrary patch classes, especially within the C condition range) or do they reflect important structural and functional thresholds within the C condition range? The observations reported here from studies at a range of scales would suggest the latter. If so, what does this mean for land condition assessment and does it matter anyway? To answer this we must consider the capability of current assessment and monitoring tools, the opportunities presented by better understanding of the patterns and processes of degradation and recovery and the likely benefits to be gained from applying the new knowledge and tools arising from it.

Whilst it could be argued that Indian couch dominated C condition landscapes are closer to the state IV (landscapes dominated by exotics) of the state and transition (SAT) model of Andrew *et al* (1994, 2001), Virginia Park studies have shown that recovery can still be achieved, albeit slower and more patchy in the early stages than with the ECOGRAZE study (Ash, 2001). As manipulation of grazing management provides the only practical option for restoring land condition on these grazed landscapes, it is important for land managers to be able to recognise the signs and processes of degradation and recovery trends within C condition, in order to better manage recovery. This may require tools that are more spatially and temporarily relevant than the ABCD *Stocktake* and land condition assessment framework (Chilcott *et al*, 2003) or the Landsat TM or *Modis* based remote sensing imagery used for time trend analysis.

Adding a spatial dimension to ABCD – dealing with patchiness and condition trend

An important step in this quest is simple, ground based assessment and monitoring the spatial and temporal patterns and processes occurring between the patch and paddock scales (or between the LFA and ABCD scale of application). One way of doing this is to use a tool such as the PATCHKEY framework to explore the size, frequency and distribution of key patch types across a range of land condition sequences at hillslope and sub-catchment scale. Those key patch types are in turn selected to represent important thresholds in infiltration, leakiness or nutrient cycling identified from detailed patch studies and linked with PATCHKEY classifiers such as plant and litter cover level, dominant functional group, basal area and erosion/deposition status (**Figure 51**).

(A)



(B)

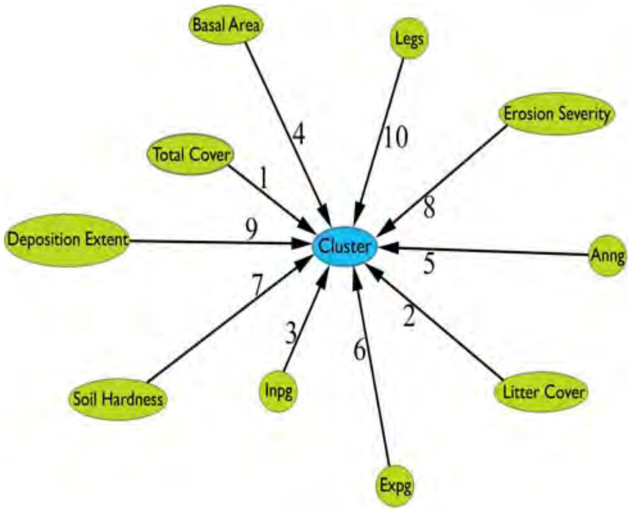


Figure 51: Using a Bayesian modelling approach to identify key drivers of patch structure and function. (A) Bayesian model showing relative importance of patch attributes for infiltration. (B) Schematic Bayesian cluster groupings of conceptual patch types, showing main contributors to patch condition within patch data collected using the PATCHKEY framework. Code explanations: 3P = palatable perennial productive tussock grasses; expg=exotic perennial grasses (mostly *Bothriochloa pertusa*); Anng-annual grasses, Inpg=increaser perennial grasses. Legs=leguminous forbs.

These thresholds can represent critical cover levels or functional group classes or transitions sitting just either side of the boundaries separating ABCD classes or important steps within C condition, which might indicate condition trend. As the PATCHKEY classification framework takes existing ABCD herbage layer classes as its primary (structural) classifier, it can also be used simply to record the size and/or frequency of ABCD patch classes along a transect or grid.

The same hillslope and sub-catchment scale grid surveys which generated the data in **Figure 49**, were also used to record the size, distribution and frequency of key patch types across study sites at Virginia Park, Blue Range and Wambiana during 2006 (**Figure 52**). Continuous patch start and end positions and patch type and size details were recorded using a differential GPS unit for increased accuracy. Grid maps of these sites were created and compare with both ground based assessment of overall land condition using standard ABCD framework methodology (Chilcott *et al*, 2003) and high resolution *Quickbird* satellite imagery (Virginia Park only to date). This ground based data has been used to improve classification of remote sensed imagery in terms of land condition characteristics beyond the standard ground cover metrics currently used (**Figure 53**).

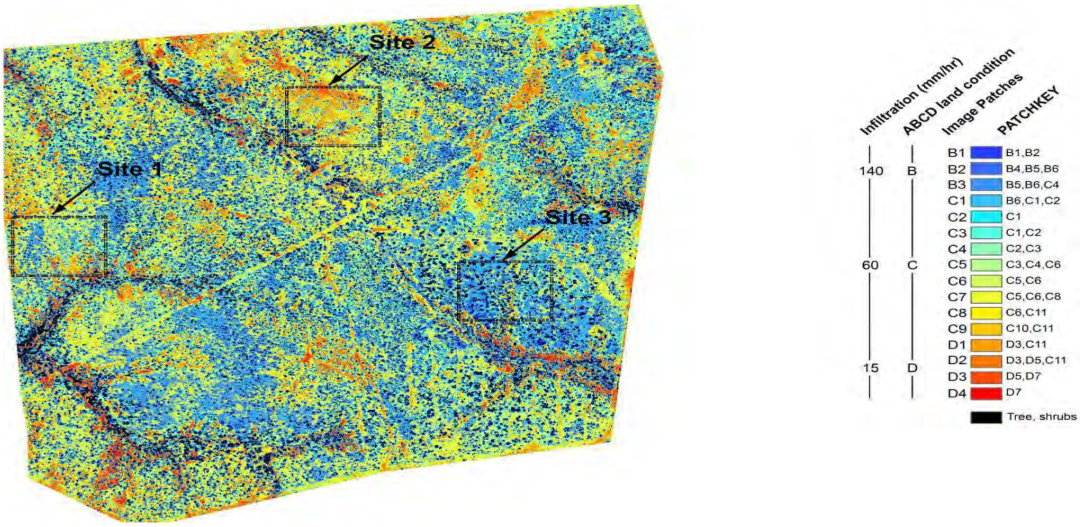


Figure 52: Use of hillslope patch transect and grid data to classify QUICKBIRD high resolution satellite imagery in terms of PATCHKEY and ABCD condition classes and derived infiltration.

(A) (B)

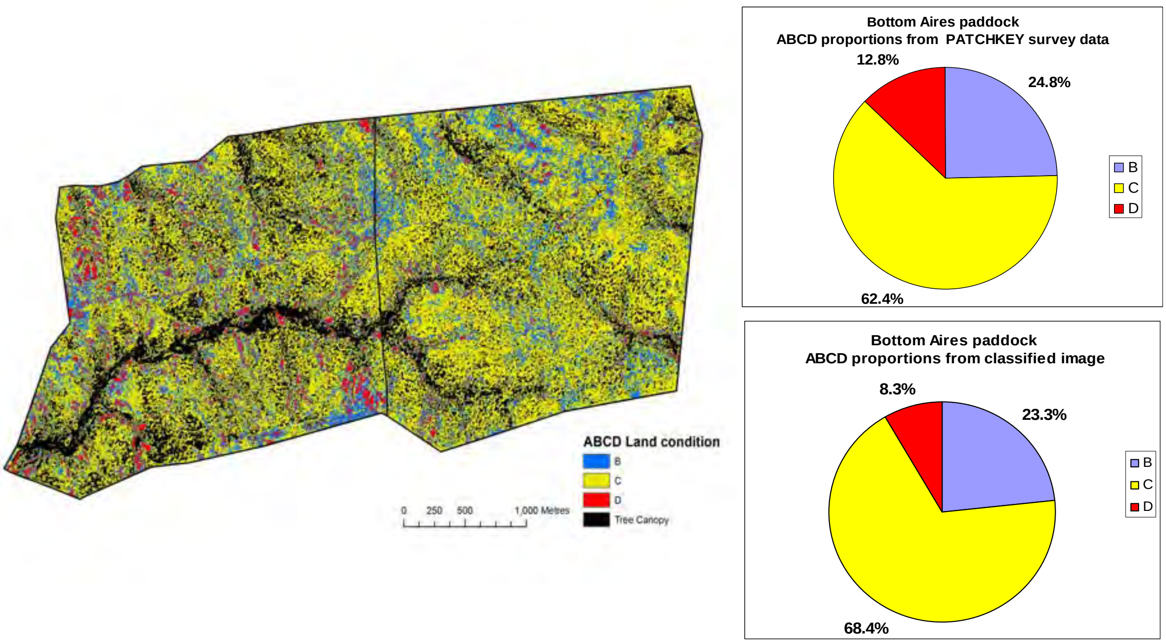


Figure 53: Comparison of ABCD land condition proportions in Aires paddocks, Virginia Park, derived from classified *Quickbird* imagery. (A) Classified map, (B) PATCHKEY ground based survey proportions; (C) classified image proportions.

The ability to identify key PATCHKEY patch types from remotely sensed imagery will help refine condition trend classification and landscape leakiness analysis. Whilst this methodology is in it's infancy and needs to be tested over a far greater range of land types and land condition situations, early results are very promising (Abbott and Corfield, 2006). Provided key patch types and reliable indicators of critical transition thresholds or condition trends can be identified, we hope to develop a robust and repeatable patchiness motoring tool which can add a spatial dimension to the ABCD framework. We envisage this as both a ground based land condition classification and monitoring survey tool and also a method for refinement of remote sensed image classification (especially high resolution imagery such as *QUICKBIRD* or *IKONIS*), linking in with the existing landscape leakiness package (Ludwig *et al*, 2005).

Underpinning ABCD with landscape and hydrological function values and thresholds

Figure 54A and **Figure 54**B show examples of soil surface condition (SSC) stability scores (Tongway and Hindley,1995) and measured infiltration values obtained for ABCD land condition classes at various sites in which detailed patch studies were conducted between 2003 and 2005. Not all measurements were carried out at all sites, but LFA soil surface condition (SSC) data is available for the entire range of crusting soil types and land/vegetation types studied. While these data should be used as a guide only to likely landscape and hydrological function for a given land condition and land type, they do provide a useful underpinning of the ABCD descriptive framework for the relevant land types covered.

(A) (A)

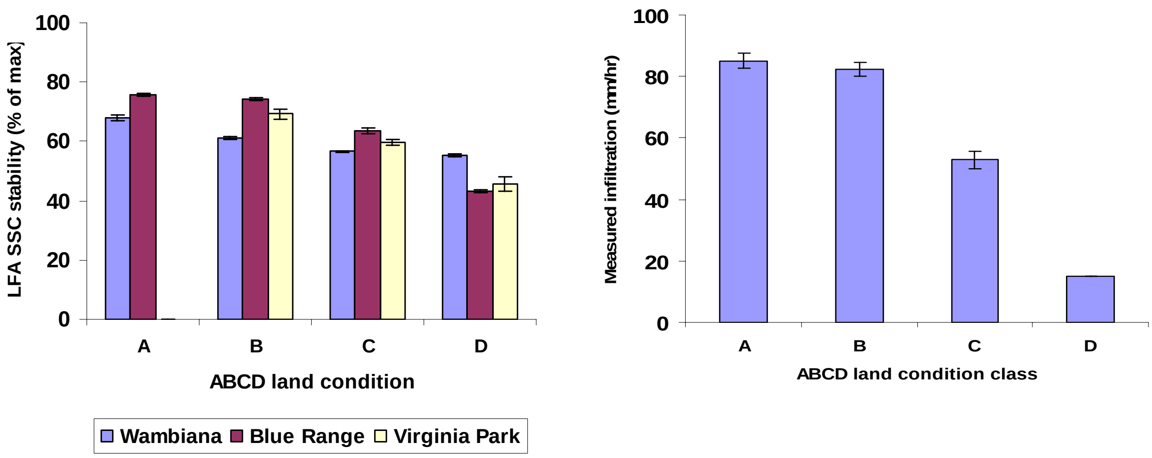


Figure 54: (A) LFA SSC stability scores for ABCD land condition patch classes Wambiana grazing trial. Blue Range and Virginia Park station patch study sites, 2004-05 (B) measured infiltration values for ABCD land condition patch classes at Blue Range study site, May 2005.

While the relationships between these metrics and ground cover remain constant, ground cover itself often declines through the dry season in response to grazing effort. Experience from this and other studies (McIvor *et al* 1995b, Roth, 2004) suggests that end of dry season ground cover levels are critical in determining the degree of run-off and sediment loss from grazed landscapes in the upper Burdekin region. Retention of adequate end of dry season pasture cover and biomass is essential to optimise infiltration, slow overland flow and provide the build-up of litter necessary to improve soil biological activity and nutrient cycling (Northup *et al*, 1999, 2003).

Results from patch studies within this project support the findings of Roth (2004) that 75% ground cover is the threshold below which hydrological function begins to decline. Results also suggest that the minimum 40% cover threshold recommended by McIvor *et al* (1995b) for limiting erosion on crusting soil types may be too low, especially in landscapes dominated by Indian couch. For recovering C condition paddocks, minimum end of dry season residual cover and biomass threshold targets are as important (and may override) ECOGRAZE based utilisation targets for matching stock numbers to carrying capacity where dry matter production remains low due to drought or reduced productive capacity following long term overgrazing.

Patch and hillslope study results from this project also suggest that a ground cover level of at least 60% relates well to the threshold on the derived infiltration curves (**Figure 40**a and **Figure 41**a) above which infiltration increases rapidly. This also falls within the end of dry season cover range specified by the ABCD framework for goldfields and sedimentary land in long term B condition. (Chilcott *et al*, 2003). **Table 13** records the average end of dry ground cover, litter cover and biomass levels for each ABCD condition class, measured on both grano-diorite (goldfields) country at Virginia Park and sedimentary country (Blue Range and Hillgrove) during 2004-05.

Table 13: Mean end of end of dry season cover, litter and biomass levels for grano-diorite and sedimentary land types in the upper Burdekin region

Land Type	Site	ABCD Class	Cover %	s.e.	Litter %	s.e.	Biomass kg/ha	s.e.
Grano-diorite Indian couch dominant – some 3P grasses	Virginia Park – combination of 2004-05 data from all study paddocks	A	78.3	6.06	33.9	8.53	2336	703.3
		B	73.6	1.73	30.5	1.99	817	41.0
		C	42.7	1.13	23.5	1.04	340	14.6
		D	32.5	5.06	26.4	4.60	76	16.5
Sedimentary Tussock grass dominant – some Indian couch	Blue Range (Springs paddock)+Hillgrove (Haler paddock) 2004-05 data	A	94.4	0.77	63.4	4.91	3909	17.8
		B	82.7	1.20	55.8	2.72	1725	108.2
		C	62.4	2.10	40.1	2.51	629	53.5
		D	13.6	6.11	13.3	6.07	10	10.1

While end of dry season ground cover levels recorded here for B condition are higher than the 60% threshold nominated, some allowance should be made for seasonal fluctuations within the range encountered over the 2002-05 study period, when B condition cover on Indian couch dominated landscapes dropped significantly in 2003.

The relationship between foliar cover and land condition usually applies to herbage biomass as well for most tussock grass communities. However, as previously state, in grazed Indian couch pastures, high cover does not necessarily mean high biomass. This is all the more reason to set minimum end of dry season (EOD) target thresholds for residual standing dry pasture in couch dominated paddocks.

To shift Indian couch dominated land from C to B condition, end of dry (EOD) season residual standing dry pasture target thresholds should approach those representative of land in B condition for that system, or at least 600-800 kg/ha (**Table 13**). For tussock grass communities, the EOD pasture biomass targets should exceed 1000kg/ha of dry standing matter where possible. These thresholds will satisfy both the recommended ground cover thresholds and also ensure there is sufficient volume of attached, dry standing herbage to slow overland flow, protect the soil surface during the first storms and provide the litter resources necessary to improve infiltration and support the biological activity essential to nutrient recycling.

The recommended end of dry season cover and biomass thresholds, together with findings on the role and scale of patchiness in assessing and monitoring land condition trends, provide important insights and tools for the management of recovery of degraded grazing lands within the upper Burdekin catchment. These suggested EOD thresholds, arising from a combination of land condition and hydrological project studies at a range of scales, should be taken into account when assessing land condition trends, especially in recovering landscapes on the granodiorite (goldfields) and sedimentary land types of the upper Burdekin catchment. For management purposes, they could be taken as guidelines or aspirational targets, when designing grazing land management strategies to promote recovery in land condition and restore long term safe carrying capacity.

6.4.5 Implications for predicting outcomes of management strategies

There are many aspects of our NAP.314 component B project studies that provide important input into understanding and predicting the likely outcomes of grazing management strategies on grazing distribution and preference, land condition and landscape and hydrological function. In summary, these include findings that:-

- Recovery of land condition is slower and patchier at a range of scales on *Bothriochloa pertusa* (Indian couch) dominated C (poor) condition grano-diorite (goldfields) landscapes than on goldfields landscapes closer to the B- (state II) condition lands used in ECOGRAZE.
- In recovering paddocks, cattle will preferentially select C and some D condition patches year round, thus impeding the rate of recovery on these patches and adjacent areas.
- C condition patches, especially those with remnant 3P populations, are consequently the most biophysically unstable of patch types, making them more vulnerable to continued degradation.
- When C condition grazing preference coincides with selective wet season use of vulnerable land types such as lower slope sodic and frontage areas, the prospect of further degradation into D condition increases significantly.
- Because of these circumstances it is difficult to shift land back from C to B condition simply by lowering overall paddock utilisation or stocking rates. Lower utilisation should be combined with wet season spelling to protect recovering 3P grasses in their most vulnerable growth phase. These should ideally be whole of wet season spells, rather than partial spells.
- Recovering C condition land can benefit significantly from consecutive wet season spells to promote recovery of 3P grasses and build up a body of plant biomass to restore cover and landscape function.
- There are strong relationships between level of dry season ground cover and litter cover and measured infiltration, directional leakiness and soil respiration on soil types studied and there is also a relationship between declining ABCD condition and decline in these and other landscape and hydrological function metrics.
- Retention of adequate end of dry season (EOD) ground cover and biomass thresholds is critical to protect soil surfaces from early storms, improve infiltration, slow overland flow and provide the litter resources for improved soil biological activity and reduced leakiness.
- The size and distribution of patches and associated ground cover across the landscape can have a significant impact on the leakiness of that landscape and the likely movement of sediment and nutrients within and off hillslopes (see section 7 of this report).

Several of the relationships developed within this project have already been employed to develop predictive models such as LISEM, which links cover distribution to hillslope delivery (Bartley *et al* 2006, Kinsey-Henderson and Post, 2006); the landscape leakiness LI calculator (Ludwig *et al*, 2005) and the Savanna AU (Leidloff, 2005). All of these predict likely landscape and hydrological function outcomes associated with spatial and temporal changes in land condition arising from modelled land management scenarios. The understandings and relationships derived from the work of this component has helped refine several of these predictive models.

The PATCHKEY classification and monitoring framework currently being refined has also drawn extensively on the relationships between patch condition, landscape function and patch distribution developed during this project (Corfield and Abbott, 2006, Abbott and Corfield, 2006). An important aim of PATCHKEY is to provide a spatial dimension to ABCD land condition assessment and monitoring, which may improve prediction of land condition trend, both from ground based and remotely sensed monitoring data.

While this project has not been in a position to deliver a comprehensive, robust predictive model of paddock-scale grazing distribution and impacts, the findings on the interaction of land condition, utilisation rates and patch scale selection preference provide a sound basis for development of grazing management guidelines and principles targeting land condition recovery. Some of these have already been included in the soon-to-be released brochure set, outlining findings and management recommendations arising from this project. These relationships will also provide a valuable input into a possible future project aimed at development of a robust spatial grazing model for Northern Australia.

6.4.6 Implications for guiding grazing management

So, how do these findings and relationships help predict the outcomes of and guide future grazing management strategies?

First, they reinforce the findings and predictions of the 1990s ECOGRAZE study (Ash *et al*, 2001) that application of lower utilisation rates (<30% utilisation) and wet season spelling can lead to recovery of land condition, even through below average rainfall years. In other words, they support the basic ECOGRAZE contention that it is management rather than climate that drives land condition (Ash *et al*, 2001).

Second, they indicate that recovery from a poorer land condition starting point, in the case of C condition couch dominant pastures, will likely be a slower and patchier process, requiring some additional monitoring of within-paddock as well as whole paddock trends and more flexible strategic management. This might include balancing seasonal utilisation targets with the need to retain adequate EOD ground cover and biomass levels. It might also involve decisions on whether to apply single or consecutive wet season spells, depending on rate and patterns of observed recovery, especially in C condition patches. This might require additional planning and resources to facilitate additional spelling and the distribution of stock which would otherwise have returned to these spelled paddocks.

Third, the findings on the relative instability of and selective grazing preference for C condition patches during recovery suggests that managing for “average” paddock condition may not be sufficient to optimise recovery of C condition paddocks. As demonstrated in the ECOGRAZE study (Ash *et al*, 2001) while recovering paddocks may return to “average” pasture biomass and cover levels approaching B-A condition, the distribution of that cover across the landscape can be very disjunct, with areas of very high and very low cover. Recovering paddocks also remain relatively vulnerable to the impacts of renewed grazing pressure due to the reduction in and disjunct distribution of 3P grass basal cover, root, organic matter and nutrient reserves, all of which take much longer than ground cover to re-build (Northup *et al*, 1999, 2003). All this leaves the soil surface vulnerable to further erosion and extension of leakiness pathways, should such “recovered “ paddocks be prematurely re-exposed higher grazing pressure. Thus, premature re-stocking of recovering paddocks in response to perceptions of improved “average” paddock condition could run the risk of an even faster decline in land condition the second time around, with the risk of moving more land from C into D condition

Fourth, the importance of adequate end of dry season cover across the landscape, but especially in lower slope and frontage zones has been well established by various studies within this project. While restoration of adequate end of dry season ground cover over the whole landscape is the goal, inadequate cover within lower slope areas is likely to result in continued loss of sediment and nutrients from these areas into adjacent gullies and stream channels. Output from the hillslope delivery and leakiness models and associated cover management guidelines will help researchers and land managers predict the likely outcome of suggested management strategies, including target EOD cover thresholds, wet season spelling, placement of fences, waters and supplement and possible water diversion or erosion stabilisations options within the hillslope.

In the case of lower slope sodic soils, exclosure fencing options are often limited by the highly dissected nature of the terrain, while mechanical cultivation (e.g. deep ripping) will likely exacerbate the problem by disturbing the highly mobile dispersive sub-soil. While mechanical diversion of overland flow up-slope of these areas may be an option in some situations, wet season spelling, lower overall utilisation and retention of adequate EOD cover and biomass up-slope are the most practical and cost effective solutions to stabilising these areas in the long term. The recommended >60% ground cover and 600-800 kg/ha pasture biomass threshold targets are aimed at retaining sufficient cover and biomass up-slope to increase infiltration and thus slow overland flow onto these vulnerable land units.

Whilst such EOD targets are regarded as minimum thresholds necessary to retain and restore landscape and hydrological function, they should be regarded as aspirational targets or guidelines rather than rules. As **Figure 55** clearly shows, at many times during recent drought periods most graziers would have struggled to retain ground cover or biomass levels approaching these targets throughout the year, let alone by end of dry season.

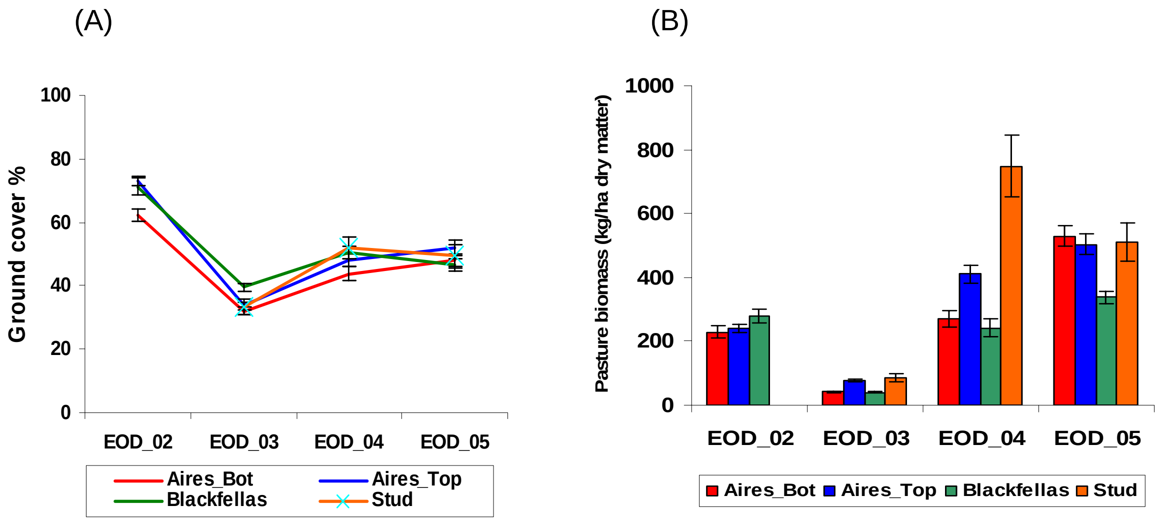


Figure 55: (A) end of dry season (EOD) ground cover trends and (B) end of dry season biomass trends in Virginia Park study paddocks (200-05). EOD=end of dry season.

This poses the question of whether in such circumstances, total de-stocking might be the only viable option to arrest further decline in land condition and commence the recovery process. In many case during the period 2003-05 graziers on goldfields country in the upper Burdekin had little choice but to de-stock and sell or agist their stock, when pasture biomass levels fell to almost un-recordable levels (<100kg/ha dry matter). Virginia Park was one of many properties in the Mingela district to take this path. As a consequence, several of our study paddocks were de-stocked for lengthy periods during 2003. While this made no difference to pasture yields or ground cover levels, due to absence of soil moisture, it probably reduced hoof impact and localised disturbance associated with selective grazing for a time.

One important message arising from these findings is that managing for recovery in these Indian couch dominated C condition landscapes involves a more complex set of considerations than might have previously been applied to property planning and management in earlier, more 3P pasture-rich times. The need to consider differential rates and patterns of response to recovery may require more flexibility in balancing different grazing management strategies. The relative instability of C condition patches and the difficulty of shifting land from C to B condition might also necessitate strategies that focus on managing for the proportion of C condition land present, rather than average paddock condition, to optimise recovery.

Such tasks are not necessarily new to experienced land managers of today, but they will require greater hands-on recognition, observation and management of the consequences of variable recovery processes and patterns. This might include increased knowledge of the key signs or indicators of land condition degradation and recovery trends, many of which are included in the *Patchy Path to Recovery* brochure produced as part of the three brochure set describing outcomes and key messages arising from this project.

6.5 Conclusion and key messages

Within project NBP.314 the overall objectives of component B was ***to develop quantitative linkages between processes that determine the location, magnitude, and consequences of grazing impacts on landscape function, by conducting measurements of relevant landscape attributes, across a range of scales at selected locations.*** The project has achieved these objectives and contributed to the overall project objectives (especially objectives 1, 3 and 5) in the following ways by:

1. Identifying key relationships between patterns and processes of grazing selection preference, land type, location and land condition impacts at patch, hillslope and paddock scale. These include findings that:-

- Grazing gradients out from water point are usually confined to <200m in these environments.
- There are few consistent linkages between edaphic landscape features and grazing patterns or preference in land types studied. The exception was an identifiable preference for selective wet season grazing of lower slope sodic and frontage areas within grano-diorite and (goldfields) and sedimentary land types.
- There is a strong relationship between utilisation rate, patch diversity and heterogeneity of grazing distribution and intensity across paddocks. As utilisation declines, both patch type diversity and opportunities for grazing selectivity increase (and vice versa) which may impact upon diet selection and diet quality.
- A key driver of small scale grazing patterns and preference is pre-existing patch condition. At low to moderate utilisation there is strong selection preference for existing C and D condition patch types, with C patches twice as likely to be heavily grazed, than B patches.
- When preference for C condition patches coincides with selective wet season use of vulnerable sodic soil and frontage areas, continued localised degradation is likely even when average paddock condition is improving.

2. Identifying the spatial and temporal patterns and processes of recovery within Indian couch dominated poor (C) condition pastures at patch, hillslope and paddock scale, in response to application of ECOGRAZE sustainable grazing management practices at Virginia Park. This has led to findings that:-

- Moving C condition couch dominated goldfields paddocks back into B condition is a slow and patchy process, due loss of resources such as 3P basal area and root reserves, soil nutrients and organic matter, all of which impact on infiltration and plant growth.
- Topographic location, land type and landscape position all contribute to small scale variability in spatial and temporal response patterns to grazing management strategies, with the common driver being the ability to trap and retain resources.
- Biophysical instability, coupled with continued selective grazing preference, impedes recovery of C condition patches and the ability to restore connectivity between patches and so reduce leakiness across hillslopes.
- Whole of wet season spelling, coupled with reduced utilisation and retention of adequate end of dry season ground cover are the keys to protecting wet season recovery of 3P grasses within C condition patches, protecting the soil surface, increasing infiltration, slowing overland flow and providing the resources for increased soil biological activity.
- In C condition couch dominant paddocks, consecutive wet season spells may be required in the early stages of recovery, to promote faster recovery of 3P grasses.
- If such strategies are followed, it is possible to achieve steady recovery of land condition, even in below average rainfall years. In fact there is evidence from Virginia Park studies, that 3P grasses have a competitive advantage over the more drought sensitive Indian couch in such years, when wet season spelling is practiced.

3. Establishing quantitative links between key descriptors of land condition and measured attributes of landscape and hydrological function at patch and hillslope scale, to underpin the ABCD framework, initially for goldfields, sedimentary and canazoic land types, and develop predictive relationships. Many of these relationships have since contributed to the development of predictive models such as:-

- The LISEM hillslope delivery model (Kinsey-Henderson *et al*., 2006)
- Versions of the Savanna AU model (Bartley et, al, 2005, Liedloff *et al*., 2005).
- The landscape leakiness (LI) index calculator (Ludwig *et al*, 2005)

Others have provided predicted landscape and hydrological function values and thresholds to underpin the current ABCD framework descriptors for these land types.

4. Development of the PATCHKEY patch classification framework linking ABCD land condition descriptors with key patch function drivers to facilitate the multi-scale investigations outlined in 2 and 3. PATCHKEY provides a spatially relevant means of quantifying ABCD land condition categories and monitoring condition trends in terms of patch distribution and frequency, which can also be useful in refining remote sensed image classification.

5. Contributing to the development of important management guidelines and principles arising from the findings outlined above. Many of these represent collaborative research, analysis and interpretation exercises across all three project components, to bring together integrated an integrated picture of the biophysical responses to ECOGRAZE style sustainable grazing management strategies at Virginia Park. This has enabled the project to develop the significant new grazing land management principles, guidelines and recommendations specifically targeted for recovering goldfields and sedimentary paddocks, which are

contained in this report. These principles and guidelines have been or will be communicated to industry stakeholders by way of:-

- Two field days at Virginia Park outlining progress and key project findings
- A complimentary set of brochures outlining major project findings, studies and providing key grazing land management messages and recommendations arising from these findings, made available to all producers within the upper Burdekin region.
- Incorporation of key elements into Edge Network GLME workshop material for use in the upper Burdekin and other relevant regions.

Key messages and recommendations arising from component B findings

Distilling the many important component B findings into a set of key messages is not an easy task, due to the complex nature of the issues and interactions studied. Many have already been canvassed in detail in the preceding results and discussion sections. However, the following points formed the basis of the key messages included in the *Patchy Path to Recovery* and *Wet Season Spelling* brochures recently prepared as part of the communications commitments of this project.

- ❖ Sustainable recovery can be achieved on C condition Indian couch dominant goldfields land, though that recovery is likely to be slower and patchier than that achieved in the ECOGRAZE study. This is due to the lower levels of 3P grass basal area and root reserves, stored soil organic matter and nutrients, all of which influence rainfall infiltration and plant growth.
- ❖ The strong selection preference for and relative instability of C condition patches, exacerbates this impeding both recovery of individual C patches and restoration of connectivity between patches, thus affecting landscape leakiness. When these factors coincide with seasonal selective use of vulnerable landscapes such as lower slope sodic or frontage areas, significant localised degradation can continue even when average paddock condition is improving.
- ❖ Whilst lower utilisation rates will contribute to increased biomass and cover levels, wet season spelling is essential to protect recovering 3P grass plants in C condition patches from selective wet season grazing. Experience from Virginia Park indicates that whole of wet season spells are required stimulate recovery of 3P grasses in couch dominated pastures, with consecutive spells being beneficial in early years of recovery.
- ❖ There are strong relationships between ground cover, litter contribution and measured infiltration, soil biological function (respiration) and directional leakiness at the patch to hillslope scale. To shift C condition land toward B condition maintain at least 60% end of dry season ground cover and 600-800kg/ha standing pasture to protect soil surface from early storms, improve infiltration and slow overland flow and provide the litter resources necessary for improved soil biological function and nutrient cycling. It is recognised that these targets may not be achievable in the early stages of recovery following drought, but they should form part of long term recovery management strategies.
- ❖ All this makes managing for recovery of C condition couch dominant goldfield paddocks a trickier proposition requiring a more flexible set of management strategies. Such strategies will need to take more account of within paddock variability and sometimes competing needs such as overall utilisation targets, end of dry cover and biomass reserves, wet season spelling requirements and protection of vulnerable land types or locations.

- Managing for sustainable recovery may also mean managing for the proportion of C condition land still present, rather than managing for "average" paddock condition. Recovering paddocks remain fragile and vulnerable to renewed decline in land condition for some time, even though "average" cover and biomass may have improved significantly. This is because of the often uneven distribution of plant cover and associated reserves of nutrients and organic matter. Premature return to higher stocking rates risks re-exposing leakiness pathways, leading to renewed loss of sediments and nutrients.

- Such tasks are not necessarily beyond the experience of current land managers of today, but it will require greater hands on recognition, observation and management of the consequences of variable recovery processes and patterns. This might include increased knowledge of the key signs or indicators of land condition degradation and recovery trends.

- Given that the slow but discernable early recovery witnessed at Virginia Park was, like the ECOGRAZE study of a decade earlier, achieved through a drought period, it gives further weight to the contention of Ash el al (2001) that it is management, not climate, that drives land condition.

Comparison of Virginia Park outcomes with the former ECOGRAZE study results can be misleading, considering that ECOGRAZE was conducted on small (<5h) relatively uniform experimental paddocks of uniform goldfields land type and topography a – a stark contrast to the commercial paddock scale catenary sequences of Virginia Park . While the first four years of both studies experienced similar below average rainfall conditions ECOGRAZE also ran for twice as long as the recent Virginia Park study. It is interesting then to revisit the longer term recovery performance of ECOGRAZE recovery paddocks which were subject to comparable utilisation and spelling treatments for the full 8 years of the study at Cardigan station. **Figure 56** indicates that the slow but steady build-up of 3P grass frequency, basal cover and root reserves over the first 4 years of recovery, provided the platform for a rapid improvement following the return of good rainfall seasons in 1998.

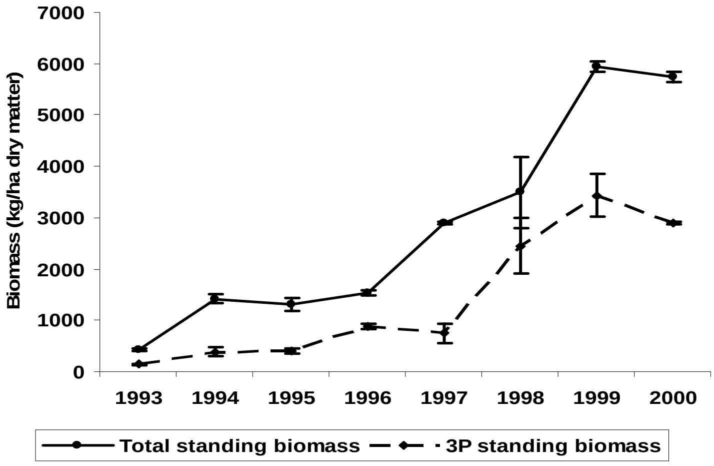


Figure 56: (A) Total 3P grass standing dry matter trends over full 8 years of ECOGRAZE study (1993-2000) Cardigan state II (B- condition), 25% annual utilisation + biennial wet season spell.

If the principles and guidelines arising from this study are adopted, there is every reason to expect that land in similar condition to that originally pertaining at Virginia Park station could sustain the same slow but steady early recovery achieved during the limited life of this study.

Future Work

There are a number of questions arising from component B studies that warrant further investigation or require further development and application beyond the scope of the current project. These include:-

- Further exploration of the drivers of grazing selectivity at the pasture species and functional group level, the linkages with diet selection and quality and impacts on patch formation and condition.
- Further exploration of the processes of patch recovery and degradation at hillslope and paddock scale, including the linkages between small scale resources distribution, location, connectivity and rate and trend of land condition change.
- Further development and testing of PATCHKEY over a greater range of land types and regions to widen its applicability as a monitoring tool capable of providing spatially relevant characterisation of ABCD land condition classes and identifying key indicators of early changes in condition trend, which can be applied at remotes sensing scale.

7 Improved prediction of sediment and nutrient export in the Burdekin catchment

7.1 Key Messages

This section of the report outlines some of the major research findings relating to water, sediment and nutrient runoff from grazed catchments in the Burdekin basin. This section contributes to the overall project objectives outlined in Section 3 of this report, in particular to objectives (2), (3) and (4). The overall objective of Component A was to 'determine the quantity and sources of sediments and nutrients which reach the streams and rivers in the upper Burdekin catchment'. This has been achieved in this research project at a range of scales. At the sub-catchment scale, new process understanding has been derived from extensive field data collection on hillslope, gully and bank erosion processes as well as channel storage in the Weany Creek catchment. Some the key findings are outlined as follows:

- The arrangement and location of ground cover on hillslopes are more important than 'average' cover conditions. This is because hillslopes with relatively high mean cover, but with small patches bare of vegetation, are shown to have between 6-9 times more runoff, and up to 50 times more sediment loss than similar hillslopes that do not contain bare patches;
- This study has highlighted that the previously documented mean ground cover thresholds that are important for infiltration and soil retention in grazing lands i.e. 40% suggested by Scanlan *et al*., (1996) and 75% as suggested by Roth (2004), are highly dependent on the size, scale and arrangement of patch types. That is, two grazing areas that have a mean cover of 40%, which is considered 'appropriate' for hydrological functioning, could have very different runoff and sediment yields depending on the arrangement and number of bare patches on the hillslope;
- On average, the majority of sediment lost from hillslopes is the finer more mobile suspended sediment, however, up to 17% of the total hillslope sediment loss may be coarse sediment, particularly in the low cover areas;
- A large proportion of the soil loss from hillslopes occurs during early wet season storm events, and therefore quality ground cover at the end of the dry season is crucial;
- The total sediment yield estimated for Weany Creek is ~ 4031 t/yr and is much lower than expected for a catchment of this size. The sediment leaving Weany Creek catchment is comprised of ~81% coarse material and 19% fine sediment, and agreement between the fine sediment yield estimated in the sediment budget and the yield measured at the catchment outlet is within 10%;
- The mean suspended sediment yield estimated in Weany Creek is 848 t/yr and the uncertainty estimated in this prediction is ±50%. Most of the uncertainty in the yield prediction is expected to come from the velocity readings and improved calibration or instrumentation is expected to reduce the uncertainty in the load estimates;
- The field data suggest that at least during drought conditions, the primary erosion source in Weany Creek is gully erosion. However, the largest source of sediment in the budget is actually associated with the remobilisation of in-channel sediment stores (that consist primarily of coarse material);
- Based on end of catchment water quality monitoring between 2000 and 2006, it has been estimated that on average 0.76 t/yr of total nitrogen (TN) and 0.25 t/yr of total phosphorus (TP) is leaving the Weany Creek catchment.

- The main implication from this work is that any land management strategies implemented in catchments such as Weany Creek may not be detectable at the end of the catchment as decreased sediment yields for many years after the management action. This is because the amount of sediment being moved from historical sources out-weighs the potential change in sediment yield from land management. This study also emphasises that land management decisions being made this decade may influence runoff and geomorphic processes for the next century.

In an attempt to look at erosion processes and sediment yields from a diverse range of sites in the Burdekin, a number of other field based studies were carried out. These included an assessment of the SedNet bank erosion rule against measured data from the Upper Burdekin Catchment. We were also fortunate in this study that we were able to compare end of catchment suspended sediment load data from three grazed sub-catchments in the Burdekin (MLA project) with data from three other sub-catchments that have had minimum grazing over the last 20 years (Australian Defence sites). The major findings from these studies are outlined as follows:

- The bank erosion rule used in the SedNet modelling seems to represent bank erosion at the large scale but should not be used to locate erosion hot spots at the reach scale without rigorous field evaluation and checking;
- Sediment yields in grazed catchments are significantly higher than in un-grazed catchments ($p<0.01$);
- Sediment yields per unit runoff in grazed catchments are twice that of grazed catchments;

It is acknowledged that a limited amount of field derived data can be collected due to the associated costs and large size of the catchments. Therefore it is extremely important that the measured data help inform and improve the larger scale catchment sediment export models such as SedNet. These models are increasingly being used to set and evaluate water quality targets and changes in land condition in catchments draining to the Great Barrier Reef. As part of this study, the whole of catchment scale sediment and nutrient budget models have been considerably improved due to revised modelling parameter estimates and input data. These improvements and the results derived from the modelling are outlined below:

- The whole of catchment SedNet modelling in this study used improved input data for a number of factors including variable ground cover (C-factor) grids, hillslope gradient, bankfull width and depth estimates and gully dimensions. Using this revised data, the Burdekin Region SedNet model determined that the main erosion processes contributing sediment to the end of the catchment are hillslope erosion (44%), followed by bank erosion (32%) and then gully erosion (24%). This ratio of sediment sources is different to previous studies;
- A total of 3878 kt/yr of sediment is exported from the Burdekin River to the estuary. Approximately 94% of the sediment leaving the catchment is fine or suspended sediment and the remaining 6% is coarse sediment;
- The improved cover grids produced very similar end of catchment loads to previous modelling projects, however, the contribution from the sub-catchments has changed considerably with more sediment coming from Granodiorite areas and less from coastal catchments;
- The amount of nitrogen reaching the estuary from the Burdekin catchment is ~18,731 t/yr, of which ~65% is sourced from hillslopes, and ~71% leaves the catchment in particulate form.
- For the phosphorus budget, 3820 t/yr of phosphorus reaches the estuary from the catchment. At least 78% of the phosphorus is sourced from hillslopes, and 90% of the phosphorus leaves the catchment in particulate form.
- The highest per unit area sediment yields are coming from the Don, Haughton, Broken and Stones Rivers, which all have suspended sediment yields > 1.0 t/ha;

- The sub-catchments with the highest per unit nitrogen yields are the Townsville catchments (obviously related to point sources), the Broken River and the Running River. The highest per unit phosphorus is coming from the Broken River, the little Bowen River and the Clarke River.
- The Broken River (in the Bowen region) is in the top 3 catchments for suspended sediment, nitrogen and phosphorus. This is most likely due to its coastal location in the steeper, wetter parts of the Burdekin catchment, and doesn't necessarily reflect poor landuse, although this result would suggest that further work should be carried out in this catchment to assess the main source of sediments and nutrients.
- There is a reasonable match between the measured and modelled fine sediment loads (~20%) at a number of sites within the catchment. It is important to remember that the data were collected during drought conditions;
- There is poor agreement between the measured and modelled nutrient loads at a number of sites within the catchment. This is because the enrichment ratio that was used in previous models runs was not used in this study as it masks the inadequacies in the process understanding of nutrient transport in the model.

Future work:

Based on the results from this and previous MLA funded studies, we now have a reasonable understanding of the relationship between cover, patch and hillslope runoff. There is, however, an increasing need to understand how these plot and hillslope scale processes translate to the larger scale using tools such as satellite imagery. This will then allow these results to be transferred to other sites within the Burdekin catchment. There will also be an on-going need to evaluate the relationship between land use management strategies and end of catchment water quality. Having long term data sets will be a valuable mechanism for assessing (a) the magnitude of change that can be detected by water quality as a result of land use change (b) the lag times between land use change and water quality response, and (c) the influence of rehabilitation projects (e.g. gully rehabilitation). A number of other key research areas were identified in this study including:

- Residence times of fine and coarse sediment to help determine the lag effect between land management change and observations in measured water quality.
- Bedload movement rates.
- The ability to regionalise hydrology on a sub-catchment basis within the SedNet Toolkit model
- Scientific trials of scald/gully rehabilitation.
- Contribution of cow manure to nutrient budgets.

7.2 Introduction

This section of the document outlines some of major research findings relating to water, sediment and nutrient runoff from grazed catchments in the Burdekin basin. This section contributes to the overall project objectives outlined in Section 3 of this report, in particular to objectives (2), (3) and (4). The overall objective of component A, however, was to 'determine the quantity and sources of sediments and nutrients which reach the streams and rivers in the upper Burdekin catchment'. This has been achieved in this research project at a range of scales. At the sub-catchment scale, new process understanding has been derived from extensive field data collection on processes of hillslope, gully and bank erosion and channel storage. At the whole of catchment scale, sediment and nutrient budget models have been considerably improved due to revised parameter estimates and input data.

This section of the report is broken into three main areas:

1. The first section presents a summary of the results derived from the extensive data collection carried out at Virginia Park Station in the Upper Burdekin (Section 7.3):
2. The second section looks at data collected on bank erosion and end of catchment loads at a range of other sites in the Burdekin Catchment. A comparison of loads from grazed and ungrazed catchments is made (Section 7.4).
3. Section 7.5 of the report presents the results of the application of SedNet and ANNEX models to the whole of the Burdekin catchment and adjacent coastal catchments ("Burdekin region").

It is important to note that this research is focused specifically on the downstream water quality impacts of grazing on receiving water bodies (i.e. the Great Barrier Reef). There is no research focused on the local impacts to riparian vegetation and/or stream health as this component of the work was not funded within this project. Future projects should, however, address these local issues in more detail.

A list of publications that have arisen from this MLA project was presented in the Summary. The remainder of this report presents only a synthesis of the work conducted as part of Component A, and readers are encouraged to consult the relevant publications when more detail is required.

7.3 Virginia Park (Weany Creek) case study

Weany Creek is a 13.5 km^2 sub-catchment of the Burdekin Basin (Figure 57). The catchment is located on a cattle property, Virginia Park Station, that is owned and run by Rob and Sue Bennetto. It 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*., 2001a), but also because of the willingness of the landholders to trial sustainable grazing practices. The sustainable grazing practices would (a) help maintain soil on their property for future cattle production and (b) help reduce sediment and nutrient export to downstream water bodies, and in particular the GBR.

One of the main aims of the study at Virginia Park was to develop a sediment budget that would help identify the main erosion processes contributing to the end of catchment sediment yield. A range of field experiments and monitoring programs have been carried out in the Weany Creek catchment looking at hillslope, gully and bank erosion as well as end of catchment sediment yields and patch infiltration. The details of these studies, and the methods used are presented in detail in Bartley *et al*., (2007) and Bartley *et al*., (2006). Only a summary of the results will be provided in this section.

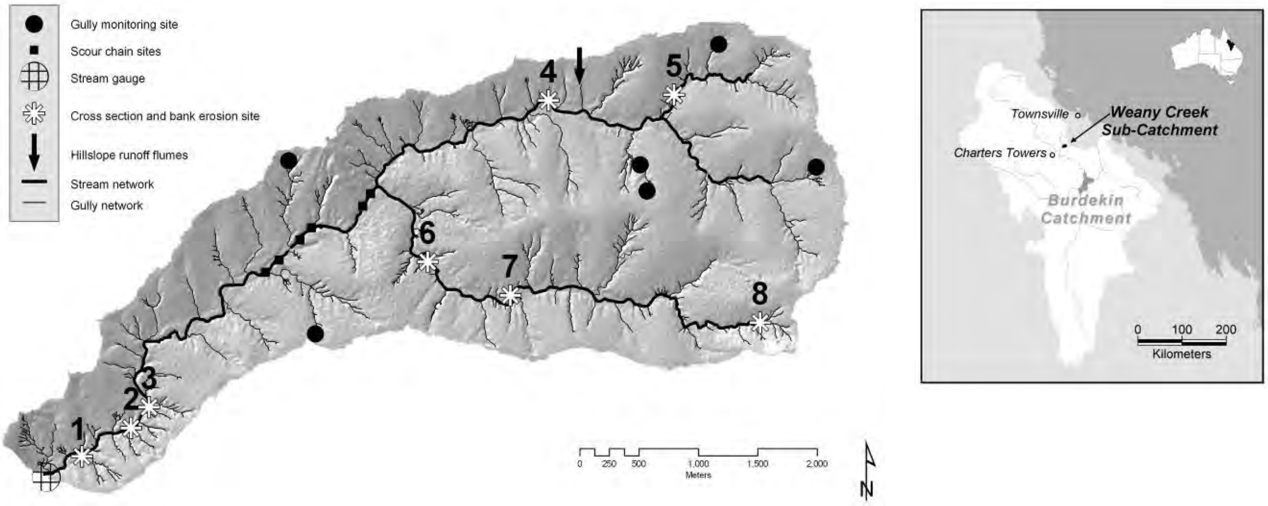


Figure 57: The Weany Creek catchment showing the location of field monitoring sites.

7.3.1 Methods

Calculating vegetation cover and hillslope erosion

Vegetation cover in the Weany Creek catchment was classified by creating a vegetation index from scanned colour airphotos with 25 cm pixels and then comparing the reflectance of red and green visible light (Kinsey-Henderson *et al*., 2005b). In this study, we classified these data into two categories: ‘low’ cover and ‘medium to high’ cover. Based on field measurements from a variety of sites in the Burdekin catchment (Roth, 2004; Roth *et al*., 2003), areas in the low cover category typically have vegetation covers of <20%, and areas in the medium to high category have vegetation covers of ~ 20-100%. In the Weany Creek catchment, the area of low cover ground represents ~27% of the catchment area. Trees, high cover and medium cover are located on the remaining ~73% of the surface. The vegetation classification was undertaken in 2003.

To measure water and sediment yields from hillslopes with different cover patch arrangement, three hillslopes with similar morphological structure, but different cover arrangements were chosen (see **Figure 18**). The three hillslopes were located within 400 meters of each other in the same field. On each hillslope, flumes were installed to quantify runoff and sediment loss following rainfall events. Data were collected over three wet seasons from November 2002 to February 2005. For the remainder of this report the sites will be referred to as Flume 1, Flume 2 and Flume 3.

Table 14 describes the cover, rainfall and grazing conditions found at the three experimental flumes sites for the 2003-2006 period. The erosion rates from Flume 1 data were used to represent hillslope erosion rates from medium-high cover areas in the Weany Creek catchment (73% of the catchment area) and data from Flume 3 were used to represent rates from low cover areas in the catchment (27%). An overview of the processes, methods and timescales of data collection is given in Table 15 and more detail on the methods can be found in Bartley *et al* (2006) and Bartley *et al*., (2007).

Table 14: Mean cover (%), rainfall (mm) and grazing conditions for each flume site for the three years of data collection.

		2003	2004	2005
Flume 1	Cover (Stand. Dev)	61 % (17.6)	34 % (6.6)	44 % (22.6)
	Rainfall	250 mm	238 mm	299 mm
Flume 2	Cover (Stand. Dev)	58 % (10.3)	38 % (4.95)	34 % (14.8)
	Rainfall (mm)	~250 mm*	255 mm	298 mm
Flume 3	Cover (Stand. Dev)	68 % (19.8)	46 % (14.3)	47 % (20.7)
	Rainfall (mm)	~250 mm*	221 mm	255 mm
Wet season spelling** conditions		Jan 2003 - Dec 2003 no spelling, 25% utilisation (due to little pasture growth)	Dec 2003 - January 2005 full wet season spelling (4 months), 35% utilisation	February 2005 - August 2005 full wet season spelling (6 months), 35% utilisation

* separate rain gauges were not installed at flumes 2 and 3 until the second year of measurement; ** spelling refers to a period without cattle

<u>Gully and bank erosion and channel deposition measurements</u>

Traditional erosion measurement methods (e.g. erosion pins, flumes and cross-section changes) were employed in this study to estimate soil loss and movement. 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 initial estimates of the sources and sinks of sediment in this savanna landscape. The more reliable tracing methods used elsewhere (e.g. Wallbrink *et al*., 1998; Walling, 2002) were not considered appropriate in this preliminary study for a number of reasons: (a) there was only one land use of interest in this study (grazing) and tracers are best used to differentiate sources from different land use types (e.g. cropping vs forestry or different geology and soils); (b) tracers are not always able to differentiate between the different processes or sources responsible for erosion (e.g. bank vs gully erosion). A summary of the different methods used to estimate soil loss contributions from gullies, channel banks and the channel bed are shown in **Table 15** and more detail can be found in (Bartley *et al*., 2007).

Table 15: Overview of processes, methods and timescales over which data was collected

Process/variable measured	Method used	Period data was collected
Net hillslope runoff and sediment loss	Flumes	2002-2005
Gully head cutting	Erosion pins	six years for three gully heads (1999-2005) and one year 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 one year for five gullies
Erosion/deposition of gully floor	Pins, x-sects and scour chains	six years for one gully system (1999-2006) and one year for five gullies
Bank erosion	Erosion pins	2002-2005
Channel storage	Bench marked cross-sectional change	2002-2005
Patch infiltration study	Hood infiltrometer	2004
Sediment loss at catchment outlet	Gauging station	2000-2005*

* only data for 2002-2005 was included in final budget

<u>End of catchment load monitoring</u>

To estimate discharge and sediment yield at the outlet of Weany Creek, an automatic gauging station was installed. The specific methods used are outlined in detail in Section 7.4.2.

7.3.2 Significant findings from Weany Creek study

Field data

There are a number of major findings to come out of the Virginia Park field work. Hillslope erosion at Virginia Park is very variable in space and time and has been shown to be highly dependent on the arrangement of bare patches in space. Hillslope areas with large areas without ground cover were shown to have much higher runoff and sediment yields than areas with more uniform cover distribution (Figure 58). Sediment loss is also generally higher at the beginning of the wet season when there is less ground cover when the early wet season storms arrive (Figure 59). The first flush phenomenon has been qualitatively observed in these semi-arid catchments, however, this is the first study to document the process. These results emphasise how important it is to have good uniform cover on all paddocks at the end of the dry season. We have also shown that there are strong relationships between % cover and infiltration as well as soil surface condition and infiltration for a variety of patch types at Virginia Park station (Figure 60). This implies that as we increase the amount and quality of cover on the hillslopes, it is possible to increase infiltration and reduce runoff and subsequent sediment loss.

This study has also highlighted that the previously documented mean ground cover thresholds that are important for infiltration and soil retention i.e. 40% by Scanlan *et al*., (1996) and 75% as suggested by Roth (2004) are highly dependent on the size, scale and arrangement of patch types in the grazing area being used to quantify mean ground cover condition. That is two grazing areas with a mean cover of 40% that may be considered ‘appropriate’ for hydrological functioning could have very different runoff and sediment yields depending on the arrangement of the bare patches.

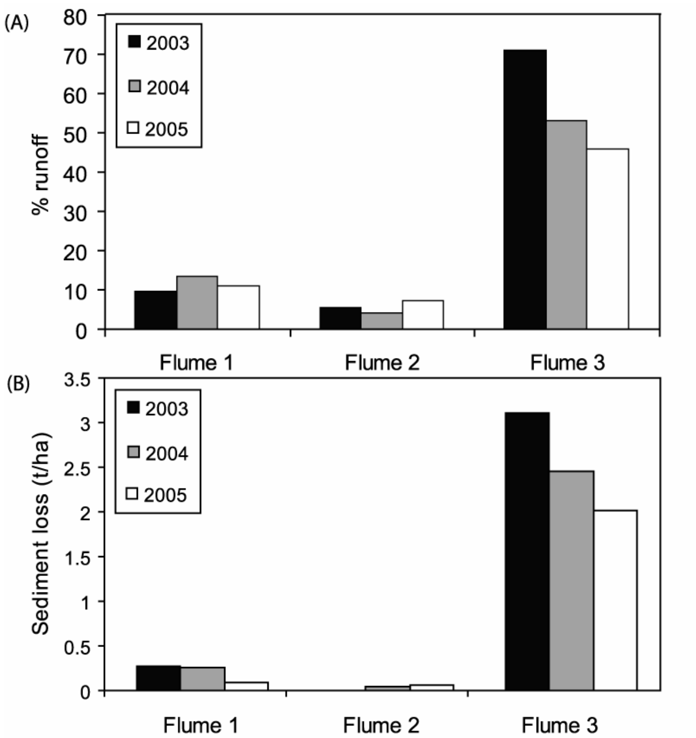


Figure 58: Variation in % runoff and total soil loss (t/ha) from the 3 flumes at Virginia Park over the 3 year study period

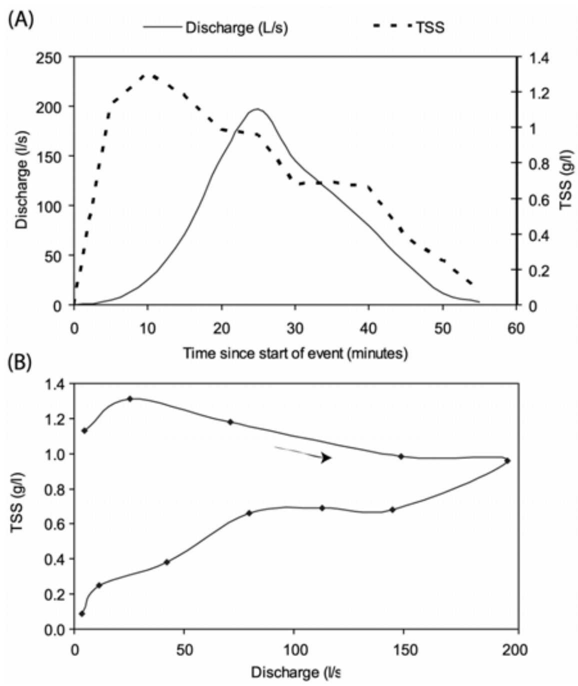
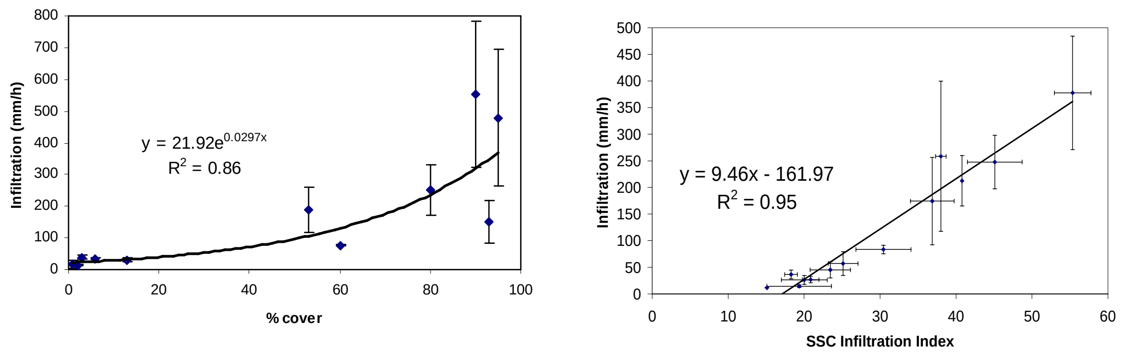


Figure 59: (A) Relationship between discharge and total suspended sediment (TSS) for a typical runoff event for Flume 1 (this event occurred on 13/12/04) and (B) the strong clockwise hysteresis for the same event demonstrating the strong first flush process. These relationships highlight that the majority of fine sediment is lost from the hillslope at the beginning of the runoff event. This is because ground cover is often low during early wet season events, exposing bare soil. This fine sediment then becomes exhausted as the wet season progresses and ground cover increases.



(A) (B)

Figure 60: (A) Relationship between % cover and measured infiltration (mm/h) (B) Relationship between the soil surface condition (SSC) Infiltration Index (of Tongway and Hindley, 2004) and the measured infiltration rate (mm/h).

Hillslope modelling work

It is not practical to expect that detailed field measurements such as those undertaken in Weany Creek can be undertaken for the entire Burdekin catchment. Therefore it is important to be able to use catchment models to represent processes where field data does not exist. In an attempt to improve our understanding of hillslope runoff and erosion processes, a number of models have been applied using the flume data from Weany Creek. The three models used are the LISEM model (Kinsey-Henderson and Post, 2006; Kinsey-Henderson *et al*., 2005a; Post *et al*., 2006a), the Savanna.au model (Liedloff *et al*., 2005) and the cover based directional leakiness index (CDLI) (Ludwig *et al*., 2005). The results of this work are presented in a range of publications and only a brief summary of the results will be given here.

<u>Summary from LISEM modelling</u>

- The model shows that patterns of vegetation and slope can have subtle implications for flow concentration that can influence the spatial patterns of runoff and potentially the way in which sediments and nutrients are detached and moved from hillslopes
- Runoff can almost double, without any change in average hillslope cover, depending on the size and spatial distribution of vegetation patches
- The LISEM model was used to derive a spatially explicit hillslope sediment delivery ratio (HSDR) based on travel times for the hillslopes in Weany Creek (Post *et al*., 2006a).
- This spatially variable HSDR appears to improve the estimates of HSDR for catchments the size of Weany Creek, however, the approach has limitations when applied at the whole of the catchment scale due to lower resolution of the digital elevation models (DEMs) at larger scales (Kinsey-Henderson and Post, 2006).

<u>Summary from Savanna.au modelling</u>

- It was identified that there is often a mismatch between the scale and resolution of data collected in the field and the data required to run models at scales such as the hillslope;
- Nonetheless, the Savanna.au model confirmed that the spatial arrangement of cover within a hillslope can have large implications for runoff and sediment yield;
- The plant production component of the model needs to be improved to help improve the ability to predict the link between infiltration and runoff.

<u>Summary from cover –based directional leakiness index (CDLI)</u>

- The CDLI matched the measured hillslope flume data reasonably well and appears to be a useful conceptual approach to estimating how vulnerable ecosystems are to potential loss of water and sediments
- The CDLI approach is only suitable for un-channelised hillslopes and remains to be tested on a range of other vegetation types and patch configurations

7.3.3 Sediment budget

In addition to the hillslope erosion work described above, bank and gully erosion monitoring has been conducted at Virginia Park. The channel bed has also been monitored for changes in sediment storage volume. A summary of these results is presented in the form of a sediment budget in Table 16 and Figure 61 (Bartley *et al*., 2007). The results suggest that that ~4205 t/yr of sediment was lost from Weany Creek catchment, 81% of which was coarse sediment and 19% fine sediment. The data suggests that, at least during drought conditions, the primary erosion source in the Weany Creek catchment is gully erosion. However, the largest term in the sediment budget is actually derived from the remobilisation of in-channel sediment stores; this bed material is primarily coarse grained.

Due to the large amount of sediment being sourced from the channel bed in the initial sediment budget, an additional 6 scour chain sites were installed in the channel bed between site 2 and the junction of the upper and lower arms of Weany Creek, as well as just upstream of the junction (see Figure 57). This site was not initially monitored due to the potential interference from the cattle camp site in this area. The one year of data from the 2005/06 wet season does suggest that there is a considerable amount of coarse sediment being deposited upstream of site 3 and this could be as high as 2815 t/yr (Figure 61). This means that the total sediment yield from Weany Creek could be as low as 30% of the original yield estimate. Nonetheless, most of this deposition is coarse sediment and the major findings from the sediment budget study are largely the same.

The higher than expected bedload volumes found in Weany Creek could be because the proportion of fine sediment has declined. Two of the primary fine sediment sources, hillslope and gully erosion, are now in the ‘mature’ stage of their lifecycle. Most of the A-horizon has been removed from the hillslopes over the last 100 years of cattle grazing, and although the B horizon is now eroding, the amount of fine sediment from hillslope erosion being measured at the catchment outlet may be much lower now than it was in historical times. Many of the gullies are approaching the ridge-tops in the catchment, and erosion rates are possibly much lower now than in the past, and will continue to decline in the next few decades. Bank erosion, along with the fine sediment stored in the bed is probably the main source of fine sediment to the catchment outlet.

This study found that the contribution from hillslope erosion to the total sediment budget is smaller than anticipated; however, this does not reduce the significance of maintaining good ground cover on the hillslope surface. It is well known that gully systems can be initiated and exacerbated by excess overland flow. Therefore good ground cover is also important in preventing further gully formation, as well as channel erosion and bedload remobilisation. Roth (2004) has shown in grazing lands of the Burdekin catchment that cover levels need to be above 75% for periods up to 15 years in order for soil hydrologic function to be re-established and for the potential of runoff generation to be significantly reduced.

The main implication from this work is that any land management strategies implemented in catchments such as Weany Creek may not be detectable at the end of the catchment as decreased sediment yields for many years after the management action. This is because the amount of sediment being moved from historical sources out weighs the potential change in sediment yield from land management. This study also emphasises that land management decisions being made this decade may influence runoff and geomorphic processes for the next century.

It is also important to recognise that when a large rain depression (or cyclone) does hit the Weany Creek area, there is potentially ample fine sediment stored on the hillslopes, as well as coarse sediment stored in the channel, available for mobilisation. The increased sediment flux associated with drought breaking events has been identified in the coral record (McCulloch *et al*., 2003). Therefore it is likely that a sediment budget measured during high rainfall years, following drought conditions, will be very different to the sediment budget presented in this paper.

Table 16: Sediment budget for Weany Creek Catchment developed using measured field data. Positive values represent sediment loss or erosion and negative values represent sediment deposition or storage. Na = no measurements made at catchment outlet

Sediment source	Sub-section	Mean sediment Yield (tonnes/yr)		
		Fine	**Coarse**	**Total**
Hillslopes		490	102	592
Gullies	Headcut	700	1049	1749
	Head wall	71	106	177
	Middle wall	48	72	121
	Valley wall	-179	-269	-449
	Gully floor deposition	-694	-2082	-2775
Net gully flux		55	-1123	-1178
Banks		125	187	311
Channel bed		224	4255	4479
Total		**785**	**3420**	**4205**
Mean annual load measured at catchment outlet		848	Na	na
% difference between measured fine sediment and load estimates		7 %		

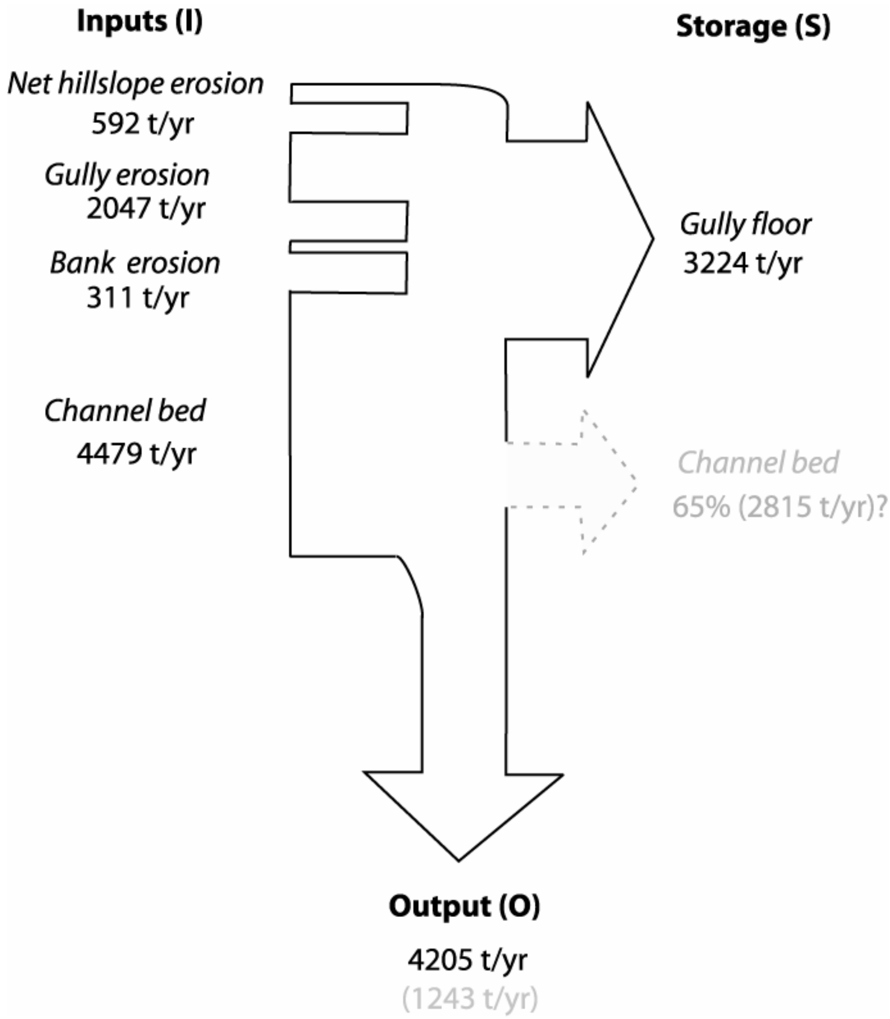


Figure 61: Schematic representation of the main erosion and deposition processes occurring in the Weany Creek catchment based on the measured sediment budget presented in this report. The amount of sediment leaving a catchment outlet (O) is the amount of sediment supplied to the catchment as input (I) minus the amount of sediment stored (S). The values noted in grey are based on recent bed deposition data that has not been included in previously published material. Further monitoring data is required to refine this budget. It is important to note that the amount of hillslope sediment storage is not explicitly described in this budget.

7.3.4 Nutrient budget

Methods

To develop the nutrient budget for Weany Creek, the erosion rates developed for the sediment budget (Table 16) were multiplied by the total nitrogen (TN) and total phosphorus (TP) concentrations found in the various morphological units in Weany Creek (Table 17 and Table 18). We have assumed that on an annual basis the net biological inputs and outputs are small compared to physical sources, and therefore are not explicitly accounted for; however, there is a need to quantify the source of TN and TP from cow manure as it may be a significant source in semi-arid systems. We also do not account for denitrification during flow events, as generally water flows in these systems for less than 5% of the year. Total nitrogen (N) and phosphorus (P) were determined using autoanalyser techniques (Rayment and Higginson, 1992) following digestion using the Kjeldahl wet oxidation method described by Bremner and Mulvaney (1982)

Table 17: Concentrations of nitrogen (N) found in the various morphological units within Weany Creek. The concentrations of nitrogen from the hillslope were based on water samples collected at the bottom of the hillslope (mg/L) and then converted to kg/ha. All other samples are based on soil samples collected from the gullies, banks and channel bed and are presented as mg/kg except for the hillslope samples that are presented as kg/ha.

Sediment source	Sub-section	Mean nitrogen concentrations (mg/kg)	
		Fine	**Coarse**
Hillslopes*		0.49 kg/ha	<1%
Gullies	Wall sediments	396	105
	Floor sediments	209	36
Banks		530	160
Channel bed		78	9

* concentrations measured at the bottom of the hillslope

Table 18: Concentrations of phosphorus (P) found in the various morphological units within Weany Creek. The concentrations of phosphorus from the hillslope were based on water samples collected at the bottom of the hillslope (mg/L) and then converted to kg/ha. All other samples are based on soil samples collected from the gullies, banks and channel bed and are presented as mg/kg except for the hillslope samples that are presented as kg/ha.

Sediment source	Sub-section	Mean phosphorus concentrations (mg/kg)	
		Fine	**Coarse**
Hillslopes*		0.14 kg/ha	<3%
Gullies	Wall sediments	657	205
	Floor sediments	577	173
Banks		458	130
Channel bed		407	148

* concentrations measured at the bottom of the hillslope

Results

The TN and TP contributions at the catchment outlet are presented in Table 19 and Table 20. There is a remarkable agreement (4%) between the TP estimated using the sediment budget approach and the 6 year TP load measured at the catchment outlet (Table 20). The match between the TN load predicted at the catchment outlet using the sediment budget approach and the amount of TN measured at the gauge is not as strong as for phosphorus (within 17%) and suggests that there may be an biological source, possible cow dung, that has not been accounted for in the nutrient budget.

Table 19: Nitrogen budget for Weany Creek Catchment developed using measured field data. Positive values represent sediment loss or erosion and negative values represent sediment deposition or storage. Na = no measurements made at catchment outlet

Sediment source	Sub-section	Mean nitrogen Yield (kilograms/yr)		
		Fine	**Coarse**	**Total**
Hillslopes		662	-	662
Gullies	Headcut	277	110	387
	Head wall	28	11	39
	Middle wall	19	8	27
	Valley wall	-71	-28	-99
	Gully floor deposition	-145	-75	-220
Net gully flux		108	26	134
Banks		66	30	96
Channel bed		17	38	55
Total		**853**	**94**	**947**
Mean annual load measured at catchment outlet		1024	Na	Na
% difference between measures fine sediment load estimates		17 %		

Table 20: Phosphorus budget for Weany Creek Catchment developed using measured field data. Positive values represent sediment loss or erosion and negative values represent sediment deposition or storage. Na = no measurements made at catchment outlet

Sediment source	Sub-section	Mean phosphorus Yield (kilograms/yr)		
		Fine	**Coarse**	**Total**
Hillslopes		189	-	189
Gullies	Headcut	460	215	675
	Head wall	46	22	68
	Middle wall	32	15	47
	Valley wall	-118	-55	-173
	Gully floor deposition	-400	-360	-760
Net gully flux		20	-163	-143
Banks		57	24	81
Channel bed		91	630	721
Total		**357**	**491**	**848**
Mean annual load measured at catchment outlet		342	Na	Na
% difference between measures fine sediment load estimates		4%		

Summary of results

The results from this study have highlighted that temporal field based data can provide important information to help adjust and inform larger scale sediment budget modelling projects. The results of this study provide the process understanding required to improve such models. Future catchment scale modelling projects carried out in these systems need to take into account the presence and re-activation of historical sediment stores. It is common to use large scale sediment budget models to evaluate different land use management scenarios to help reduce soil loss (e.g. Bartley *et al*., 2004). However, the scenarios do not take in account the temporal lag and remobilisation of stored sediment, which may move through the stream network many years following management intervention. Recent advances in modelling temporal variations in sediment transport by Wilkinson *et al*., (2006a) may allow this remobilisation to be taken into account in future catchment sediment budget studies.

7.4 Field measurement derived data from the Burdekin catchment

The most intense field data collection was carried out at Virginia Park Station as described in the previous section. There have, however, been a number of other field monitoring and measurement campaigns in the Burdekin Catchment. In this section we present the findings from a bank erosion study on the Upper Burdekin (Section 7.4.1), and the end of catchment load monitoring results from 8 sites in the catchment which includes a comparison of loads from different geological areas (Section 7.4.2).

7.4.1 Upper Burdekin bank erosion results

Sediment budgets, in the form of the SedNet Model, have been developed for the Burdekin Region to determine catchment loads and evaluate various land use management scenarios (Cogle *et al*., 2006; Prosser *et al*., 2001a). The contribution from bank erosion in this model is based on an empirical relationship which was derived from a review of global meander migration estimates (see Walker and Rutherfurd, 1999). In fact, data from only three Australian rivers, none of which are in the tropics, were included in the review. This is because there are few or no quantitative bank erosion estimates for streams in Australian tropical catchments. Without this basic field data, it is difficult to determine whether the current modelling tools are suitable for estimating bank erosion, particularly for the high energy tropical stream systems. More importantly, the use of existing models of river bank erosion and migration without adequate calibration can lead to large systematic errors in the prediction of bank erosion rates (De Rose *et al*., 2005).

In an effort to better understand the suitability of the bank erosion rule for use in the Burdekin Catchment, an investigation into the rates and influences of bank erosion has been conducted for a 250 km study reach of the Upper Burdekin River. Full details of the study are described in Bainbridge (2004). An historical analysis of channel change between 1962 and 2002 along the study reach has identified an average annual increase in channel width of 0.03%. Although this finding is comparatively low by world standards, the historical analysis has identified measurable rates of erosion to be occurring locally along the reach.

Using the historical data, the accuracy of the SedNet bank erosion rule was tested. The results found a remarkable agreement between the average rate of erosion measured along the study reach for the 40-year period (0.0753 m/yr), and the corresponding rate generated by the SedNet model (0.0728 m/yr). However, study showed that the model had a number of flaws:

- Although the model was able to predict the average erosion rate over the 250 km reach with a high degree of accuracy, the ability to predict bank erosion rate at a given stream link was relatively poor (Figure 62). This highlights the fact that bank erosion is the result of a set of complex natural processes that depend on in-channel hydraulic conditions as well as the physical character of the banks, both of which are highly variable within a single river, as well as between rivers (Piegay *et al*., 2005). Unfortunately, however, the poor predictability at the reach scale reduces the suitability of this model for targeting stream management works, and rigorous field evaluation of sites is encouraged before the modelling results are used for targeted land management;

- Because one of the main purposes of the model is to investigate erosion hot spot areas, the model only represents bank erosion and does not account for channel contraction in alluvial river systems. Channel contraction is possible for rivers that are in dynamic equilibrium that will undergo periods of channel contraction and expansion over time.
- The mean bank height of 3 m that is used to convert the bank erosion rate to a sediment yield is much lower than the measured bank height of 6.45 m for the Upper Burdekin.

Based on the findings presented in Bainbridge (2004) the stream width and height data were revised for the Burdekin SedNet modelling exercise (see Appendix C). However, improving the actual bank erosion rule will require field data from many more river systems around the country, and in particular from tropical regions. Therefore, the bank erosion rule in the latest application of the SedNet model remains the same, and caution is issued for those wanting to use the results at small reach scales.

Table 21: Descriptive statistics comparing the historically measured rates of bank erosion for each individual study site with those predicted by the SedNet model (Bainbridge, 2004)

Parameter	Historically measured (m/yr)	SedNet modelled (m/yr)
Mean	0.0753	0.0728
Median	0.07	0.0570
Std. Deviation	0.1875	0.0424
Range	1.06	0.21
Minimum	-0.36	0.01
Maximum	0.70	0.22

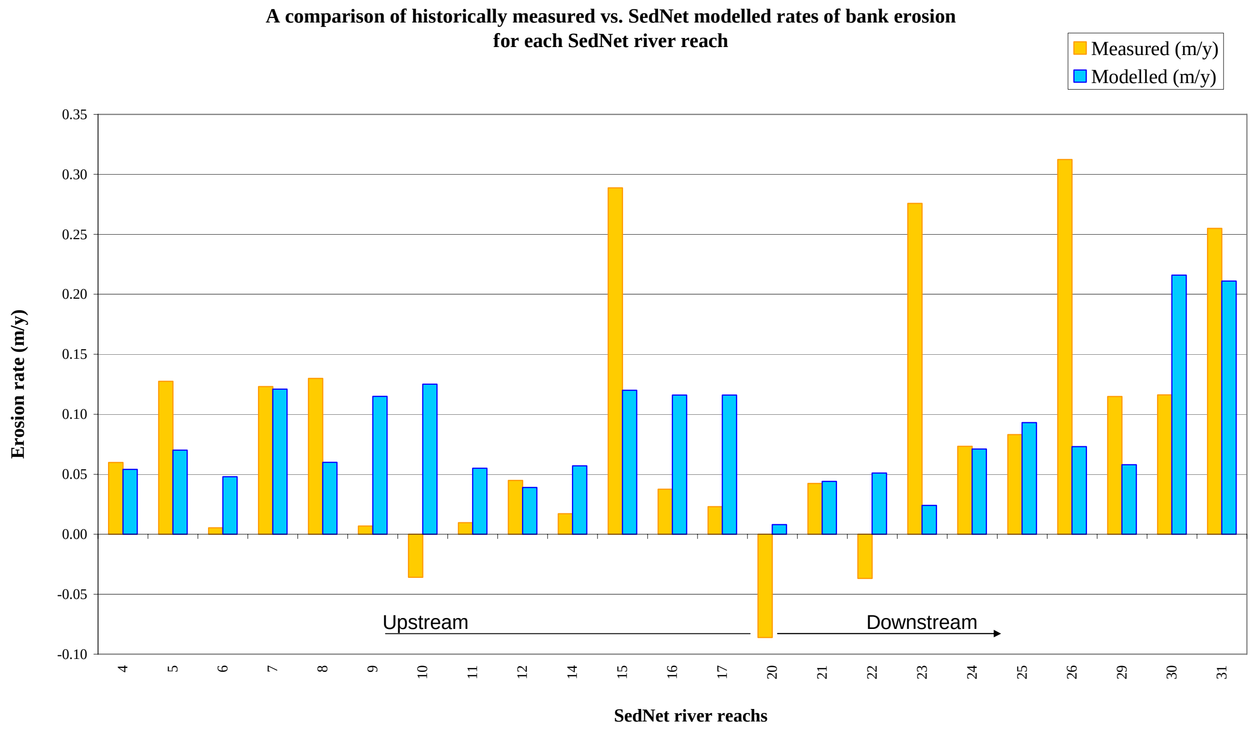


Figure 62: A comparison of historically measured vs. SedNet modelled average rates of bank erosion for 23 SedNet river reaches in the Upper Burdekin Catchment (Bainbridge, 2004).

7.4.2 End of catchment loads

Understanding the impact of land use change in grazing lands requires estimates of sediment and nutrient fluxes over time. Therefore as part of MLA's long term commitment to assessing the impact of grazing in the Burdekin catchment, a total of 5 end of catchment flux stations have been installed in grazed catchments of various sizes. It is anticipated that with improved grazing management, a reduction in sediment and nutrient loads will be observed at some of these sites in the future.

To provide a comparison with the grazed catchment sites funded by MLA, a further 4 sites were installed on the Department of Defence Townsville Field Training area (TFTA) and a discussion of the sites and methods employed are given in Post *et al*., (2006b). Most of these sites have had little or no commercial grazing for the last 20 years and the main disturbance in the area is due to some permanent military tracks (Roth, 2004) A tenth site was installed in the Bowen catchment and is funded by the Burdekin Dry Tropics Board (BDTB). The Bowen site has a mixture of land use types and geologies. A map and description of the ten monitoring sites are given in **Figure 2** and **Table 22**.

Table 22: CSIRO end of catchment monitoring sites in the Burdekin Catchment

Site Number	Site Name	Area (km^2)	Location (WGS84)	Parameters Measured	Turbidity sensor	Operator	Funding source
1	Wheel Creek	11	S19.818197 E146.558012	Discharge, TSS, Turbidity, WQ	Greenspan TS100	CLW	MLA
2	**Main Creek**	**13**	**S19.508408 E146.321561**	**Discharge, TSS, Turbidity, WQ**	**McVan Analite NEP390**	**CLW**	**TFTA**
3	Weany Creek	14	S19.914713 E146.492775	Discharge, TSS, Turbidity, WQ	Greenspan TS100	CLW	MLA
4	**Thornton Creek**	**84**	**S19.662494 E146.214080**	**Discharge, TSS, Turbidity, WQ**	**McVan Analite NEP390**	**CLW**	**TFTA**
5	Blue Range Creek	106	S19.15 E145.47	Discharge, TSS, Turbidity, WQ	McVan Analite NEP390	CLW	MLA
6	**Fanning River West Branch**	**146**	**S19.586554 E146.447568**	**Discharge, TSS, Turbidity, WQ**	**McVan Analite NEP390**	**CLW**	**TFTA**
7	Station Creek	148	S19.902052 E146.488994	Discharge, TSS, Turbidity, WQ	McVan Analite NEP390	CLW	MLA
8	**Keelbottom Creek**	**1,170**	**S19.702186 E146.198622**	**Discharge, TSS, Turbidity, WQ**	**McVan Analite NEP390**	**CLW**	**TFTA**
9	Bowen @ Myuna (120205)	7,200	S20.583 E147.583	Discharge, TSS Turbidity, WQ	McVan Analite NEP180	NR&M, CLW	BDTB
10	Burdekin @ Macrossan (120002)	36,390	S19.998583 E146.437065	Discharge, Turbidity	Greenspan TS300	NR&M, CLW	MLA

Methods

To estimate discharge and sediment yield at the outlet of each of the sites, an automatic gauging station was installed. 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. At the Weany Creek site, 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 at each site.

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), nitrogen, phosphorus 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 (Figure 63) and used to determine flow weighted suspended sediment concentration (after Gippel, 1995; Grayson *et al*., 1996). Strong relationships exist between Turbidity and TSS (**Figure 63**), TN and turbidity (Figure 64A) and TP and turbidity (**Figure 64**B) for each of the gauged sites. Note that relationships were derived for each individual catchment using all of the data available for that catchment over the period 1999-2006. By comparison, **Figure 63** and **Figure 64** show data for just the 2005/06 wet season.

Initial end of catchment load calculations for Weany Creek were based on the Turbidity and TSS relationships derived for each of the individual wet seasons from 2001-2005 and these data are published in Bartley *et al*., (2007). More recent analysis has shown that it is more robust to estimate loads using the Turbidity/TSS relationship for all of the years combined, rather than for individual years (Figure 65). These turbidity relationships, along with the velocity and channel dimensions, were used to calculate the sediment and nutrient loads at the catchment outlet during events. The event based sediment and nutrient loads were then totalled for each wet season to provide an annual suspended sediment yield at the catchment outlet. As a result, the yields presented here are different to those presented for Weany Creek in Bartley *et al* (2007). This improved method for estimating sediment and nutrient loads also highlights the importance of long term (>3-5 years) data sets in these highly variable systems.

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 ±50%.

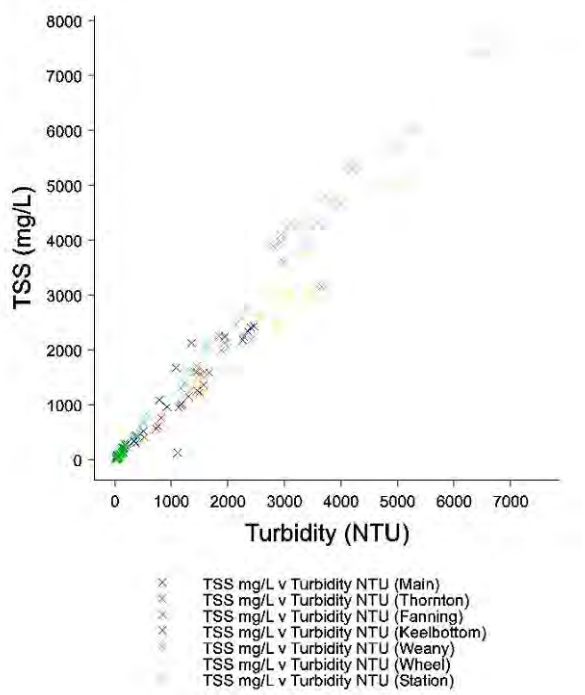


Figure 63: Relationship between turbidity and TSS for the TFTA and grazed catchments for 2005/06

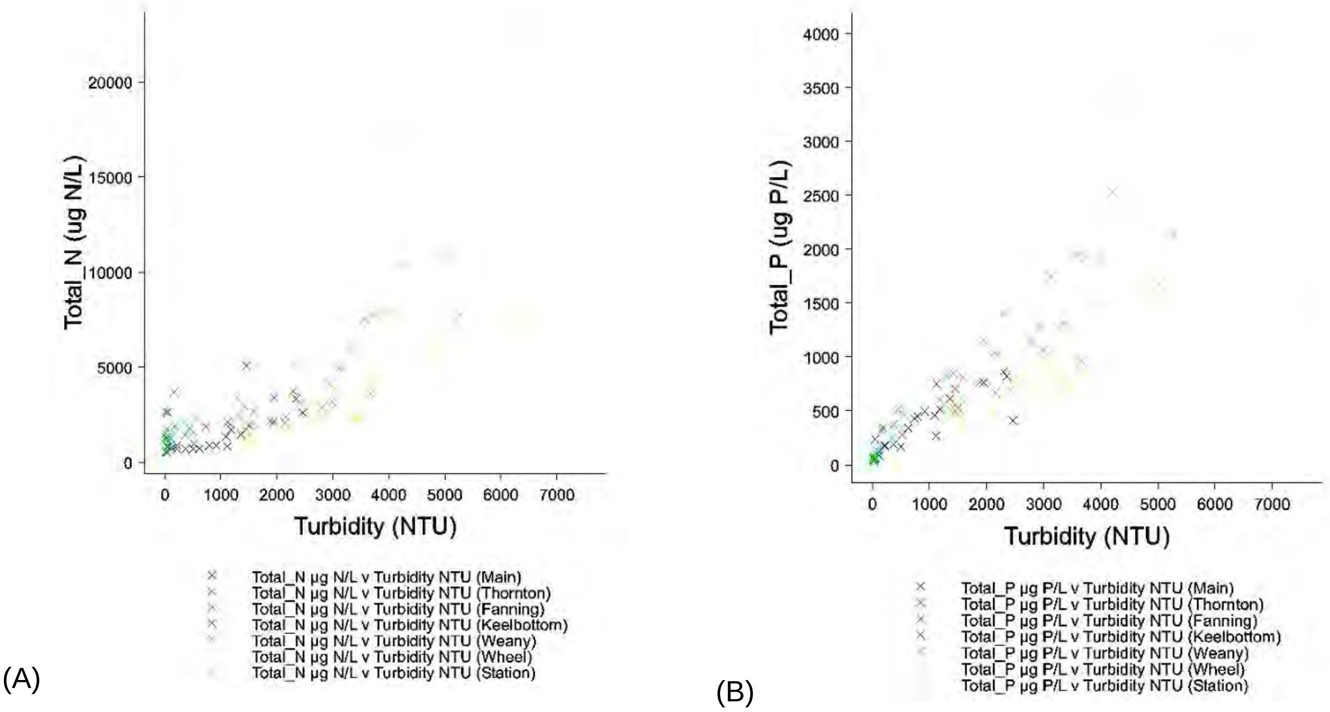


Figure 64: Relationship between (A) turbidity and Total N and (B) between turbidity and Total P, for the TFTA and grazed catchments for 2005/06

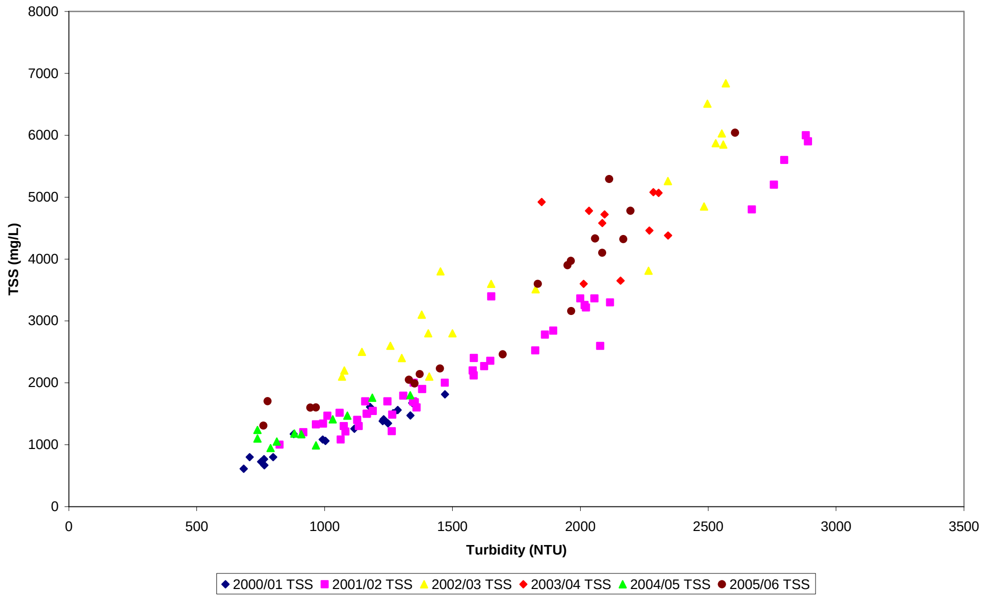


Figure 65: Shows the Turbidity and TSS relationships for the 6 years of data from Weany Creek. The plot demonstrates that the 6 year trend is very different to the trend for individual years, particularly for 2003/04 and 2004/05.

Results

Runoff, sediment and nutrient loads for each of the Burdekin sites are given in Table 23. Due to difficulties with the instrumentation, no results are presented for Blue Range and Fanning River. There is a strong power function relationship between catchment area and sediment yield (Figure

66). The data highlight that the majority of the nutrients from the grazing lands are dominated by particulate sources as the relationship between catchment area and TN and TP yield are very similar to that for sediment (Figure 67).

Wasson (1994) presented relationships between catchment area and sediment yield for a range of regions in Australia. The majority of sites had exponent (b) values less than one which suggest that most of the sediment in catchments is produced in steep headwater areas where drainage density is highest and storage small. The b value for the relationship between catchment area and sediment yield for the Burdekin basin is 1.08 (Figure 66). Other studies have suggested that when b > 1.0, the catchment is dominated by a secondary reworking of deposits in the valley floor rather than primary erosion sources (Church and Slaymaker, 1989; Slaymaker, 2006). This finding is consistent with the results presented in Bartley *et al*., (2007) that suggest that much of the sediment from the Weany Creek catchment is derived from remobilised sediment that has been stored in the channel. Therefore, it is likely that the sediment loads of many of the other sites in the upper Burdekin are dominated by channel sources and in channel stores. Further dating and tracing work will help determine the residence time and primary sources of the sediments.

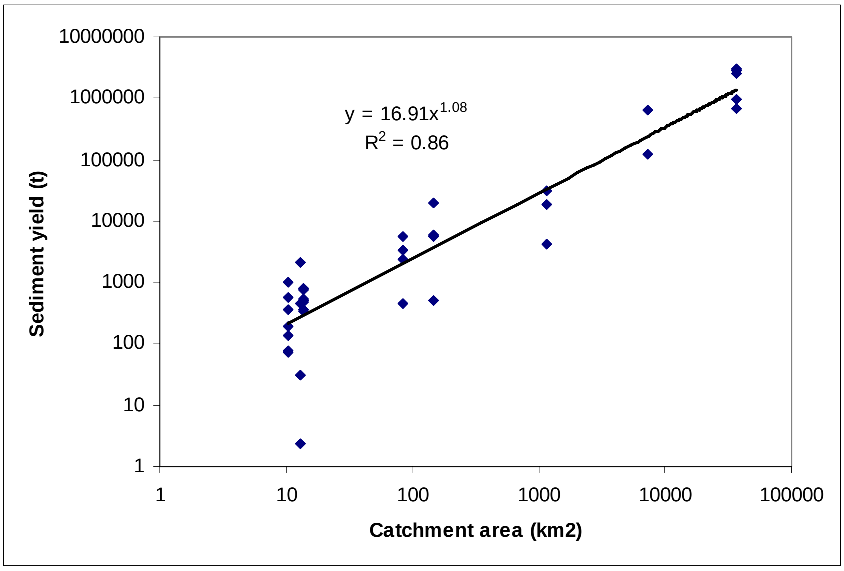


Figure 66: Average annual suspended sediment yield (t) against catchment area (km^2) for 8 sites in the Burdekin Catchment.

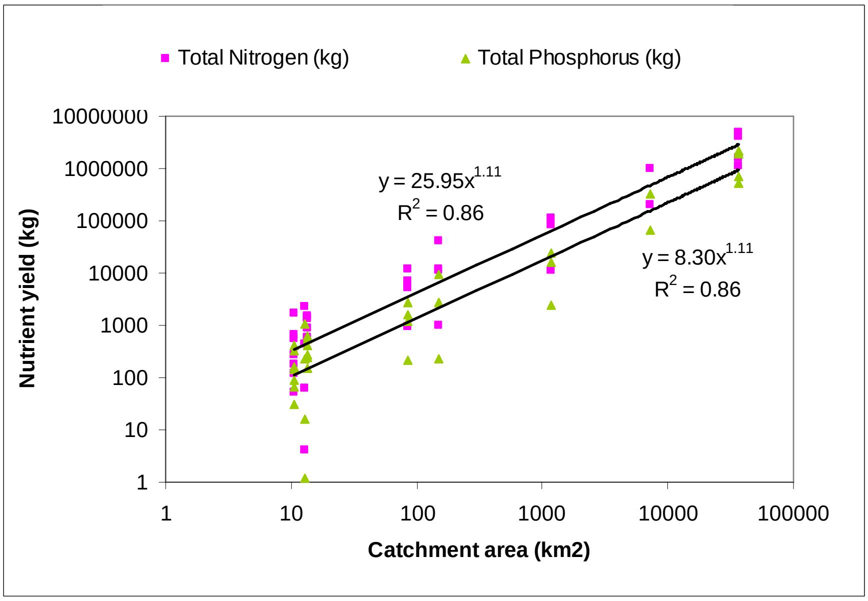


Figure 67: Average annual total nitrogen and phosphorus yield (t) against catchment area (km^2) for 8 sites in the Burdekin Catchment.

Table 23: Monitoring data results for the 10 gauges sites in the Burdekin. The sites with a grey background are not grazed.

Site Number	Site	Catchment area (km^2)	Years of data collection (year wet season started)	Years of data	Average annual rainfall (mm)	Average annual runoff (mm)	% Runoff	Average annual sediment yield (t)	Average annual sediment yield (t/ha)	Average annual TN (kg/ha)	Average annual TP (kg/ha
1	Wheel Creek	11	1999-2005	7	512.33	39.31	6.52	349.21	0.38	0.48	0.17
2	Main Creek	13	2001-2005	5	422.33	50.48	8.92	662.90	0.51	0.53	0.26
3	Weany Creek	14	1999-2005	7	445.43	30.00	6.68	541.00	0.40	0.76	0.25
4	Thornton Creek	85	2001-2005	5	305.33	23.79	8.45	2948.83	0.35	0.75	0.17
5	Blue Range*	106	2005	1	-	-	-	-	-	-	-
6	Fanning River**	146	2002-2005	4	-	-	-	-	-	-	-
7	Station Creek	148	2001-2005	4	410.67	37.04	9.05	7982.53	0.54	1.12	0.26
8	Keelbottom Creek	1170	2002-2005	4	366.00	30.48	7.52	18164.52	0.16	0.59	0.12
9	Bowen @ Myuna	7200	2003-05	3	525.00	28.22	5.38	375238.00	0.52	0.83	0.27
10	Burdekin@Macrossan	36390	2001-2005	5	462.50	45.74	9.45	1987398.80	0.55	0.91	0.41

* insufficient data collection and errors with equipment; ** data to be re-analysed due to the relocation of equipment

Comparison of sediment and nutrient loads from grazed versus ungrazed catchments

This section of the report describes some of the water quality differences observed between the grazed and ungrazed catchments in the Burdekin Catchment. The data show that total suspended sediments (TSS) (Figure 68) and particulate nitrogen and phosphorus concentrations (Figure 69) are all higher in grazed than in un-grazed catchments.

Interestingly, the average % runoff (the amount of rainfall that turns into runoff) is actually higher in the un-grazed than in grazed catchments (data not shown), however, it is likely that there are large errors in calculating the amount of rainfall. Rainfall was calculated using one rain gauge adjacent to the stream gauge, and it is acknowledged that there can be enormous variability in rainfall input within and between catchments. Therefore rainfall may have been grossly under or over estimated, particularly in the larger catchments. When the runoff data is interpreted for per unit catchment area, the amount of runoff per unit area is higher in the grazed catchments (2.25 mm/km^2) than in the un-grazed catchments (1.43 mm/km^2).

Overall, the sediment yields per unit runoff are significantly higher ($p<0.01$) in grazed than in un-grazed catchments (using the methods from Zar, 1996 p.360). Figure 70 shows that the sediment yield per unit runoff in grazed catchments is twice that from un-grazed catchments.

Some of the differences between the sediment and nutrient yields from grazed and ungrazed catchments can partly be explained by a difference in ground cover. A comparison of ground cover and foliage projective cover has been estimated for 3 grazed and 4 un-grazed catchments as well as for the entire Burdekin catchment (Table 24). To estimate tree cover, the foliage projective cover (FPC) from NRM&W was applied, and to estimate ground cover a landsat image taken in August 2004 (end of dry season) was used (Post *et al*., 2006b).

The average ground cover across the TFTA is 60%, compared to 53% for the remainder of the Burdekin catchment, whereas the foliage projective cover was basically the same for grazed (19%) and ungrazed (18%) sites. Other studies in the semi-arid grazed areas of Queensland have shown that there can be up to a 78% increase in runoff following vegetation clearing (Siriwardena *et al*., 2006), however, there is no significant difference in the % tree cover between grazed and un-grazed catchments in this study, and hence very little difference in runoff coefficients.

Although there is no difference in the tree cover, there are differences in the % ground cover. The 3 grazed sites (Wheel, Weany and station Creeks) used in the sediment yield estimates had an average cover of 44% whereas the 3 un-grazed sites (Main, Thorton and Keelbottom Creeks) had average cover levels of 52%. This difference in likely to contribute to the higher sediment yields from grazed catchments.

Despite the differences in mean cover levels between grazed and un-grazed sites, it is now established that the arrangement of cover, rather than the mean ground cover per se, is a more important influence on sediment and nutrient loss (Bartley *et al*., 2006). Therefore as well as the differences in ground cover between grazed and un-grazed sites, there are more bare patches adjacent to stream networks in grazed catchments, and therefore although the runoff volumes per unit area are similar, the amount of sediment at the bottom of hillslopes available to be removed by the runoff is much higher. Field and aerial photo data collected on gully densities also highlight that gully densities are much higher in grazed areas of the Burdekin catchment, ~4.5 km/km^2 (Heine, 2002) than in un-grazed areas which have gully densities of ~0.29 km/km^2 (Post and Alewijnse, 2002). Other studies carried out in semi-arid parts of the world also suggest that soil surface condition, in particular the variation in crust formation can have a large influence on the hydrological behaviour of catchments (Casenave and Valentin, 1992). This was highlighted by the work of Roth (2004) who showed that there is a difference in the soil properties from grazed and un-grazed sites. Therefore it is likely that the combination of bare ground quantity and arrangement, quality of the ground condition (i.e. crusting) and higher gully densities are adding to the doubling of sediment yields per unit runoff in grazed catchments.

It is important to point out that although statistically significant differences were found between the sediment yields from grazed and un-grazed sites, further work is required to determine if land use is the main cause of this difference. It may be that differences in the geology at the various sites and/or grazing histories mean that it is not necessarily suitable to directly compare these sites. More work is planned on this issue in the future.

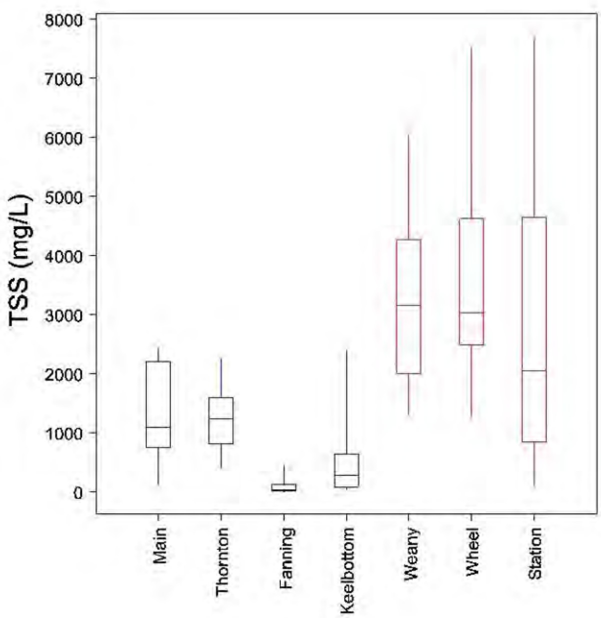
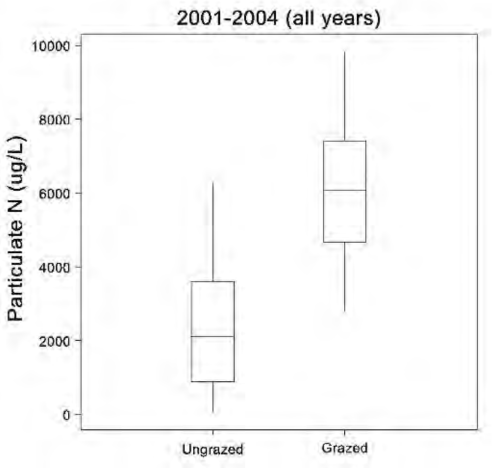


Figure 68: Comparison of TSS concentration from grazed (Weany, Wheel and Station) and ungrazed (Main, Thorton, Fanning and Keelbottom) sites for the 2005/06 wet season only



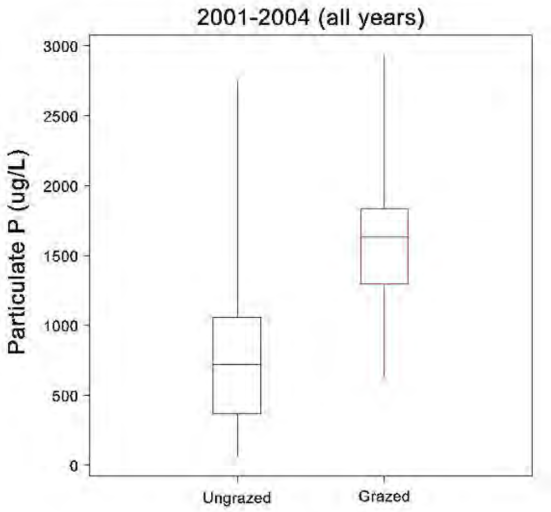


Figure 69: comparison of particulate N and P for grazed vs ungrazed sites

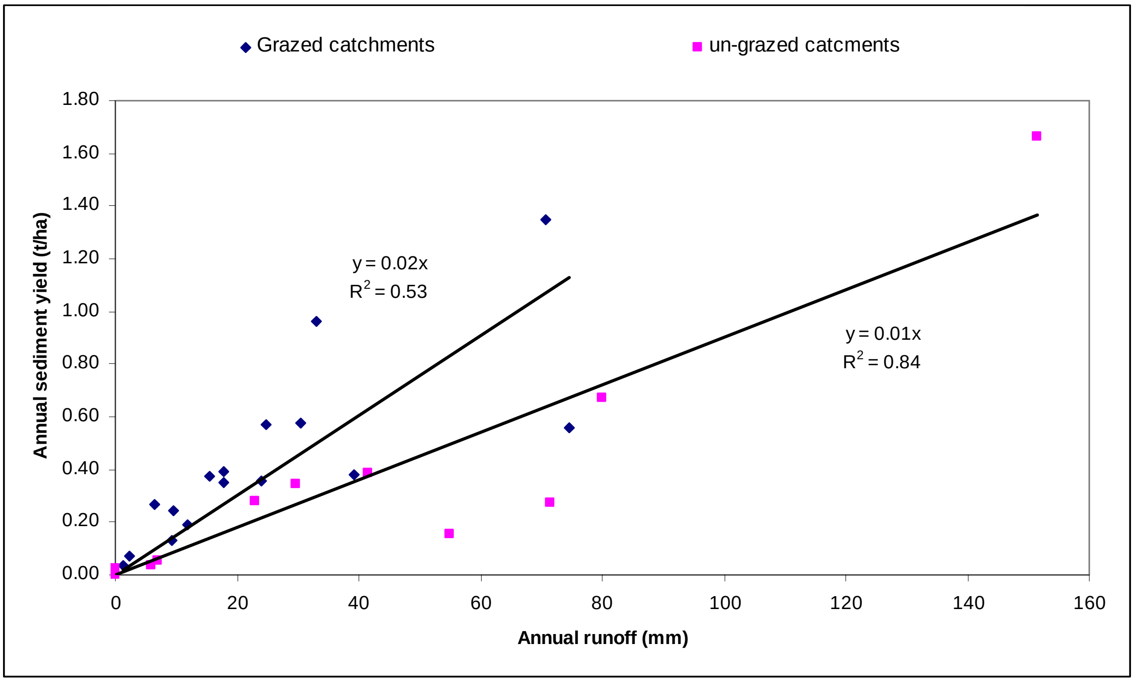


Figure 70: Difference between catchment area (km^2) and sediment yield (t/ha) for grazed and un-grazed catchments is significant at $p<0.01$.

Table 24 : Distribution of ground cover and foliage projective cover across all catchments (Post *et al*., 2006b)

	Whole of Burdekin	Station Creek	Weany Creek	Wheel Creek	Whole of TFTA	Thornton Creek	Main Creek	Fanning River	Keelbottom Creek
	Grazed	Grazed	Grazed	Grazed	TFTA	TFTA	TFTA	TFTA	TFTA
Ground cover									
10th percentile	27	22	21	19	38	37	26	52	33
25th percentile	40	33	31	30	49	47	34	60	45
50th percentile (median)	**53**	**46**	**43**	**43**	**60**	**57**	**43**	**68**	**56**
75th percentile	64	58	53	57	69	66	51	75	64
90th percentile	72	67	62	67	75	73	58	81	69
Foliage projective cover									
10th percentile	10	5	5	6	7	6	5	14	7
25th percentile	14	10	12	13	12	10	9	21	11
50th percentile (median)	**19**	**16**	**18**	**17**	**18**	**15**	**13**	**29**	**17**
75th percentile	26	22	22	22	26	20	18	36	25
90th percentile	33	27	26	27	36	25	22	42	35

7.5 Whole of catchment modelling results: SedNet and ANNEX

Due to the large size of the Burdekin region, and the long time frames involved in collecting field data, catchment and sub-catchment scale sediment budgets need to be calculated using a modelling approach. In this report the Burdekin region refers to the Burdekin catchment as well as the adjacent coastal catchments near Townsville such the Haughton River and Barratta Creek (**Figure 71**). The SedNet and ANNEX models have been used to estimate sediment and nutrient budgets for the Burdekin region on a number of occasions over the last 5 years (see Table 25). As part of this MLA report we have re-run the SedNet and ANNEX models using the latest toolkit versions of the model (Wilkinson *et al*., 2004). These re-runs have also included improved data inputs as described below.

7.5.1 Background

SedNet is a software package developed by CSIRO for use in the Australian National Land and Water Resources Audit in 2000 ("NLWRA" – www.nlwra.gov.au). It was used by the NLWRA to assess water quality in the major catchments throughout Australia. Information on SedNet model development and its application are detailed in a series of CSIRO Land and Water technical papers and related publications (McKergow *et al*., 2005a; McKergow *et al*., 2005b; Prosser *et al*., 2001b; Wilkinson *et al*., 2006a; Wilkinson *et al*., 2006b). ANNEX is the sister model to SedNet that is used to evaluate nutrient loads.

SedNet and ANNEX were originally developed in AML scripting language in Arc/INFO TM. Now it has been ported into a freely available downloadable software package. A full description of the SedNet model software and data requirements are contained in the SedNet Users Guide (Wilkinson *et al*., 2004), which can be downloaded from the Toolkit website (www.toolkit.net.au), as can the complete software package.

In brief, the SedNet model simulates river sediment loads for catchments by constructing material budgets that account for the main sources and stores of sediment. In order to do this, the model makes estimates of erosion rates (gully, bank and hillslope) for available climate, soil, topography and land use data as well as information relating to the catchment's hydrological processes (mean annual flow, extent of floodplain, channel dimensions). The SedNet model employs a simple conceptualisation of hydrological transport and deposition processes (Wilkinson *et al*., 2006b). Outputs from SedNet include maps of sediment sources, stream loads, and areas of deposition within the system. The contribution of sediment from each watershed to the river mouth can be traced back through the system, allowing downstream impacts to be put into perspective.

The SedNet model has been run over the Burdekin a number of times in the recent past, with each new version addressing aspects of the model identified for improvement (Table 25).

Table 25: Previous SedNet models for the Burdekin

Year	Undertaken by	Issues addressed
2001	NLWRA (2000)	Original model done as part of the National Land and Water Resources Audit (NLWRA)
2002	Prosser *et al*., (2001a) - CSIRO	First application of model to an individual catchment
2004	Brodie *et al*., (2003) and McKergow *et al*., (2005a); (2005b) – ACTFR and CSIRO	Dissolved Nutrients (ANNEX), Landuse,
2006	Cogle *et al*., (2006) – QNRM&E and CSIRO	Erosivity, dissolved nutrient data, landuse, bank erosion, plus port to the Toolkit version (not ANNEX)

The SedNet model for this project has built on previous work done as part of the QDNRMW's Short Term Modelling Project (Cogle *et al*., 2006) and covers the same area (i.e. The Burdekin River Basin plus the coastal catchments from Black River North of Townsville to the Don River at Bowen, collectively referred to as the Burdekin Region in this report). Details of the datasets used for the Short Term Modelling (STM) project are described in Cogle *et al*., (2006) and Fentie *et al*., (2006) which can be found at http://www.wqonline.info/products/short_term_modelling.html. The data inputs and parameter setting used in this report, and how they differ from the STM project, are described in detail in Appendix B. In summary, the main areas where this project has improved on previous modelling projects in the Burdekin includes:

- A spatially variable cover-factor in rangeland areas (~95% of total modelled area), allowing for hillslope erosion rates based on RUSLE to be related directly to estimated ground cover levels (see Appendix B)

- Improved spatial resolution of the slope (S)-factor in the revised universal soil loss equation (RUSLE) estimates of hillslope erosion. The S-factor is based on 90m DEM data from the Shuttle RADAR Topographic mission (SRTM) (see Appendix A and Appendix B)

  NB. improvements in spatial resolution in both the S and C-factors will couple together to result in an improved RUSLE based hillslope erosion grid by providing much more localised estimates of hillslope erosion than previous projects.

- Revised gully cross-sectional area estimate based on field measurements (see Appendix B and Appendix C)

- Improved estimates of channel width and depth based on field measurements, allowing for improved estimates of channel deposition and bank erosion (see Appendix C).

- Use of the transient bedload model (see Appendix B) available now in SedNet

- Porting of ANNEX to the Toolkit.

The results of the modelling work are outlined in the following sections.

7.5.2 Results

Sediment budget

A sediment budget for the whole of the Burdekin region is presented in Table 26. The results suggest that a long-term average of ~11,312 kt/yr of sediment reaches the Burdekin River, with ~7433 kt/yr of sediment being stored in the system in reservoirs, floodplains and similar storages, and a total of 3878 kt/yr of sediment being exported to the estuary. Approximately 94% of the sediment leaving the catchment is fine or suspended sediment and the remaining 6% is coarse sediment.

Hillslope erosion is the highest contributor of sediment to the river system (44%) followed by bank erosion (32%) and then gully erosion (24%). In previous applications of the SedNet model in the Burdekin region, gully erosion was predicted as the highest or second highest contributor of sediment (Cogle *et al*., 2006; Prosser *et al*., 2001a). The fact that gully erosion has the lowest overall contribution in this study is a function of the revised cross-sectional area employed in this model run. The increased contribution from bank erosion is a function of the improved estimates of channel widths and depths in the model which predict higher bank heights in the main channels.

The general pattern of hillslope, bank and gully erosion from the Burdekin region is given in Figure 72. To determine which areas of the catchment were contributing the most sediment and nutrients, the Burdekin region was broken up into 53 sub-catchments as recommended by the Australian Centre for Freshwater Research (ACTFR) (Figure 71). [NB: There are some discrepancies in the boundaries of the sub-catchments due to erroneous placement of stream networks by the SedNet Model used for this report (a consequence of the AUSLIG 9-second DEM chosen for the SedNet framework – See Appendix B)]. Table 27 details the total suspended sediment contributions from each of the sub-catchments with the highest per unit sediment yields coming from the Don, Haughton, Broken and Stones Rivers, which all have suspended sediment yields > 1.0 t/ha.

Table 26: Sediment budget for the Burdekin region

Summary Budget	**Total sediment (kt/yr)**	**% of total**
Sediment Supply		
Hillslope	5015	44
Gully	2762	24
Bank	3535	32
Total Inputs	*11312*	
Storage		
Reservoir	5156	
Floodplain	1141	
Channel	1137	
Total storage	*7433*	
Sediment delivery to the estuary	**3878**	
Suspended	3628	94
Bedload	250	6

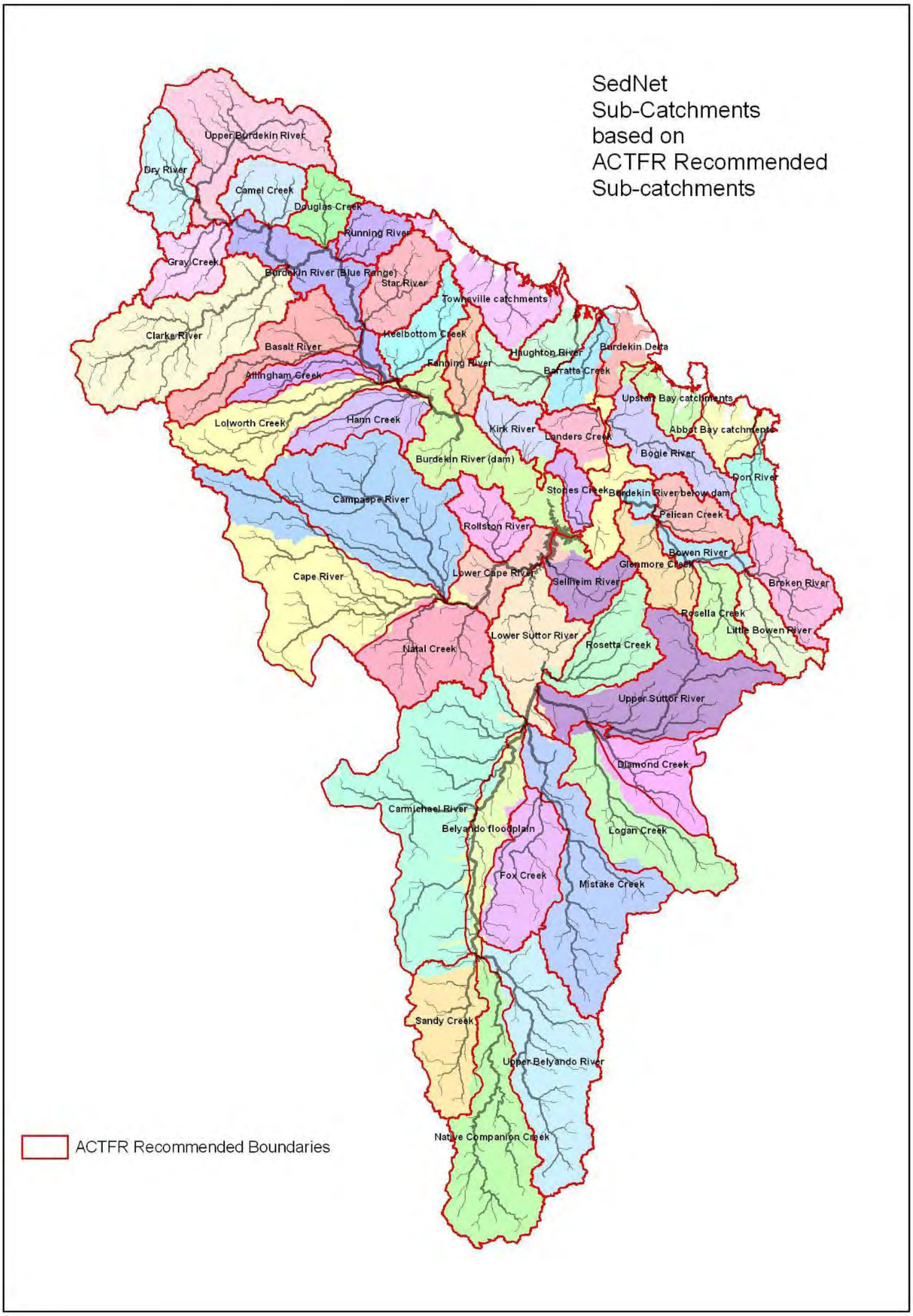


Figure 71: The Burdekin region was broken up into 53 sub-catchments for the purpose of reporting on sediment and nutrient yields

Table 27: Total suspended sediment from each of the sub-catchments identified in Figure 71.

Catchment	Sub-Catchment	Area (km^2)	Sediment Load (kt/y)	TSS / unit area (t/ha)
1	Abbott Bay Catchments	1,118	91	0.82
2	Aliingham Creek	1,190	23	0.19
3	Barratta Creek	1,067	98	0.92
4	Basalt Creek	2,897	80	0.28
5	Belyando Floodplain	25,241	591	0.23
6	Bogie River	2,227	177	0.80
7	Bowen River	9,353	801	0.86
8	Broken River	2,193	256	1.17
9	Burdekin Delta	129,168	2,750	0.21
10	Burdekin River (Blue Range)	30,466	1,439	0.47
11	Burdekin River (dam)	113,370	732	0.06
12	Burdekin River below Dam	128,334	2,564	0.20
13	Camel Creek	1,585	70	0.44
14	Campaspe River	8,141	279	0.34
15	Cape River	15,884	425	0.27
16	Carmichael River	9,397	206	0.22
17	Clarke River	6,450	305	0.47
18	Diamond Creek	2,417	37	0.15
19	Don River	1,037	140	1.35
20	Douglas Creek	1,227	68	0.55
21	Dry River	1,946	81	0.42
22	Fanning River	1,099	81	0.73
23	Fox Creek	3,179	46	0.14
24	Glenmore Creek	1,567	87	0.56
25	Gray Creek	1,667	71	0.43
26	Hann Creek	1,867	57	0.31
27	Haughton River	2,295	280	1.22
28	Keelbottom Creek	1,627	91	0.56
29	Kirk River	1,239	90	0.72
30	Landers Creek	954	67	0.70
31	Little Bowen River	1,455	123	0.84
32	Logan Creek	3,372	67	0.20
33	Lolworth Creek	4,427	111	0.25
34	Lower Cape River	73,065	1,969	0.27
35	Lower Suttor River	51,420	1,275	0.25
36	Mistake Creek	9,197	199	0.22
37	Natal Creek	3,376	96	0.28
38	Native Companion Creek	5,460	142	0.26
39	Pelican Creek	1,452	142	0.98
40	Rollston River	1,448	53	0.37
41	Rosella Creek	1,459	77	0.53
42	Rosetta Creek	2,520	80	0.32
43	Running River	1,095	94	0.86
44	Sandy Creek	2,810	53	0.19
45	Selheim River	1,404	114	0.81
46	Star River	1,988	137	0.69
47	Stones Creek	766	85	1.11
48	Townsville Catchments	2,268	188	0.83
50	Upper Belyando River	11,101	359	0.32
51	Upper Burdekin River	7,402	286	0.39
52	Upper Suttor River	10,999	222	0.20
53	Upstart Bay Catchments	1,070	78	0.73

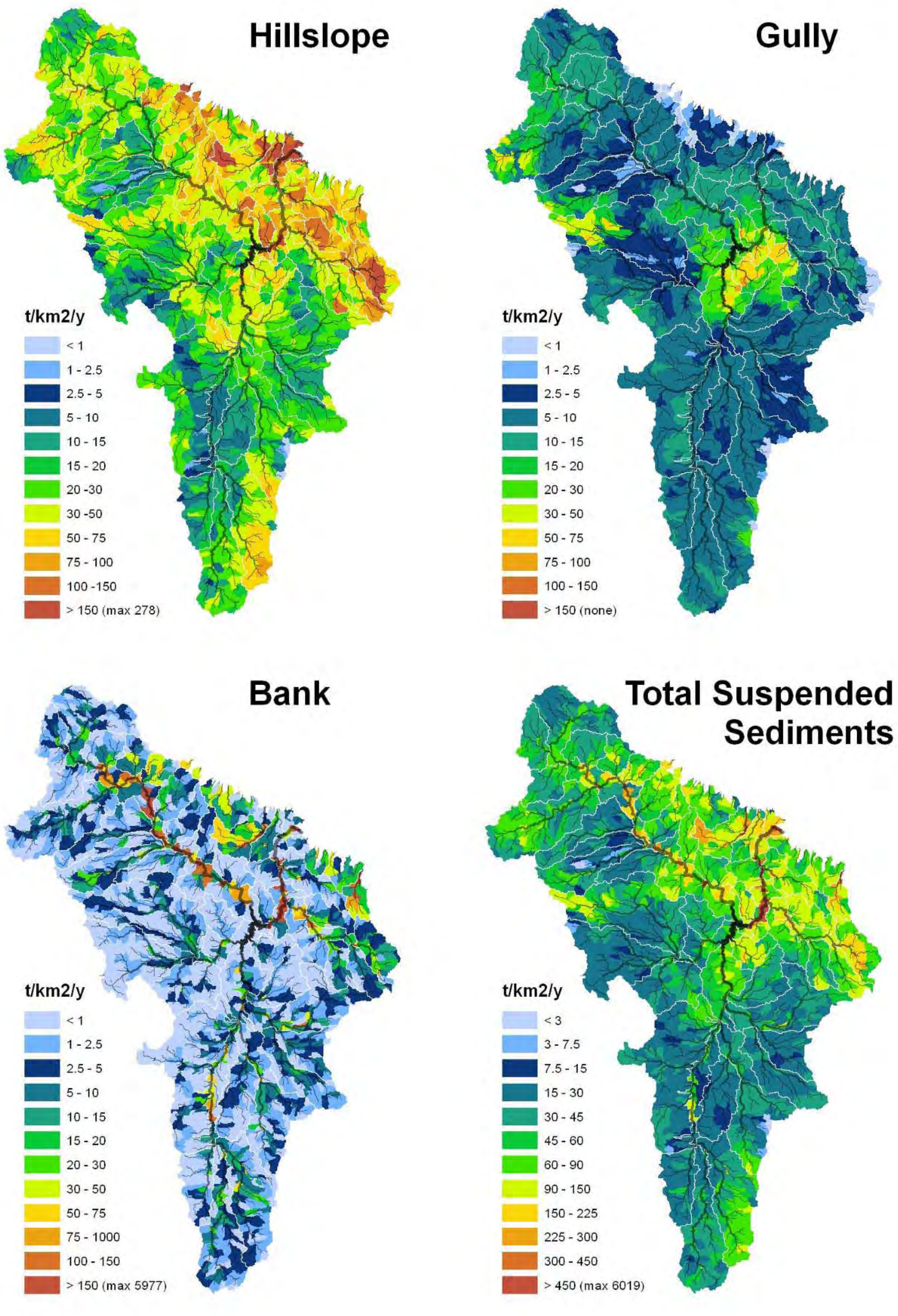


Figure 72: Pattern of fine (suspended) sediment erosion as rate per unit area for each SedNet watershed.

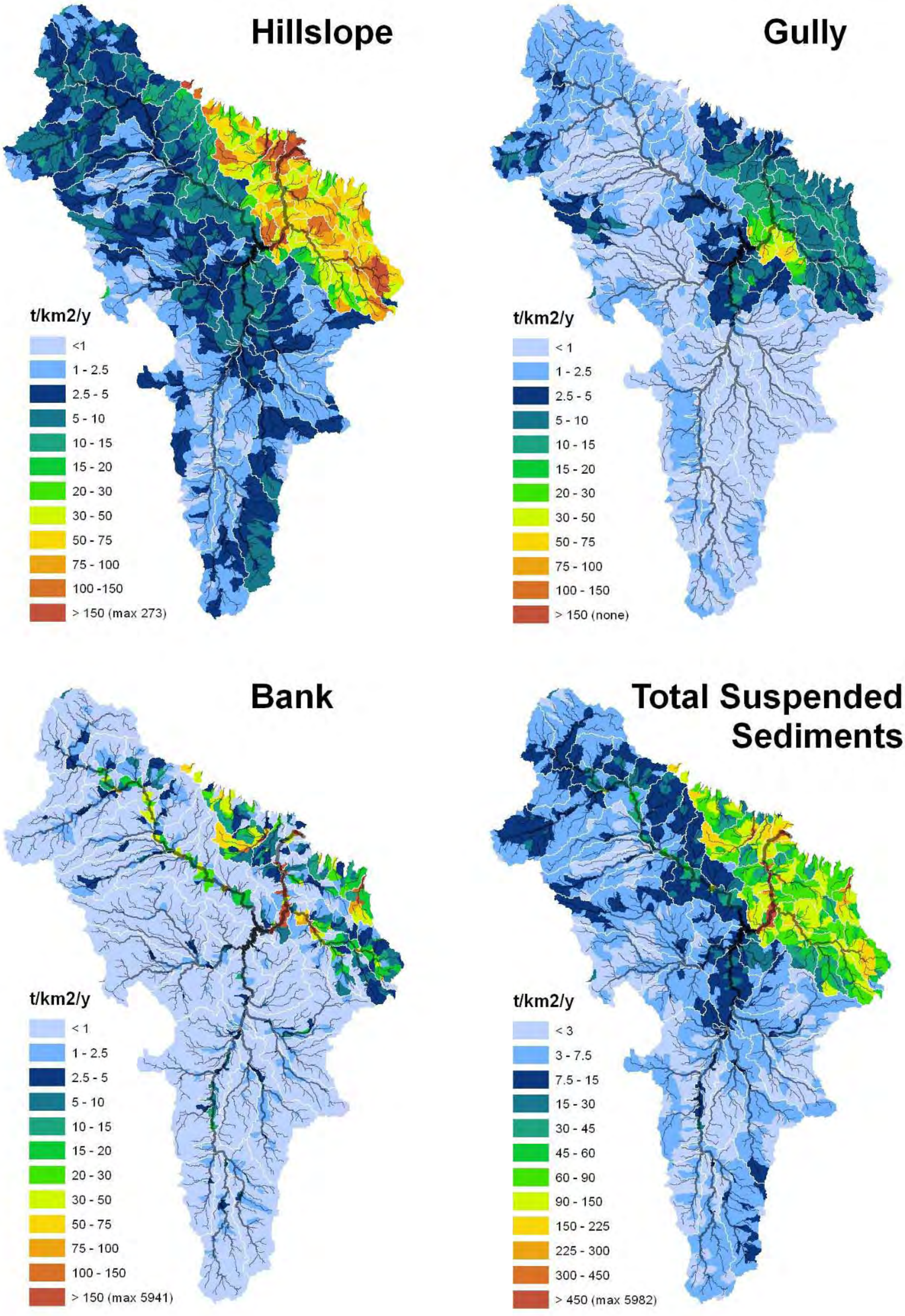


Figure 73: Contribution of fine (suspended) sediment to the coast as contribution per unit area per SedNet watershed.

Nutrient budget

Nitrogen and phosphorus budgets for the whole of the Burdekin region are presented in Table 28 and Table 29. For the nitrogen budget, the results suggest that 34,139 t/yr of nitrogen reaches the Burdekin River stream network and 15,409 t/yr is lost via storage or denitrification, so that ~18,731 t/yr reach the estuary. In the nitrogen budget, ~65% of the nitrogen is sourced from hillslopes, and ~71% leaves the catchment in particulate form.

For the phosphorus budget, 9064 t/yr of phosphorus reaches the stream network, with ~5244 being stored and 3,820 being lost from the catchment. At least 78% of the phosphorus is sourced from hillslopes, and 90% of the phosphorus leaves the catchment in particulate form. It is important to note that the contribution from cow manure (or decayed organic matter) is not included in any of the nutrient budgets.

The general pattern of nitrogen and phosphorus loss is given in Figure 74 and Figure 75, respectively. **Table 30** details the total nutrient contributions from each of the sub-catchments with the highest per unit nutrient yields.

The sub-catchments with the highest per unit nitrogen yields are the Townsville catchments (related to point sources), the Broken River and the Running River. The highest per unit phosphorus is coming from the Broken River, the little Bowen River and the Clarke River. The Broken River is in the top 3 catchments for suspended sediment, nitrogen and phosphorus. This reflects mostly its high hillslope erosion rates due to it's location in the steeper, wetter parts of the Burdekin region, and doesn't necessarily reflect poor landuse management, although this result would suggest that further work should be carried out in this catchment to assess the main source of sediments and nutrients.

Table 28: Components of the nitrogen (N) budget for the Burdekin region.

Nutrient Budget	Total Nitrogen (t/yr)	% of source or output
Hillslope to stream delivery	22254	65
Gully erosion	2762	8
Riverbank erosion	3535	10
Dissolved runoff	4293	13
Point source	1295	4
Total supply	34139	100
Floodplain storage	3902	
Denitrification	17	
Reservoir loss	11490	
Total storage/loss	*15409*	
Nitrogen delivery to the estuary	***18731***	
Dissolved inorganic nitrogen (DIN)	*3408*	*18*
Dissolved organic nitrogen (DON)	*1991*	*11*
Particulate nitrogen	*13331*	*71*

Table 29: Components of the phosphorus (P) budget for the Burdekin catchment.

Nutrient Budget	Total phosphorus (t/yr)	% of input or supply
Hillslope to stream delivery	7090	78
Gully erosion	690	8
Riverbank erosion	884	10
Dissolved runoff	338	4
Point source	62	1
Total supply	9064	99
Floodplain storage	1321	
Reservoir loss	3923	
Total storage/loss	5244	
Phosphorus delivery to the estuary	***3820***	
Particulate	*3446*	*90*
Other (FRP and DOP)	*373*	*10*

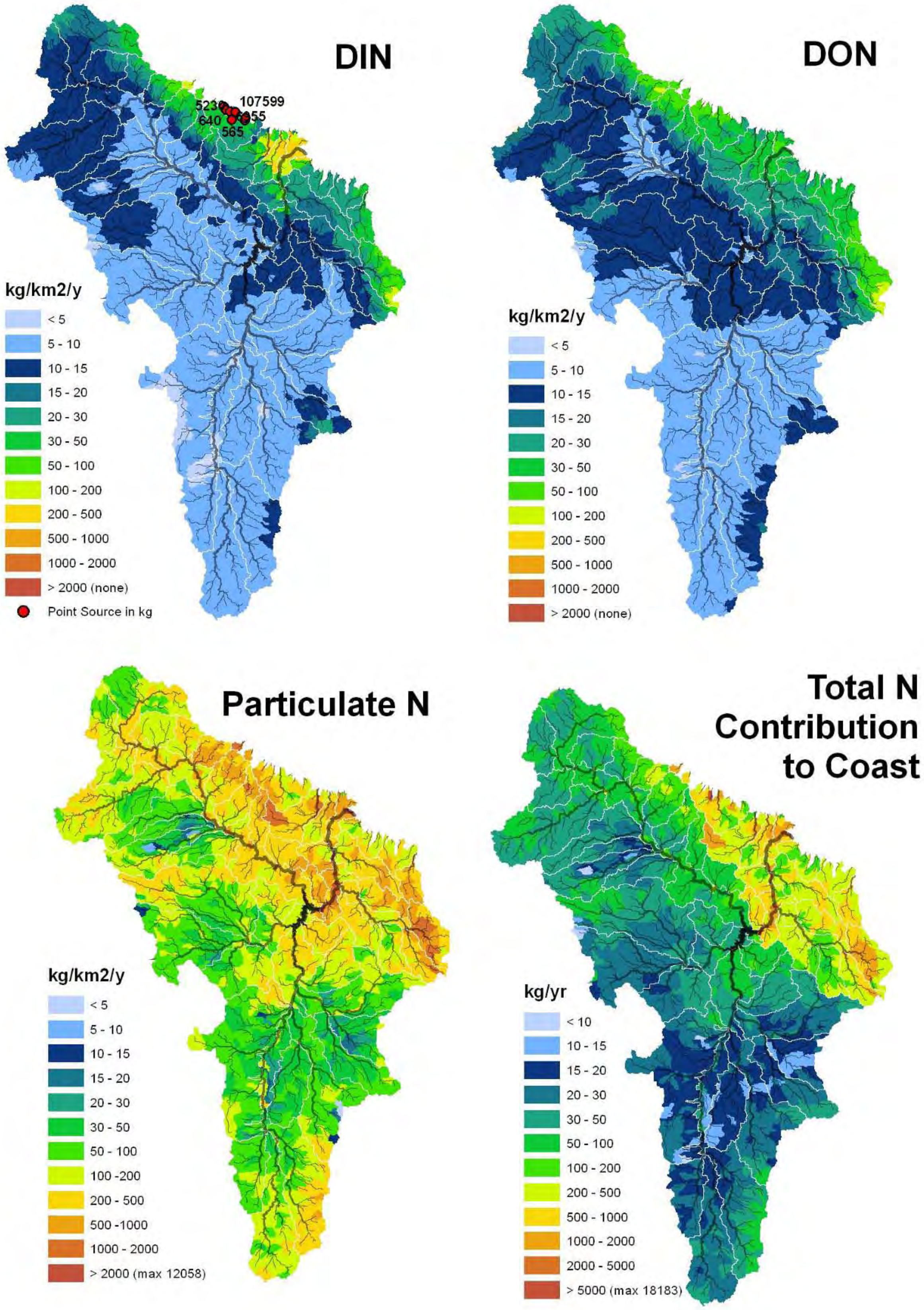


Figure 74: The distribution of nitrogen in runoff in the Burdekin region as predicted by the locally calibrated ANNEX model

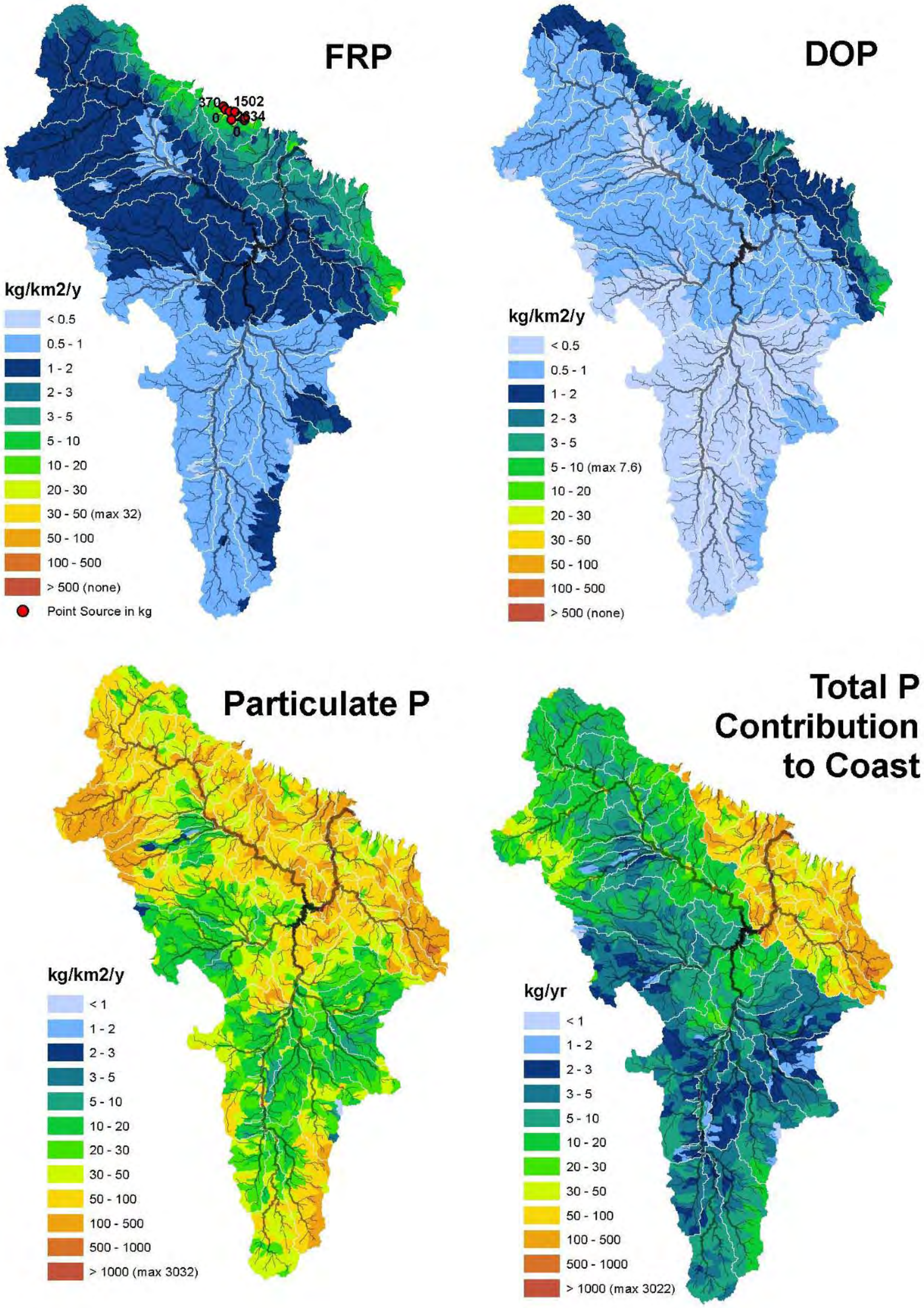


Figure 75: The distribution of phosphorus in runoff in the Burdekin region as predicted by the locally calibrated ANNEX model

Table 30: Mean annual N and P loads predicted from each of the sub-catchments identified in Figure 71.

Catchment	Sub-Catchment	Total nitrogen (kg/ha/yr)	Total phosphorus (kg/ha/yr)
1	Abbott Bay Catchments	3.13	0.70
2	Aliingham Creek	0.57	0.35
3	Barratta Creek	4.85	0.93
4	Basalt Creek	0.94	0.80
5	Belyando Floodplain	0.86	0.26
6	Bogie River	3.73	0.68
7	Bowen River	4.53	1.15
8	Broken River	8.89	2.36
9	Burdekin Delta	1.03	0.23
10	Burdekin River (Blue Range)	2.05	0.78
11	Burdekin River (dam)	0.42	0.09
12	Burdekin River below Dam	0.97	0.22
13	Camel Creek	1.83	0.47
14	Campaspe River	1.27	0.32
15	Cape River	0.99	0.24
16	Carmichael River	0.74	0.27
17	Clarke River	1.69	1.26
18	Diamond Creek	0.38	0.10
19	Don River	5.51	1.22
20	Douglas Creek	2.88	0.58
21	Dry River	1.61	0.72
22	Fanning River	4.25	0.88
23	Fox Creek	0.42	0.13
24	Glenmore Creek	2.72	0.55
25	Gray Creek	1.75	0.82
26	Hann Creek	1.17	0.30
27	Haughton River	5.96	1.00
28	Keelbottom Creek	3.54	0.70
29	Kirk River	3.43	0.80
30	Landers Creek	4.06	0.71
31	Little Bowen River	4.65	1.41
32	Logan Creek	0.54	0.16
33	Lolworth Creek	0.90	0.60
34	Lower Cape River	0.97	0.26
35	Lower Suttor River	0.85	0.25
36	Mistake Creek	0.64	0.21
37	Natal Creek	1.06	0.28
38	Native Companion Creek	1.06	0.30
39	Pelican Creek	4.51	0.89
40	Rollston River	1.57	0.34
41	Rosella Creek	1.75	0.46
42	Rosetta Creek	1.34	0.29
43	Running River	6.47	0.90
44	Sandy Creek	0.73	0.23
45	Selheim River	3.31	0.70
46	Star River	4.66	0.71
47	Stones Creek	5.53	1.02
48	Townsville Catchments	10.31	1.12
50	Upper Belyando River	1.32	0.38
51	Upper Burdekin River	1.80	0.63
52	Upper Suttor River	0.61	0.15
53	Upstart Bay Catchments	2.61	0.48

7.5.3 Comparison of results with previous modelling projects in the Burdekin region

Improvements made to the modelling input data and model setup in this project have had a number of implications for the end of catchment loads as well as erosion processes contributing to the sediment input to the Burdekin region, when compared to previous projects. The improved C and S factor values contributing to the hillslope erosion grids have resulted in an overall reduction in the total sediment yield since the QDNR&M Short Term Modelling (STM) project, although the sediment yields are greater than originally predicted by Prosser *et al*., (2001a) (Table 31). The nutrient loads, however, have increased since the STM project due to changes in the nutrient enrichment ratio.

The various applications of the model over time have also altered the proportion of sediment coming from hillslope, gully and bank erosion. The results in this report suggest that hillslope erosion is the highest contributor, followed by bank and then gully erosion (Table 32). The STM project determined that gully erosion was the largest contributor to sediment yields, however, this was based on using a default cross-sectional area of 10m^2. The field data used in this study suggests that gullies have cross-sectional areas of ~5.5 m^2, and thus the overall contribution from gullies has been reduced.

Table 31: Current estimates of sediment and nutrient export from the Burdekin region to the estuary

	Total sediment (kt/yr)	Total Nitrogen (t/yr)	Total Phosphorus (t/yr)	Reference
Burdekin Region	4824	22426	4398	Appendix 2 of Cogle *et al*., (2006) Fentie *et al*., (2006)
	3878	18731	3820	This report

Table 32: Erosion process as a % of the total sediment input in the Burdekin region

Erosion Process	Hillslope	Gully	Bank	Reference
Burdekin Region	38%	39%	23%	Fentie *et al*., (2006)
	44%	24%	32%	This report

7.5.4 Comparison of measured and modelled results

The SedNet model has been used extensively to help catchment managers (e.g. Burdekin Dry Tropics Natural Resource Management Board) and policy makers (e.g. Department of Environment and Heritage) to plan the on-ground actions required to meet their commitments under the Reef Water Quality Protection Plan (RWQPP). While this model represents the state of the art in catchment modelling, its outputs have largely gone untested because of a lack of suitable long term monitoring data. This project represents a valuable opportunity to test SedNet model predictions against the fluxes of suspended sediment and nutrients monitored on the TFTA and nearby grazed catchments.

The relatively large scale at which SedNet operates, means that data from the smaller catchments (Main Creek, Wheel Creek and Weany Creek) are of little use as a comparison to the model outputs. Six of the ten monitoring sites had two or more years of data suitable for calculating loads. In this section, we will compare SedNet model predictions to observed fluxes from Station Creek, Thornton Creek (TFTA), Keelbottom Creek (TFTA), Bowen River @ Myuna, and Burdekin River @ Macrossan (Sellheim). Unfortunately the data was collected during some of the driest years on record, therefore a direct comparison with the long term average data used in SedNet is not necessarily appropriate. However, a comparison of results will allow us to test whether the measured and modelled results are in the same order of magnitude and therefore suitable for long term average load predictions and target setting.

A comparison of measured and modelled sediment and nutrient yields are shown in **Table 33** and Figure 76, Figure 77 and Figure 78. It is important to remember that there can be ±50% uncertainty with the measured load estimates (Bartley *et al*., 2007) and therefore there are errors in both the measured and modelled estimates, however, we consider that there are greater errors with the modelled estimates due to process representation issues. Many of these issues are being worked on in a number of research projects outside of the MLA project.

The modelling results in the Burdekin region suggest that SedNet predicts end of catchment sediment yield reasonably well, and all but one of sites (Keelbottom Creek) are within 60% of the measured values. Given the differences in the rainfall patterns used to calculate the measured and modelled loads, these differences are reasonable, and somewhat expected (Figure 76).

The match between the measured and modelled nutrient values are much poorer than for sediments. In four out of five cases ANNEX over-predicts both nitrogen and phosphorus yield by as much as 600%, and these large over-predictions cannot be entirely explained by climate conditions. In previous applications of the ANNEX model to the Great Barrier Reef (GBR) catchments, the ANNEX model employed an enrichment factor of 0.5 to account for a mismatch between measured and modelled nutrient data (Brodie *et al*., 2003; McKergow *et al*., 2005a). In this study the enrichment factor was not used as it was considered to mask the limitations in the processes understanding with respect to nutrient modelling. Removal of the enrichment factor highlights the need for further research with respect to the nutrient input grids as well as processing algorithms.

Table 33: Comparison of measured and modelled sediment and nutrient loads for 6 sub-catchments in the Burdekin. Note there are estimated ±50% errors in the measured load data and the modelled errors are not yet quantified. Values are rounded to one decimal place.

Catchment	Area (km^2)	Sediment load (kt/yr)		Nitrogen load (t/yr)		Phosphorus load (t/yr)	
		Measured	Modelled	Measured	Modelled	Measured	Modelled
Weany Creek	14	0.5	0.8	-	-	-	-
Thornton Creek	85	2.9	3.2	69.4	18.7	14.1	5.1
Station Creek	148	8.0	9.8	16.5	44.7	3.8	13.8
Keelbottom Creek	1170	18.2	71.1	69.4	503.4	14.2	89.1
Bowen @ Myuna	7200	375.2	584.4	594.3	3382.2	191.9	903.5
Burdekin @ Macrossan	36390	1987.4	1755.8	3321.9	7407.6	1486.8	2690.6

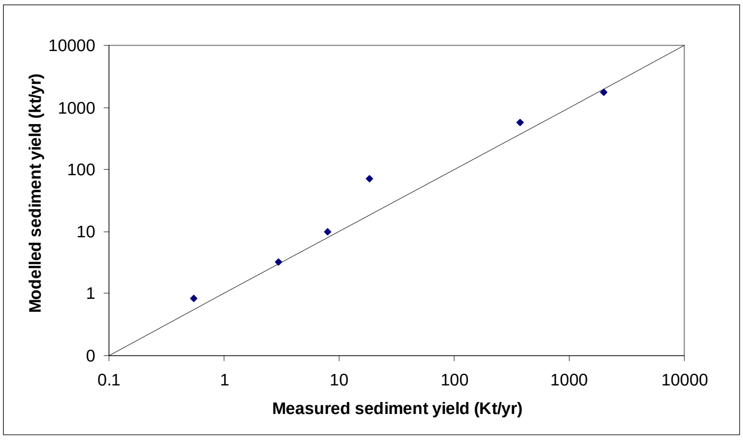


Figure 76: Comparison of measured suspended sediment yields with SedNet predicted sediment yields for 6 sites in the Burdekin catchment

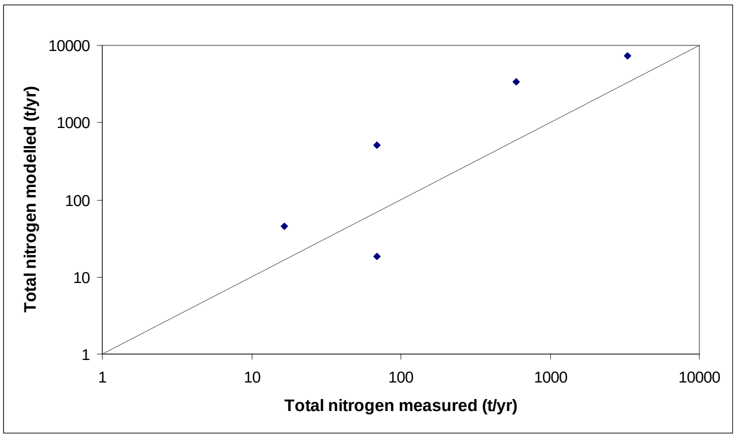


Figure 77: Comparison of measured total nitrogen yields with SedNet predicted nitrogen yields for 5 sites in the Burdekin catchment

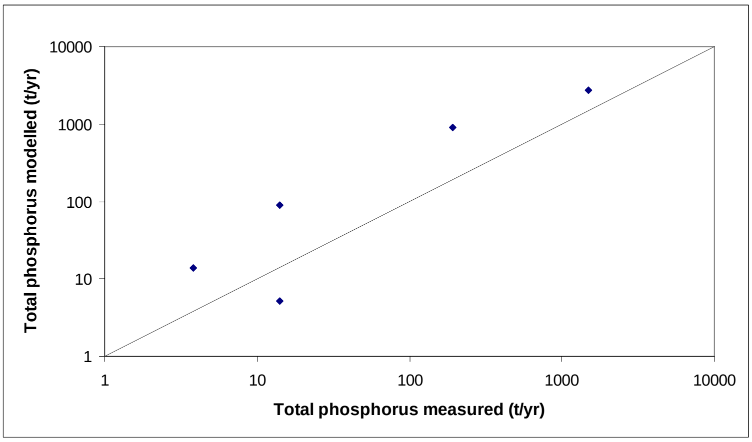


Figure 78: Comparison of measured total phosphorus yields with SedNet predicted phosphorus yields for 5 sites in the Burdekin catchment

7.6 Summary

The overall objective of Component A was ***to determine the quantity and sources of sediments and nutrients which reach the streams and rivers in the upper Burdekin catchment.*** This project has achieved this objective, as well as contributing to the overall project objectives in the following ways:

- Monitoring of sediment and nutrient flux from a range of sites in the Burdekin catchment, that included a range of grazing conditions types and geologies, has provided sediment and nutrient load data at a range of scales. This provided important data for refining and improving the large scale catchment models such as SedNet. It also provides important bench-mark conditions against which to assess future changes in land management practice;
- This study provided both measured and modelled sediment and nutrient budgets at a range of scales which has provided quantitative measurements on the relative sources of sediments and nutrients in grazed catchments. This assists in focusing potential areas for rehabilitation and highlights the need to evaluate all of the processes contributing to sediment and nutrient runoff including bank and gully erosion;
- This study helped determine that the variation in cover is more important than the mean cover condition at the hillslope scale, and therefore management should focus their attention on reducing the number and size of bare patches on hillslopes. This is important information for properties that are trying to implement the ECOGRAZE Best Management Practice guidelines;
- This study has provided estimates of gully and bank erosion for the Upper Burdekin catchment which are the first known studies to quantify these erosion processes in the savanna regions and are important data sets for refining the catchment scale models such as SedNet;

It is extremely important to highlight the immense value of the long term data sets that have been gathered within this study. The funding provided by MLA has allowed us to monitor erosion and sediment yields from grazing lands for up to 6 years in some areas, which represent the longest data sets for rangeland areas anywhere in Australia. It is hoped that this support will continue into the future.

As well as on-going support for existing monitoring, there are a number of areas of further research that would enhance the data sets collected in this study. Measured data on the bedload transport rates at the catchment outlet would provide an estimate of the coarse sediment flux leaving Weany Creek. This in turn would help determine the secondary storage of the coarse bed load. A range of techniques may be required to overcome the problems of collecting bedload data in an ephemeral relatively remote stream system. An estimate of the age and residence time of the bed material that is moving in the channel would also be useful for determining the timing of the peak erosion period in this catchment. Techniques such as optical dating or tracing may be suitable for this purpose (e.g. Olley *et al*., 2004; Wallbrink *et al*., 1998). This research would help quantify the link between land management change and sediment and nutrient yields. The lag or residence time of the sediment is important for the water quality target setting process. In addition to looking at the residence time issue for sediments and nutrients, an estimate of the contribution of cow manure from grazing lands to the overall nutrient budgets would also be a valuable contribution. Some monitored trials looking at the physical rehabilitation of gullies and scald sites could help determine if it is a viable option to invest in the rehabilitation of these sites within the Burdekin catchment.

There is a need to be able to calculate the hydrology in large catchments such as the Burdekin on a sub-catchment basis due to the large variations in rainfall and runoff over such large areas. This is currently not available in the SedNet model and needs to be incorporated. Based on the results from this and previous MLA funded studies, we now have a reasonable understanding of the relationship between cover, patch and hillslope runoff. There is, however, an increasing need to understand how these plot and hillslope scale processes translate to the larger scale using tools such as satellite imagery. This will then allow these results to be transferred to other sites within the Burdekin catchment.

8 Success in achieving project objectives

1. *Develop sustainable grazing management practices and tools for evaluating and documenting effects of a range of management practices.*

Sustainable grazing management practices have been developed and are documented in Section 5 of this report and in the information pack *Managing Recovery: Tools for sustainable grazing in the Burdekin catchment*, specifically the *Wet season spelling* brochure. The tools for evaluating and documenting the effects of these management practices include PATCHKEY as described in Section 6 of this report and *The patchy path to recovery* brochure.

2. *Refine computer models for predicting sediment and nutrient transport into waterways and throughout catchments.*

The *SedNet* model was first applied to the Burdekin catchment during the first phase of this project (1999-2002). This model has undergone considerable development and further application in the current phase of the project. This development has included:

Application of a hillslope-scale model, *LISEM* to determine the influence of the patchiness of cover on sediment and nutrient transport (Kinsey-Henderson and Post, 2006).

Application of the *SedNet* model at 25 m resolution across the whole of the Burdekin catchment with improved land cover characterisation derived from Landsat imagery and slope derived from the SRTM digital elevation model (Section 7.5).

Development of a spatially-explicit hillslope delivery ratio model (Post *et al*., 2006a) which unfortunately could not be applied to the whole of the Burdekin catchment because of the inadequacy of the available digital elevation models (Section 0).

3. *Provide quantitative measures of the short-term effectiveness of recommended sustainable grazing management practices (eg Ecograze) and their impacts on forage production, cover, and runoff of water, sediment, and nutrients for reducing sediment and nutrient export from grazed lands.*

Sustainable grazing management practices were defined and implemented on Virginia Park Station as described in Section 5. The impact of these practices on forage production and cover are described in Section 6.4 of this report. Despite observable impacts on forage production and cover, the impacts of changed grazing management practices could not be detected in the runoff of water, sediment or nutrients at either the hillslope or catchment scale. This is due to the inherently large climatic variability in the dry tropics, coupled with the long-term storage of sediment on hillslopes, in gullies, and in stream channels (Section 7.3). However, the application of the LISEM model did provide predictions of the likely impact of increased cover on the loss of water, sediment, and nutrients from hillslopes (Post *et al*, 2006a).

4. *Refine and validate tools for setting realistic and measurable targets for reductions in sediment and nutrient loads in rivers (NAP) based on robust and reliable modelling tools.*

Extensive application, investigation and development of the *SedNet* model occurred during the course of this project. The model was used to estimate the loss of sediment and nutrients from grazing lands in the Burdekin catchment to great effect (Objective 2). However, our investigations of this model have shown while it can be used for setting realistic and measurable targets for reductions in sediment loads in rivers, it cannot be used to determine the change in sediment and nutrient loads that will occur in rivers as a result of the change in management practices (Post *et al*, in prep). This is because the model does not have a temporal component and cannot therefore account for the lagged response to a management change due to the storage of sediment and nutrients on hillslopes, in gullies, and in stream channels. The development of such a modelling approach is continuing, with a focus on the E2 model (Post *et al*, in prep).

5. *Have all beef producers in the Burdekin informed and more knowledgeable about implementing best-practice management guidelines and their impacts on forage production, water use efficiency, and runoff.*

This will occur through distribution of the information pack *Managing Recovery: Tools for sustainable grazing in the Burdekin catchment*, consisting of the brochures *Saving for a rainy day, The patchy path to recovery, Wet season spelling,* and a summary sheet of key messages. This information pack has been pilot tested with a panel of graziers and was very well received.

9 Conclusions and recommendations

9.1 Conclusions

This study has shown that, despite an extended drought, improved grazing land management practices can have a positive impact on pasture composition and ground cover. However, due to the large inter-annual climate variability in the dry tropics, the impact of these improved land management practices could not be detected in terms of a reduction in sediment and nutrient loss at either the hillslope or catchment scale.

Despite the lack of observed changes in sediment and nutrient loss, the results from a hillslope modelling exercise show that the measured changes in pasture composition and ground cover should eventually reduce the losses of sediment and nutrients at the hillslope scale. At the catchment scale however, it seems that extensive storage of fine and coarse sediment in gullies and stream channels will delay, perhaps for many years, impacts of changed grazing management practices on the export of sediment and nutrients from the river mouth.

Current sediment and nutrient models such as *SedNet* were not designed to examine the impact of changes in land cover on sediment and nutrient export, and because of the lack of a temporal component are not capable of detecting these impacts. A new modelling approach involving models with the ability to consider the impacts of lags and storages in the system, is required. An example of such an approach is the *E2* model currently under development within the e-water CRC.

9.2 Recommendations for Future Work

Future work should focus on continued testing of wet season spelling strategies on commercial properties to determine the length of time required to recover land between condition classes (C-condition to B-condition for example). To identify these changes, the PATCHKEY tool needs to be tested over a range of land types to identify key indicators of early changes in condition trend. Finally, residence times of fine and coarse sediment need to be determined to help identify the lag time between changes in grazing management practices and impact on sediment and nutrient fluxes at the catchment scale. These field investigations should be backed with the development of a modelling framework which is able to deal with these storages and lag times.

Specifically, we need to:

- Identify end of dry season cover and pasture yield thresholds for all major land types and condition classes.
- Continue testing wet season spelling strategies on commercial properties to determine the length of time to recover land between condition classes.
- Identify and model linkages between diet selection, grazing preference and patch formation for restoring degraded rangelands.
- Link small scale resource distribution and connectivity to rate of recovery.
- Test and apply PATCHKEY over a greater range of land types.
- Use PATCHKEY to identify key indicators of early changes in condition trend which can be applied at the scale of remote sensing.
- Determine residence times of fine and coarse sediment to help determine the lag effect between land management change and observations in measured water quality.

- Determine bedload movement rates.
- Better regionalise hydrology on a sub-catchment basis within the SedNet Toolkit model
- Implement scientific trials of scald/gully rehabilitation.
- Determine the contribution of cow manure to in-stream nutrient budgets.

9.3 List of publications arising from the project

1. Abbott B.N. and Corfield J.P. 2006. Putting PATCHKEY into practice - poster and proceedings paper, *Australian Rangelands Society Biennial Conference*, Renmark, SA., Aug. 2006.
2. Bartley, R. Hawdon, A., Post, D. A. and Roth, C. H. 2007. A sediment budget measured during drought conditions in a grazed dry tropical catchment in the Burdekin basin, Australia. *Geomorphology* **87**: 302-321.
3. Bartley, R., Roth, C.H., Ludwig, J., McJannet, D., Liedloff, A., Corfield, J., Hawdon, A. and Abbott, B. 2006. Runoff and erosion from Australia's tropical semi-arid rangelands: influence of ground cover for differing space and time scales. *Hydrological Processes* **20**: 3317-3333.
4. Corfield J.P., Abbott B.N., Hawdon, A, and Berthelsen, S. 2006. PATCHKEY: a patch classification framework for the upper Burdekin and beyond – poster and proceedings paper, *Australian Rangelands Society Biennial Conference*, Renmark, SA., Aug. 2006.
5. DeRose, R., Wilson, D., Bartley, R., and Wilkinson, S. 2005. Riverbank erosion and its importance to uncertainties in large-scale sediment budgets. In Sediment Budgets I, *IAHS Publication 291*, IAHS Press, Wallingford, UK.
6. Gordon, I.J. (submitted) Linking land with the ocean: Feedbacks in socio-ecological systems. *Hydrobiologia*.
7. Gordon, I.J. & Nelson, B. (in press) Reef Safe Beef: Environmentally sensitive livestock management for the grazing lands of the Great Barrier Reef catchments. In: *Redesigning Animal Agriculture; the Challenge of the 21st Century*. CABI Publishing, Wallingford, UK.
8. Gordon I., Corfield J.P. and Abbott B.N. 2006. On the edge of the abyss: Rangeland degradation and recovery on Australia's eastern catchments – oral and proceedings paper, *New Zealand Ecological Society and Ecological Society of Australia joint conference*, Wellington, N.Z., September 2006.
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Appendix A: NRM&W 25m DEM and SRTM DEM - evaluation of utility for SedNet model

To apply SedNet at a 25 m resolution over the whole Burdekin catchment as planned requires a sufficiently high resolution digital elevation model (DEM). There are two candidate DEM's – a 25 m DEM from NRM&W which has been derived from 1:100,000 map sheet data, and a 90 m DEM derived from the Shuttle Radar Topographic Mission (SRTM). Both of these DEM's have advantages and disadvantages. The purpose of this document is to evaluate these DEM's in terms of their usefulness for SedNet modelling for the following purposes:

1) Stream link and watershed delineation
2) Spatial HSDR
3) Slope factor in RUSLE spatially explicit hillslope erosion calculations

Description and evaluation of 25m Digital Elevation Model

A series of 25m grid resolution Digital Elevation Models (DEMs) have been produced recently by the Queensland Department of Natural Resources, Mines and Water (NRM&W). To quote from the preliminary metadata for this product for the Burdekin Catchment: "ANUDEM version 4.6 was used to produce a 25 metre floating point grid. Source digital data were contours and drainage (scanned repromats) from AUSLIG 1:100000 mapsheets with a 20 metre contour interval for most areas but 40 metre contours for others. Drainage lines were pointed in the direction of flow. A hillshade of the DEM was used to identify errors in source drainage and contour data that were previously missed. The errors, including wrongly directed drainage and wrongly labelled contours, were fixed though some errors may remain." Details about ANUDEM can be found at http://cres.anu.edu.au/outputs/anudem.php.

In terms of accuracy of input data and resulting grids: "The accuracy of this DEM depends on the accuracy of the source data and the error of ANUDEM`s interpolation. The average accuracy of AUSLIGs 1:100000 source data is +/- 25 metres in the horizontal position of well defined detail and +/- 5 metres in elevation for most mapsheets. Mapsheets 9140, 9141, 9144, 9145, 9242, 9243, 9342, 9343, 9442, and 9443 have an average accuracy in the horizontal of +/- 25 metres and +/- 10 metres in elevation and mapsheets 9244, 9245, 9344, 9345, 9444, 9445 and 9541 have accuracies of +/-50 metres and +/- 10 metres in the horizontal and vertical respectively. The data accuracy of those coastal areas with 5 or 10 metre contours (9544 and 9545 areas) is +/- 10 metres in the horizontal position of well defined detail and +/-2.5 metres in elevation. This DEM was the product of 12 ANUDEM sessions mosaiced together. The average accuracy of the DEMs is a root mean square error (RMSE) of 2.5 metres with a range between 1.3 and 3.4 metres".

Advantages

Interpolated data based on surveyed information gives smooth slopes with clear flow directions and is not affected by vegetation. Stream line reinforcement based on real mapping should give good correlation with original AUSLIG 100K drainage mapping when deriving flow paths.

Disadvantages

The 100K mapping is of variable quality and does not contain enough detail everywhere to derive accurate drainage to the level of 1ha threshold areas as required for application of our HSDR model. Such DEMs can only interpolate between data points, and are thus are potentially inaccurate if information density is poor compared to the density of grid cells on the DEM being generated. This appears to be the case with the 25m DEM of the Burdekin. High resolution comes at a price computationally, and the Burdekin DEM is exceptionally large (over 2 Gb with over half a billion (29,000 by 19,000) floating point grid cells values. This may impose limitations on it's useability for many applications.

Problems Identified

Derivation of flow paths from the DEM showed incorrect stream line delineation in some places, even at the level of 1:250K drainage mapping (Figure 79). In general these flow deviations are relatively minor and reconnect correctly further downstream. In a few places, there is clear evidence that the stream line directions were not corrected. As well as potentially causing large deviations of flow, it results in wildly inaccurate slopes due to the "cutting in" of the drainage as it is forced to flow the wrong way. Only a *few* cases of incorrect stream line direction have been noted within the Burdekin Catchment DEM. However, there is a very marked error evident in the steep upland areas at the headwaters of the Haughton River catchment. Overall impact should be relatively minor in the context of whole-of-catchment modelling. However, localised effects on both flow paths and slopes may be significant (as for the Haughton).

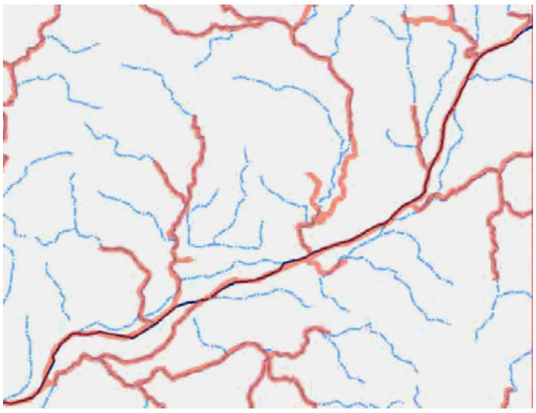


Figure 79: Comparison of flow directions derived from the 25m DEM with AUSLIG 250K drainage mapping.

Although accuracy (in comparison with input data) is quoted above as reasonably high, there are additional sources of inaccuracy, harder to quantify, but still detectable, where the DEM is unable to accurately predict terrain features/characteristics due to poor data density. Original AUSLIG mapping details (such as contour interval) vary from map sheet to map sheet. To illustrate this effect of this on the DEM, Figure 80 shows the difference in heights between the SRTM DEM (discussed next section) and the 25m DEM. There is much better correspondence between the two DEMs (less strongly coloured blue and red) in areas where there is higher level of mapped detail, despite similar terrain and vegetation, due to a change in input data density. In Figure 80, the change from 20m contours to 5m interval across map sheets can be seen as a lessening of intensity of colour (DEM differences) from north to south respectively. (NB Ignore the differences in areas of high relief (more shadows) as they will always appear to have big differences in both blue and red due to slight misregistration). In areas or lower data density, such as the northern half of the image in Figure 80, there is poor representation of some topographic features – e.g. hills and ridgelines with missing tops that appear more like mesas (e.g. Figure 81). In Figure 80, many of the red areas on the northern half of the area appear (on comparison with SRTM and Landsat) to represent such areas. This will adversely impact on slope calculations for estimations of USLE.

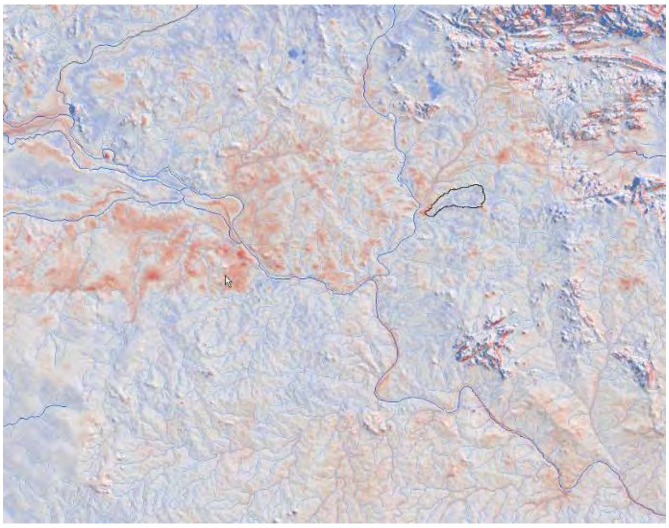


Figure 80: Differences in height between 25m DEM and the Shuttle Radar (SRTM) DEM. Stronger shades of blue and red indicate poorer match (blue is over-prediction by the 25m DEM compared to SRTM, and red is under-prediction). A clear EW line appears about halfway down where the change in mapping detail occurs.

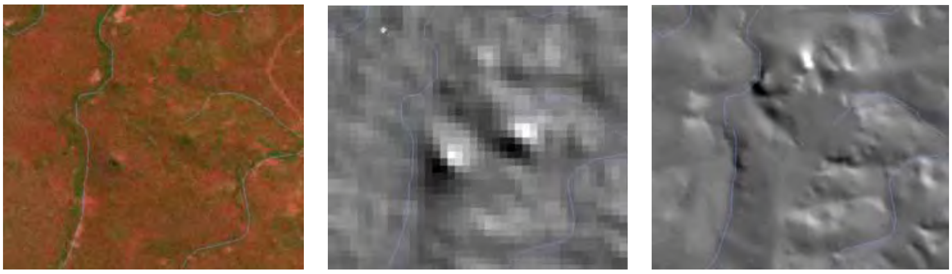


Figure 81: Example of the 25m M DEM mesa artefact. Hills are clearly visible on Landsat TM and SRTM, but missing from the 25m DEM.

In a few cases there appears to be incorrect labelling of contour heights and consequent effect on heights and slopes in the DEM (eg. some of the darker blue patches in the northern half of Figure 80). These are generally minor and would have minor impact of whole of catchment modelling. Other issues we found were that slopes may be exaggerated, particularly near streams due to stream line reinforcement "cutting" down into landscape close to contours. An example is shown in Figure 82. Although relatively minor in extent, our predictions for hillslope erosion will be biased towards areas adjacent to streams due to the assumptions about hillslope delivery ratios. Thus these exaggerated slopes may gain significance.

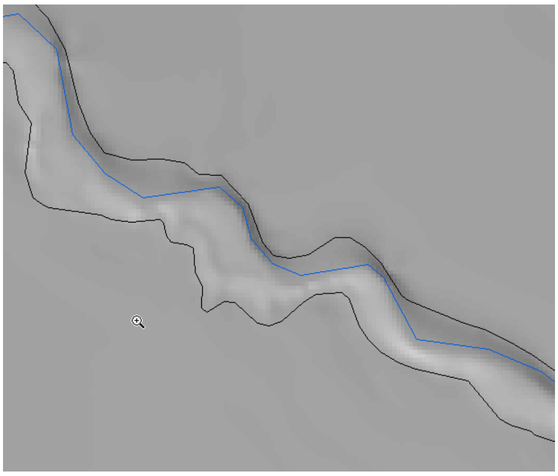


Figure 82: Example of the tendency of the 25m DEM to exaggerate slope steepness adjacent to streams where the stream occurs close to contour lines.

Shuttle Radar Topographic Mission (SRTM) DEM

The Shuttle RADAR topographic Mission (SRTM) DEM was acquired in 2000. It used space-based radar interferometry to compare two radar images taken at slightly different locations and obtain elevation or surface-change information. The gridded product for Australia is provided by NASA at 90m grid resolution. Performance requirements for the SRTM DEM were met and are as follows:

1. The linear vertical absolute height error shall be less than 16 m for 90% of the data.
2. The linear vertical relative height error shall be less than 10 m for 90% of the data.
3. The circular absolute geolocation error shall be less than 20 m for 90% of the data.
4. The circular relative geolocation error shall be less than 15 m for 90% of the data.

More details on the assessment of the DEM can be found in the on-line documentation http://www2.jpl.nasa.gov/srtm/SRTM_D31639.pdf. More product details can be found on the website http://www2.jpl.nasa.gov/srtm/index.html.

Advantages

Almost every pixel represents an actual measured height. There is no interpolation. It is data-rich and can capture information that interpolated models may miss. Like steep slopes associated with areas of mining and erosion.

Disadvantages

It is gridded at 90m intervals and is thus much coarser than the 25m DEM; 90m grid cells are also currently beyond the limits of our spatial HSDR modelling capability. It can be “noisy” and this may affect calculations of both slope and flow direction. Some of this noise is attributed to speckle, which has the characteristics of random noise, however, this has been reduced in the 90m DEM product by allowing some averaging of values. The number of data points in each 90m grid cell could range from a minimum of one (in a very few cases) up to as many as ten. Other noise effects could be due to vegetation. The “finished grade” product stores heights as integer values, not floating point. Thus the values are rounded to the nearest metre. Over a 90 m distance, we would predict this to have minimal impact, except in extremely flat areas where it may cause very flat slopes to become stepped (eg no slope or over-prediction).

Problems Identified

The SRTM DEM has height offsets when compared to the Australian Height Datum (AHD). We would not anticipate any issues with this, as the height offset is relatively constant over very large areas (100's of kilometres) and thus not an issue for deriving slopes or flow paths.

SRTM has been recognised to have problems "seeing" through vegetation, and its estimates of height may actually reflect canopy height in places with high vegetation density. While this may not affect slope calculations significantly in areas where vegetation density is relatively uniform, it may cause increased noise levels in areas where density varies, as height estimates may alternate between canopy and ground height measurements. Others have noted problems with canopy cover in relation of derivation of flow paths, as the riparian zones often have significantly denser vegetation than the surrounding terrain. A jump up in height along a riparian zone will adversely effect derivation of flow paths, as the flow will be assumed to be along the lowest path.. Our assessment of vegetation effects suggests that, while they are certainly present (e.g. between fields of differing vegetation cover levels and also along riparian zones), that the derivation of flow paths in the Burdekin is not strongly affected. Flow paths generally show good correspondence with 1:250K mapping, at least as good as the DNRM&W 25m DEM for broad-scale watershed delineation albeit noisier in detail.

Comparisons of 25m and SRTM with High Resolution DEM data

As part of the current Meat and Livestock Australia project, we commissioned several high resolution DEMs for the Blue Range and Weany Creek Sub-catchments of the Burdekin River. These were used to compare slope and flow pathway delineation based on high-resolution data with the results from both 25m and SRTM DEMs.

As part of the current Meat and Livestock Australia project, we commissioned several high resolution DEMs for the Blue Range and Weany Creek Sub-catchments of the Burdekin River. These have been used to compare slope and flow pathway delineation based on high-resolution data with the results from both 25m and SRTM DEMs.

The Blue Range and the Weany Creek DEMs were derived by Georeality (www.georeality.com) using stereographic image autocorrelation from 1:50,000 scale DNRM&W archive airphotography. For Blue range, images were scanned at 60 cm and used to derive a DEM gridded at 10m grid intervals. For Weany Creek, Images were scanned at 35 cm and used to derive a DEM gridded at 5m grid intervals. Each grid cell is a measured value and breaklines were used to help ensure known drainage patterns were followed. Effects from vegetation were minimised by manual intervention. Figure 83, Figure 84 and Figure 85 show shaded images of the three types of DEMs for Blue Range for visual comparison.

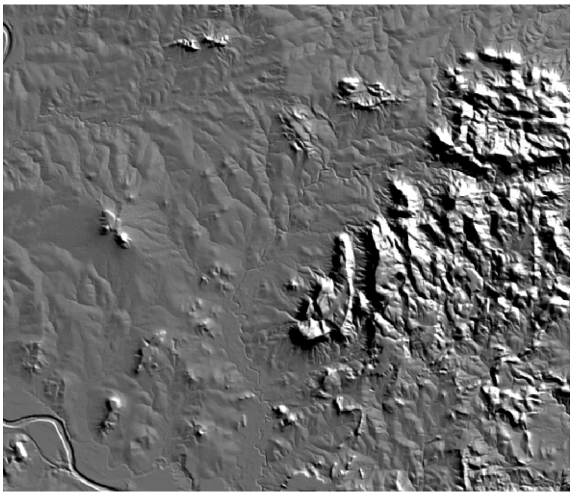


Figure 83: 10m DEM of Blue Range as a shaded relief image.

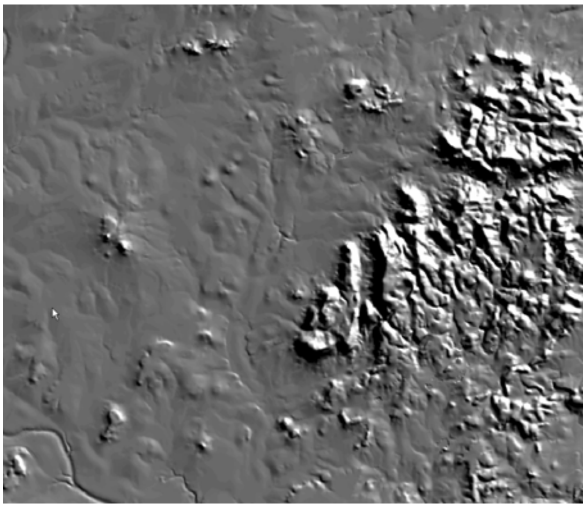


Figure 84: 25m DNRM&W DEM over Blue Range as a shaded relief image.

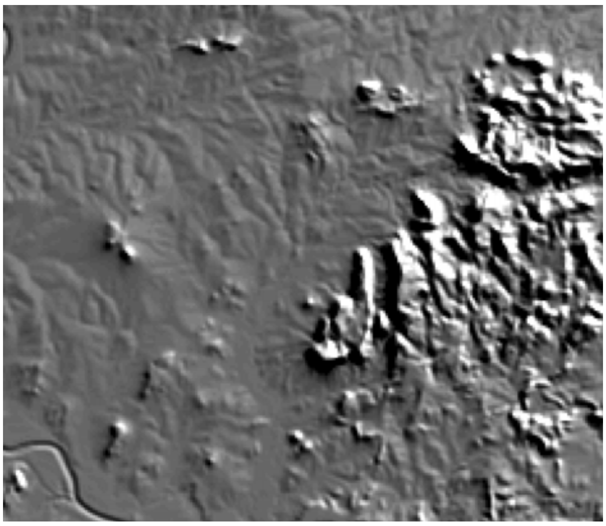


Figure 85: 90m Shuttle Radar (SRTM) DEM over Blue Range as a shaded relief image.

Flow paths for Stream and watershed delineation

For broad scale stream and watershed delineation required by SedNet we looked at whether or not we would gain any improvement over the current network based on the AUSLIG 9-second DEM. The minimum threshold area for drainage delineation was to remain at 50km^2. Flow paths were derived for Blue Range using the DEMs and are shown in Figure 86 and Figure 87 compared to the TOPO250K mapped drainage (http://www.ga.gov.au/nmd/products/digidat/250k.htm). Minor variations in height affect both the DEMs and result in some flow paths inconsistent with mapping (a small miscalculation of height can cause flow to change direction markedly). Comparison of these figures show that the 25m DEM better reproduces the 250K AUSLIG drainage patterns, although both show some errors in flow paths.

We attempted to create a SedNet configuration (stream link and watershed network foir the whole of the Burdekin using the 25m DEM and a 50km^2 threshold. It took over 6 days to run. It was decided that 6 days was an unacceptable length of time. The SRTM was not trialled, as it's use raised objections by the expert community. A hydrologically corrected SRTM DEM is attempting to be constructed currently by CSIRO (Gallant, *pers comm*).

Thus, the 9-second DEM used in all previous studies (including the STM project) was used for the current study. However, it has recently became obvious that it had some serious flow direction issues, resulting in very poor delineation of sub-catchments as evidenced in Figure 71 of this report. However, it was too late in the project to address the issue.

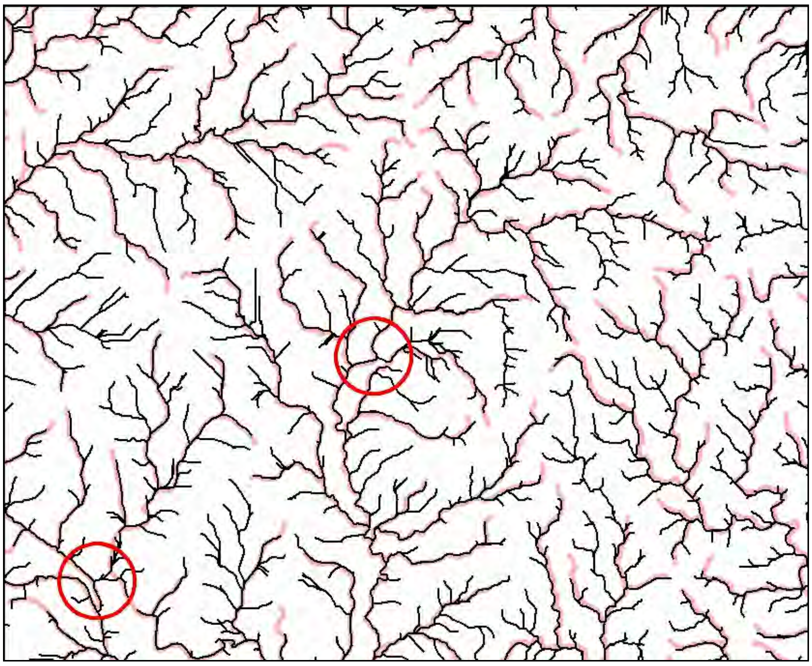


Figure 86: Comparison of >10 hectare flow paths derived from 25m DNRM&W DEM data (black) and the 1:250K AUSLIG mapped drainage (pink). Red circles show incorrect drainage delineation/capture by the 25m DEM

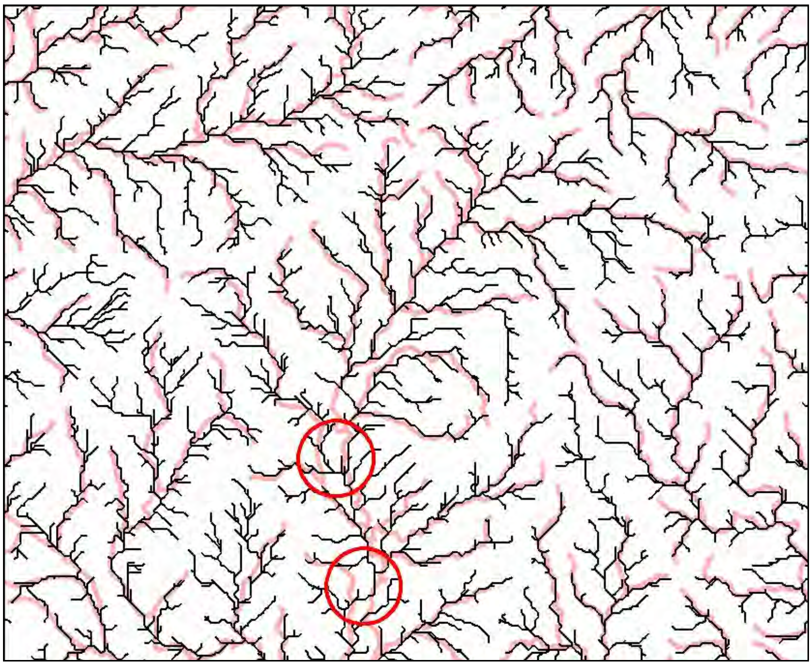


Figure 87 Comparison of >10 hectare flow paths derived from 90m SRTM DEM data (black) and the 1:250K AUSLIG mapped drainage (pink). Red circles show incorrect drainage delineation/capture by the SRTM DEM.

Spatial HSDR one hectare threshold flow paths

We needed to extend the flow path analysis in the section above to a finer threshold (1 hectare) as required for application of the spatially explicit Hillslope Delivery Ratio (HSDR) (Kinsey-Henderson and Post, 2006; Post *et al*., 2006a). The SRTM DEM was not usable for a 1 hectare threshold flow, as 1 hectare was at the limit of its resolution (90m grid size equals 0.81ha) and resulted in almost every pixel being over the threshold area. Thus, the 25m DEM was the only option. However, its data-poor nature was revealed when flow paths were derived at this resolution (see **Figure 88**). Similar flaws were revealed over Weany Creek (see **Figure 89** and **Figure 90**).

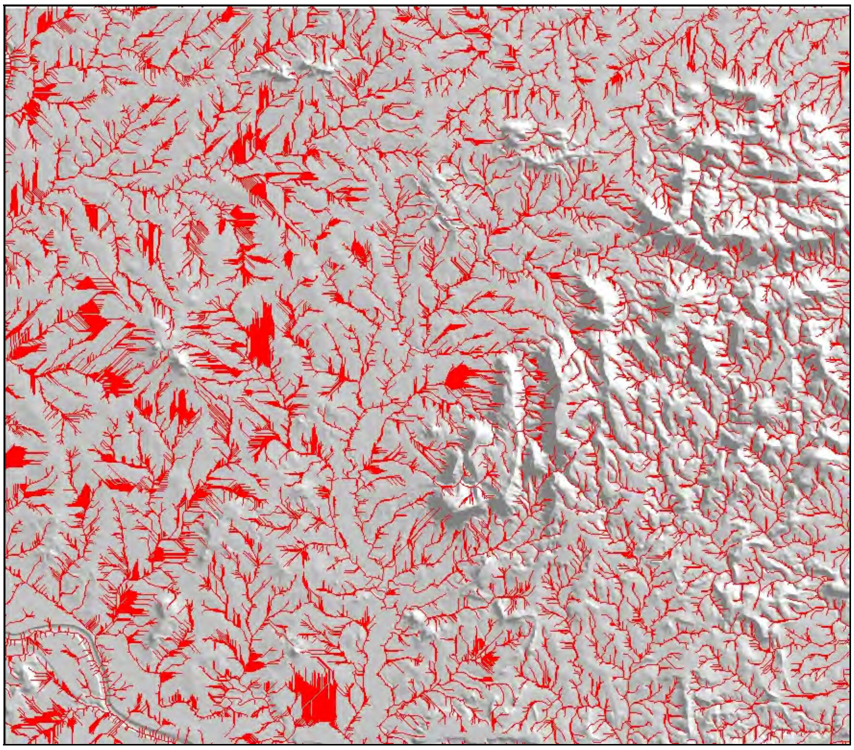


Figure 88: One hectare threshold flow paths derived from the NRM&W 25m DEM over Blue Range. Large areas of closely spaced parallel flow (artificially induced due to interpolation in the DEM) make this DEM unsuitable for spatially explicit HSDR derivation.

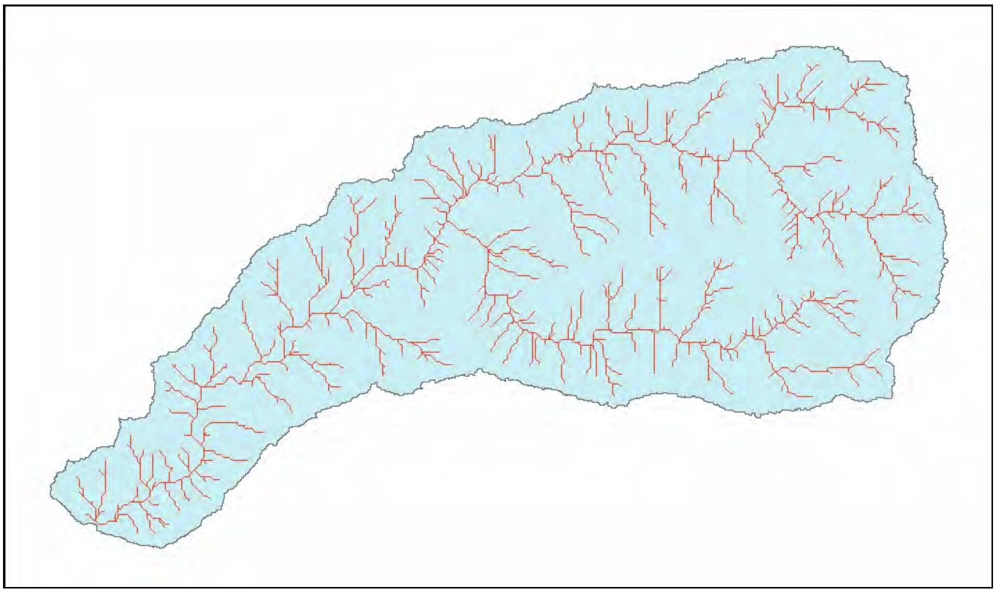


Figure 89: 1ha threshold streams from Georeality 5m DEM resampled to 25m over Weany Creek. This flow pattern showed good correspondence with the mapped gully system.

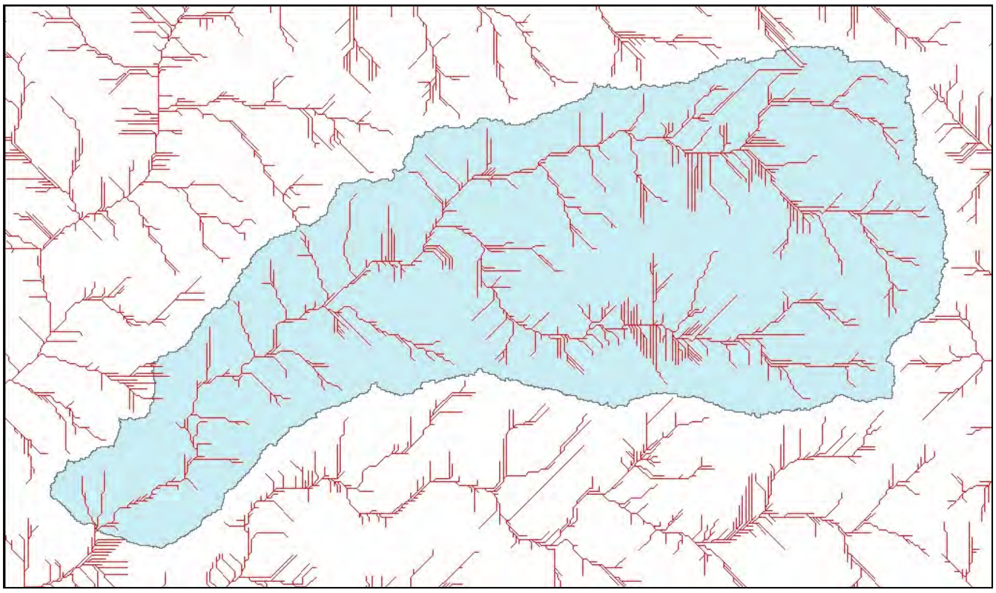


Figure 90: 1ha threshold streams from the NRM 25m DEM over Weany Creek.

Derivation of Slope

For comparing the slopes in the 10m Georeality DEM over Blue Range with the 25m and 90m SRTM DEM's, the 10m DEM was resampled taking the average height value over each 25m and 90m grid cell area. Slight reductions in slopes are expected and predictable when resampling any DEM to larger grid sizes, so comparisons should be done on grids of equivalent grid cell size. Sine of the slope was compared as it is the units used for the derivation of RUSLE slope factor and thus an indicator of how much erosion estimates would be affected by the DEMs. Results are shown in Figure 91 and Figure 92 below.

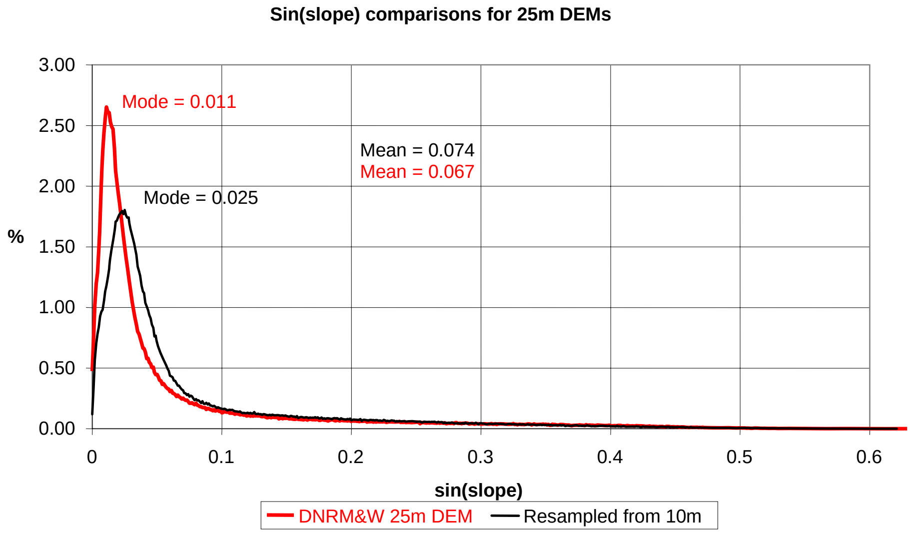


Figure 91: Histograms of slopes derived from the 25m NRM&W DEM and the 10m DEM resampled to 25m.

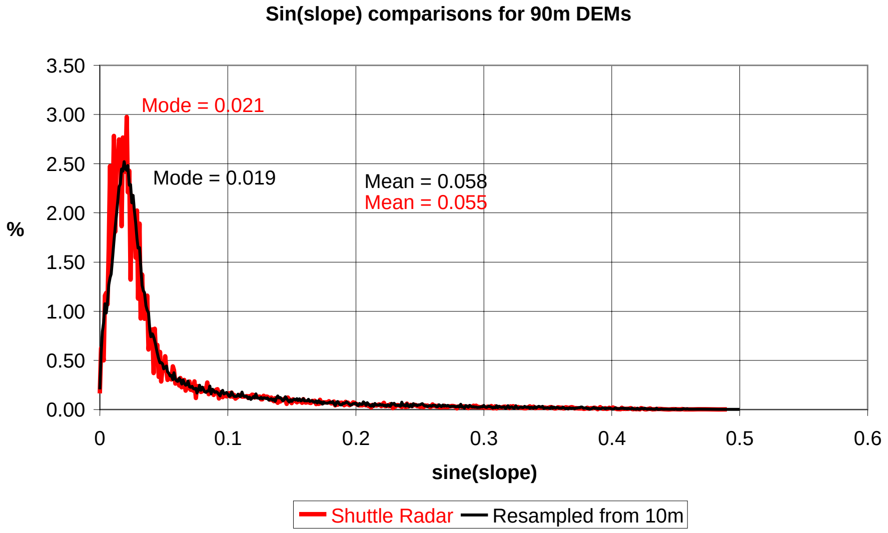


Figure 92: Histograms of slopes derived from the Shuttle Radar (SRTM)DEM and the 10m DEM resampled to 90m.

A 5% reduction in the mean value and almost no change in the mode (most common slope value) is observed when comparing the SRTM to the 90m resampled DEM. However, a 10% reduction in the mean value and reduction by over one *half* in the mode is observed when comparing the 25m DEM from DNRM&W to the resampled 10m DEM. The relatively low (10%) change in mean value compared to the change in the mode (over 50%) suggests that there is a population of higher slope values in the 25m DEM that is not very obvious in the histogram but that is biasing the mean to a closer match with the 10m DEM. The population of high slopes is probably attributable to the exaggerated slopes noted in examples such as Figure 82. The results shown in Figure 91 and Figure 92 would suggest strongly that the best DEM to use for slope estimation in the USLE calculations would not be the 25m DEM, but the SRTM.

Recommendations

Based on the analysis outlined above, the following recommendations are made for the SedNet project:

- The 9-sec DEM is to be retained for broad stream and watershed delineation. However, recent attempts to divide the Burdekin into sub-catchments have revealed major flow path errors (notable in Figure 71 of the report) and we would not make this recommendation for any future modelling work.
- None of the Burdekin-wide DEM datasets is able to accurately derive flow directions down to the 1 ha threshold required for the estimation of a spatial hillslope delivery ratio (HSDR). Therefore we cannot apply the HSDR approach outlined in Post *et al*., (2006a).
- Shuttle Radar DEM should be used for slope calculations in the RUSLE hillslope erosion grid.

Appendix B: 2006 MLA Burdekin SedNet model

Background and Introduction

A complete description of SedNet is given in the documentation available from the Catchment Modelling Toolkit website http://www.toolkit.net.au. This appendix gives more complete details about the input data used and assumptions made for the various parts of the model.

Version 2.0.0 of SedNet was used for this latest modelling work. It is freely available and was downloaded from the Catchment Modelling Toolkit website. The previous Burdekin model by NRM&W's Short Term Modelling (STM) Project used SedNet version 1 combined with CSIRO's in-house Arc/INFO based ANNEX (nutrient) sub-model. SedNet Version 2 (the current release) includes the ability to model nutrient fluxes (ANNEX) as well as sediment.

Modelling Framework

The basic unit of a SedNet Model is a stream link. Stream links are generated automatically from a DEM. Also from the DEM, the unique watershed for each stream link was identified (Figure 93). The watersheds, as well as providing the means of calculating upstream catchment area for hydrological parameterisation, define the areas within which spatially distributed data (such as hillslope erosion and dissolved nutrients) are summarised for each stream link. For the Burdekin model, a minimum threshold of $50km^2$ was used, subdividing the catchment into 1812 unique stream links and watersheds.

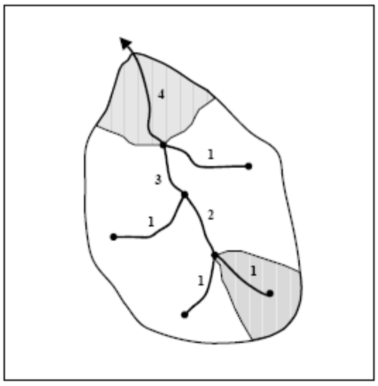
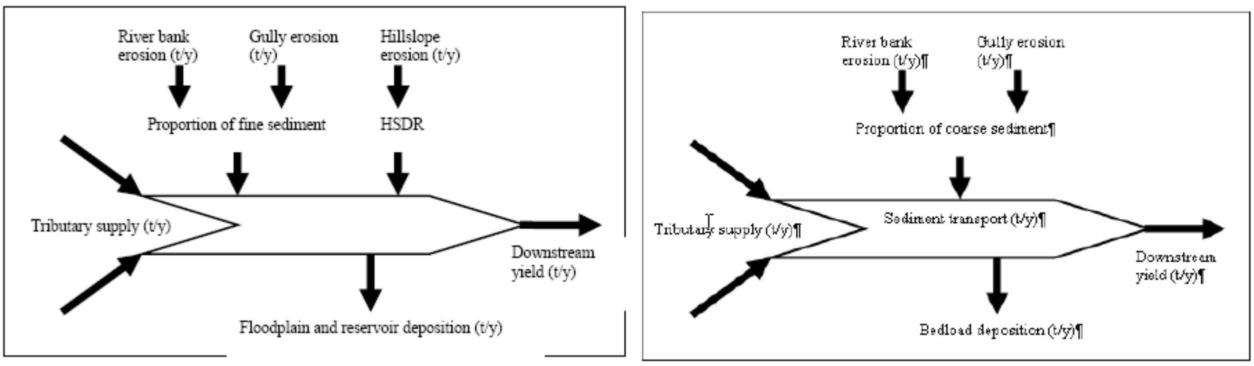


Figure 93: The basic units of SedNet - stream links and their associated watersheds.



(a) (b)

Figure 94: Stream Link budgets for (a) suspended sediment, (b) bedload Routing downstream through the stream link network allows for prediction of output loads from river mouth exit links while inclusion of input, storage and loss terms from each stream link (or associated watershed area) allows for a complete budget to be compiled for a river system.

Input data and Parameter settings

The current model is based largely on the work done in the Short Term Modelling (STM) Project by Queensland Natural Resources, Mines and Water (Cogle *et al*., 2006; Fentie *et al*., 2006). Thus the details to follow mostly reflect the STM model configuration, except where differences have been noted and explained. *Blue italicised text* indicates direct quotations from the Short Term Modelling Reports. The order and naming conventions for datasets of parameter settings approximately reflect the order in which data is requested by the SedNet model.

Digital elevation model

For stream link definition and the framework of watersheds (i.e. the Configuration setup), the same DEM (i.e. based on the AUSLIG 9-sec 250m DEM.) was used as for the STM project. Our investigation into DEM choices for this application is given in Appendix A**.**

Cogle et al.(2006): The GEODATA 9 Second DEM Version 2, produced under a co-operative effort by the (former) Australian Surveying and Land Information Group (AUSLIG), the Australian Geological Survey Organisation (AGSO) and the Australia National University's Centre for Resource and Environmental Studies (CRES), was used. The DEM was derived from a combination of spot heights from the AUSLIG GEODATA TOPO-250k Relief theme, watercourse features from the GEODATA TOPO-250k Hydrography theme, coastline from the GEODATA COAST-100k theme, coastal inlets from the GEODATA TOPO-250k theme, radar altimeter spot heights from the National Geodetic Data Base Spot Heights, and topographic information digitised from1:100,000 scale map sheets. The DEM was generated using ANUDEM v5.0, developed by Dr Mike Hutchinson of CRES. The DEM was reprojected using ESRI ArcMap from GDA94 geographic coordinates to a GDA94 Albers conical equal area coordinate system. DEM cell size was resampled from 9 seconds to 250 metres during this process.

Potential evapo-transpiration (PET)-Rainfall ratio

The PET Rainfall ratio is used to determine the runoff coefficient for each stream link catchment. We used the same PET Rainfall ratio grid as used for the STM Project. The grid resolution from the STM project is 250m resolution.

Cogle, et. al, (2006): The PET-Rainfall layer as used in Brodie et al. (2003) was used. This dataset was derived from the Mean Annual Potential Evapo-Transpiration National Land and Water Resources Audit (NWLRA) dataset, created using the Priestly-Taylor method, and a 5 km resolution mean annual rainfall grid sourced from Bureau of Meteorology SILO data.

Water storages

Lakes were modelled as sediment deposition sites. However, there appeared to be many lakes in the STM Project data that were over-represented in extent and area (due to a buffering routine and the definition of "lake" that had been applied). We did not include lakes for this model, as a close inspection of the original lakes data, suggested there were none that would have a major hydrological impact considering the highly seasonal nature of runoff and flow experienced in the catchment (i.e. they were near the tops of watersheds, or they were small and/or ephemeral).

We used the same reservoir storages as identified for the STM project Burdekin Dam, Eungella Dam, and Clare Weir) (Table 34). Regulated flow was not considered as the Burdekin is the only dam that would strongly impact on flow regime and it is only the few remaining stream links below the Burdekin Dam that would be affected. Although not documented, it was found that the capacities shown in **Table 34** were in fact halved for the STM SedNet modelling work – we accordingly halved the dam capacity for the current model. The capacity reduction was apparently undertaken to compensate for the strong seasonality of flow which appears to overestimate the trapping effect of the Burdekin Dam (Jon Brodie, pers. comm.) although this yet to be tested and further work on the trapping efficiency of the Burdekin Dam is planned.

Fentie, et al. (2006): The SedNet model uses shapefiles to represent lakes within the stream link network in order to model depositional processes. The lakes dataset used by Brodie et al. (2003) was used for this modelling exercise.

The reservoir dataset as used in Brodie et al. (2003) was used as a base dataset. Where further reservoir features were required, missing data was sourced from the Department of Natural Resources, Mines and Water 1:100,000 scale dataset 'QLD_DAMLAKE_100K'. This dataset stores the location of departmental dams and natural lakes. Capacity in gigalitres was appended to each reservoir, sourced from the Australian Water Resources Assessment (2000) national point coverage of flow control structures higher than 10 m. Where reservoir capacities were unavailable, the Department of Natural Resources, Mines and Water layer 'DAMWEIREXIST_100K_P' was used where possible. This dataset stores information regarding the location of existing dams, weirs and barrages controlled by the Department of Natural Resources, Mines and Water. For the Burdekin, there were a total of three reservoirs and 38 lakes used in the SedNet models of the Burdekin Dry Tropics catchments.

Table 34: Water storages and capacity (GL) used in the SedNet model of the Burdekin region.

Storage	*Catchment*	*Capacity (GL)*
Clare Wier	*Burdekin*	*12*
Eunjella Dam	*Broken*	*131*
Burdekin Falls Dam	*Burdekin*	*1860*

Floodplain extent

The same floodplain extends as for the STM project were used.

Floodplain extent data originally created for the NLWRA, and as used in Brodie et al. (2003), was used by SedNet for the calculation of floodplain deposition. Floodplain extents were mapped from the GEODATA 9 Second DEM, and represent an assessment of floodplain extents at a discharge equivalent to the 1 in 25 year flood annual series. A detailed description of methodology is available in (Pickup et al., 2001).

Configuration Parameter values

Stream link channel width estimates were improved by the use of field data collected in the Burdekin (Bainbridge, 2006). These sites allowed us to put accurate estimates on the regionalisation coefficients instead of using the default values supplied in the Toolkit model (see Appendix C). All other parameter values are as per the STMP.

Drainage area threshold (km²)	50
Minimum first order link length (km)	2
Channel width coefficient	12.03
Channel width area exponent	0.29
Slope exponent	0

Flow data

SedNet incorporates a number of hydrological parameters into the calculation of river sediment budgets. These are based on stream gauge observations and are used for calculations of patterns of river basin deposition, river bank erosion, and denitrification. The parameters need to be predicted (interpolated) for each river link across the at hydrological gauging stations within the region. The variables used are:

- the mean annual flow (Qa)
- the bankfull discharge (Qbf); and
- a representative flood discharge for floodplain deposition (in this case median overbank flow – Qob)

As with the STM project, values for these variables were derived from times series of daily flows from 27 river gauging stations (QDNR, 2003) with more than 20 years of good quality flow record and no regulation. They are the same data as used in the GBR SedNet study (Brodie *et al*., 2003) (Table 35). A full description of the hydrology can be found in Wilkinson *et al*., (2004) and Wilkinson *et al*., (2006b).

Table 35: Calibrated values of the hydrologic parameters and the associated coefficient of efficiency used in the STM modelling project (Fentie *et al*., 2006)

Runoff coefficient (ROC)	
a	*0.167*
b	*1.71*
(Coeff of efficiency)	*(0.55)*
Sigma daily (σd)	
c	*3.75*
d	*0.0004*
(Coeff of efficiency)	*(0.0005)*
Bankfull flow(Qbf)	
e	*6.23*
f	*0.77*
(Coeff of efficiency)	*(0.94)*
Median daily flow (Qmo)	
g	*1.27*
h	*0.80*
Coeff of efficiency	*0.91*

Fentie et al. (2006) have shown that total sediment export is not sensitive to parameters associated with Sigma daily, while it is highly sensitive to parameter B associated with runoff coefficient and parameters associated with bankfull flow (i.e. parameters E and F in Table 35*). Therefore, the low coefficient of efficiency value associated with Sigma daily is expected to be less of a concern.*

Cogle *et al* (2006) recommended: "In large catchments characterised by significant rainfall variability and/or uneven densities of stream flow gauging stations, (e.g. Fitzroy and Burdekin), hydrologic regionalisation should be performed on smaller sub-catchments (e.g. Upper Burdekin, Belyando, Suttor) rather than on the whole catchment." However, the current version of SedNet does not support the capability include different hydrological regimes in one model.

Riparian Vegetation

Riparian Vegetation cover estimates are used to estimate the stream channel's susceptibility to bank erosion. Data from the STM project was used. The grid supplied had been resampled from the original 25m of SLATS to 150m.

Cogle, et al., (2006): The proportion of riparian vegetation along each stream link affects the rate of bank erosion. SedNet calculates this proportion by averaging the amount of vegetation present in the riparian zone for each subcatchment. The Queensland Department of Natural Resources, Mines and Water Statewide Landcover and Trees Study (SLATS) Derived 2001 v8 25 m landcover dataset was used to generate riparian vegetation data. The data is derived from Landsat TM satellite imagery acquired by Geoscience Australia with a nominal ground resolution of 30 m. The dataset was re-projected and mosaiced from separate UTM Zone 54, 55 and 56 datasets to a single GDA94 Albers conical equal area projection. Foliage Projective Cover (FPC) was derived from the imagery and image pixels with a FPC of greater than 20 percent were considered to be remnant vegetation. A buffer of 50 m was applied either side of stream lines and the proportion of remnant riparian vegetation was calculated within the buffer. The landcover was then reclassified into a Boolean dataset representing the proportion of vegetation. Woody vegetation, regrowth and orchards was classified as one and pasture (<12% foliage percentage cover) crops, settlements, or bare areas were classified as zero. Values of zero represented areas of degraded vegetation, with values of one representing healthy vegetation. Water and unclassified areas were represented by null values. For the Burdekin, Riparian vegetation has been clipped out from the tree cover data obtained from the SLATS project at a 150 m resolution. Fentie, et. al ,(2006): Riparian vegetation has been clipped out from the tree cover data obtained from the SLATS project at a 150 m resolution. Wilkinson et al., 2004 shows the details of the procedure to clip out this data, and the data format requirement for this dataset.

Hillslope Erosion

Hillslope erosion is considered to contribute to sediment loads purely on the basis of suspended loads. Associated particulate nutrient loads are estimated using the average watershed hillslope erosion and an estimate of A-horizon clay content (to which all particulate nutrients are assumed to be associated). Hillslope erosion was estimated using the revised universal soil loss equation (RUSLE):

Soil loss (tonnes ha^{-1} $year^{-1}$) = RKLSCP, Equation 1

where R = rainfall erosivity factor; K= soil erodibility factor; L = hill length factor; S = hillslope factor; C= vegetation cover factor; P = land use practice factor. All factors may be represented as spatially variable grids, allowing derivation of a spatially distributed hillslope erosion grid.

Erodibility remained unchanged from STM, as we had no opportunity to look at improvements. The hill slope factor (S) was improved as discuss below, but the hill length factor (L) remained the same as that used for the STM Project. C-Factor was improved as discussed below. The land use practice factor accounts for the effects of contours, strip cropping or terracing. As these are not as these practices are not relevant to relatively natural systems, and have been implicitly incorporated into the C-factor for horticultural landuses, the P-factor was not used (i.e. it was set to 1).

Rainfall erosivity (R)

Rainfall erosivity (R) is a measure of the intensity of rainfall events and so is determined by climatic data. It is gridded at approximately 270m resolution. The erosivity grid used is the same as that used for the STM project.

Cogle, et. al, (2006): Rainfall erosivity is defined as the mean annual sum of individual storm erosion index values, EI30, where E is the total storm kinetic energy and I30 is the maximum 30 minute rainfall intensity (Lu et al., 2001). This surface was generated using the methods described by Yu and Rosewell (1996), in a similar way to the National Land and Water Resource Audit. The rainfall erosivity was calculated at 0.05 degree (approx. 5 km) resolution using daily rainfall data obtained from the SILO database (NRMW) and the final result was re-gridded to 9" (approx 250 m) resolution. This R factor surface was calculated using rainfall data from 1915 to 2001, whereas the Audit used a much shorter period (1980 to 1999). The longer rainfall data set, along with incremental improvements the Silo daily rainfall product, should result in a rainfall erosivity surface which is more representative of Queensland climatology than the surface used in the Audit (pers comm. David Rayner, NRMW).

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Soil Erodibility (K)

Erodibility (K) is a measure of the susceptibility of the soil to erosion. It is based on the nature (structure, texture, etc.) of the topsoil. We used the same erodibility grid as for the STMP. It is gridded at 1km resolution.

Cogle et. al, 2006: Soil erodibility is the average soil loss per unit area for a particular soil in cultivated, continuous fallow with an arbitrarily selected slope length of 22 m and slope steepness of 9%. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute. Fentie et. al, 2006: The K factor for the Burdekin was estimated from an established relationship with A horizon soil texture, soil clay content and the saturated hydraulic conductivity of the A horizon (Lu et al., 2001), as for the NLWRA a value of unity has been assigned to the L-factor in all landuses, except cropping where it has been calculated using the algorithm described by Lu et al. (2001).

Slope Steepness (S) Factor

The hillslope factor accounts for the fact that soil erosion increases with increasing slope. For the STM project, the slope factor used was that developed for the NLWRA (2000). This slope factor had been developed for continental scales and indirectly predicted slope factor by relating high resolution estimates of slope factor to terrain and geological attributes available at coarser scales.

With the recent availability of the Shuttle RADAR Topographic Mission data, we had the ability with this project to directly measure slopes. Our comparison with higher resolution DEM data (see *Appendix A*) reassured us that the effects of 1) the relatively coarse gridsize (90m) relative to slope length and 2) returns from vegetation canopy (which are particularly noticeable in riparian zones and make SRTM of limited value as a flow direction predictor), appear to be statistically insignificant in terms of slope prediction. Methodology for directly calculating S-factor from The SRTM DEM was the same as quoted below in the STM project documentation:

Cogle, et.al,(2006): The slope steepness factor is defined as the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions. The slope steepness factor is calculated using the equations:

$$S = 10.8 \times \sin\theta + 0.03 \quad \sigma \leq 9\% \qquad \text{Equation 2}$$

$S = 16.8 \times \sin\theta + 0.03\ \sigma > 9\%$

where θ is the angle of slope and σ is the slope gradient in percentage and is derived from the gridded DEM using 3x3 pixel filter functions (McCool et al., 1989). The slope values are generated from the digital elevation models (DEMs) using the standard ArcGIS (ESRI, Redlands) algorithm.

Slope Length (L) factor

The L-factor incorporates the assumption that, in forests, grasslands and open woodlands, the hill-length term (*L*) is considered invariant (Prosser and Rustomji, 2000) and is set to 1, while for other landuse types it reflects increasing runoff volume (and thus eroding power) downslope. We used the same slope length L-factor grid as for the STM Project. It is gridded at 1km resolution.

Cogle, et.al, 2006: The slope length factor is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff water enters a well defined channel that may be part of a drainage network.

The slope length factor is evaluated using the equations in the RUSLE (McCool et al., 1989). The slope length component of the slope length factor is calculated from the DEM using the drainage network as the slope length cut off point. The ArcGIS flow path length algorithm was used to generate the surface. The maximum flow length valid in the USLE is 300 metres. This was set as the upper limit for the flow length raster. The slope length factor was set to 1 for all land uses except cropping as described in Lu et al. (2001). In Fentie, et al., (2006) as in previous studies (Brodie et al., 2003; Prosser et al., 2002), a value of unity has been assigned to the L-factor in all landuses, except cropping where it has been calculated using the algorithm described by Lu et al., (2001)

Cover (C) Factor

In the STM project, a C-factor was determined for each landuse (based on lumped groupings of QLUMP landuse codes) and applied as a constant over the area of each landuse to produce a C-factor grid. The C-Factor grid used in our current study applied a variable cover factor (based on an estimate of ground cover levels) within landuse types (Figure 95) of grazing and remnant vegetation and within the Townsville Field Training Area (i.e. about 95% of the catchment). The recent availability of a NRM&W Landsat product predicting Bare ground cover levels (Searle *et al*., 2006 - Draft), in combination with the SLAT Foliage Protection Cover (FPC) product, enabled us to predict C-factor spatially at 25m grid intervals based on ground cover levels where canopy cover was <40%. We assumed the SLATs FPC to be indicative of canopy. Thus where FPC was <40%, the following equation was applied,

$$\text{C-factor} = (0.964337^{GRASS}) \times ((-0.001237)*FPC + 0.45807) + 0.000093268*FPC - 0.01507 \qquad \text{Equation 3}$$

Where: FPC = NR&M Foliage Protection Cover SLATs Product (Searle *et al*., 2006 - Draft) and *GRASS* = the inverse of the Bare Ground image (100 – [Bare Ground]). If *FPC* was above 40% in these landuses, a C-factor of 0.005 (equivalent to “other minimal landuse” in table below) was applied. A comparison of the C factors used for the two projects are shown in Table 36.

Table 36: the C-factors as applied for the current model and how they varied from the STM project C-factors.

Lumped Landuse (current study)	C-factor	STM C-factor	Landuse in STM Report
Grains	0.1	0.1	Irrigated Cropping
Grazing	variable	0.0398	Grazing (assumed 60% cover)
Mining	0.5	0.5	Mining
Other	0.003	0.003	Residential
Other agriculture	0.1	0.1	Agriculture
Production Forestry	0.003	0.003	Production Forestry
Sugar	0.5	0.5	Irrigated Cropping
Tree Fruits e.g Bananas	0.1	0.1	Irrigated Fruit Trees
Ungrazed savannah/woodland	0.005	0.005	Other Minimal Landuse
Wetland	0.001	0.001	Wetland
Water body	0	0.001	Wetland
Remnant Vegetation	Variable	0.005	Other Minimal Landuse
Townsville Field training Area	variable	0.005	Other Minimal Landuse

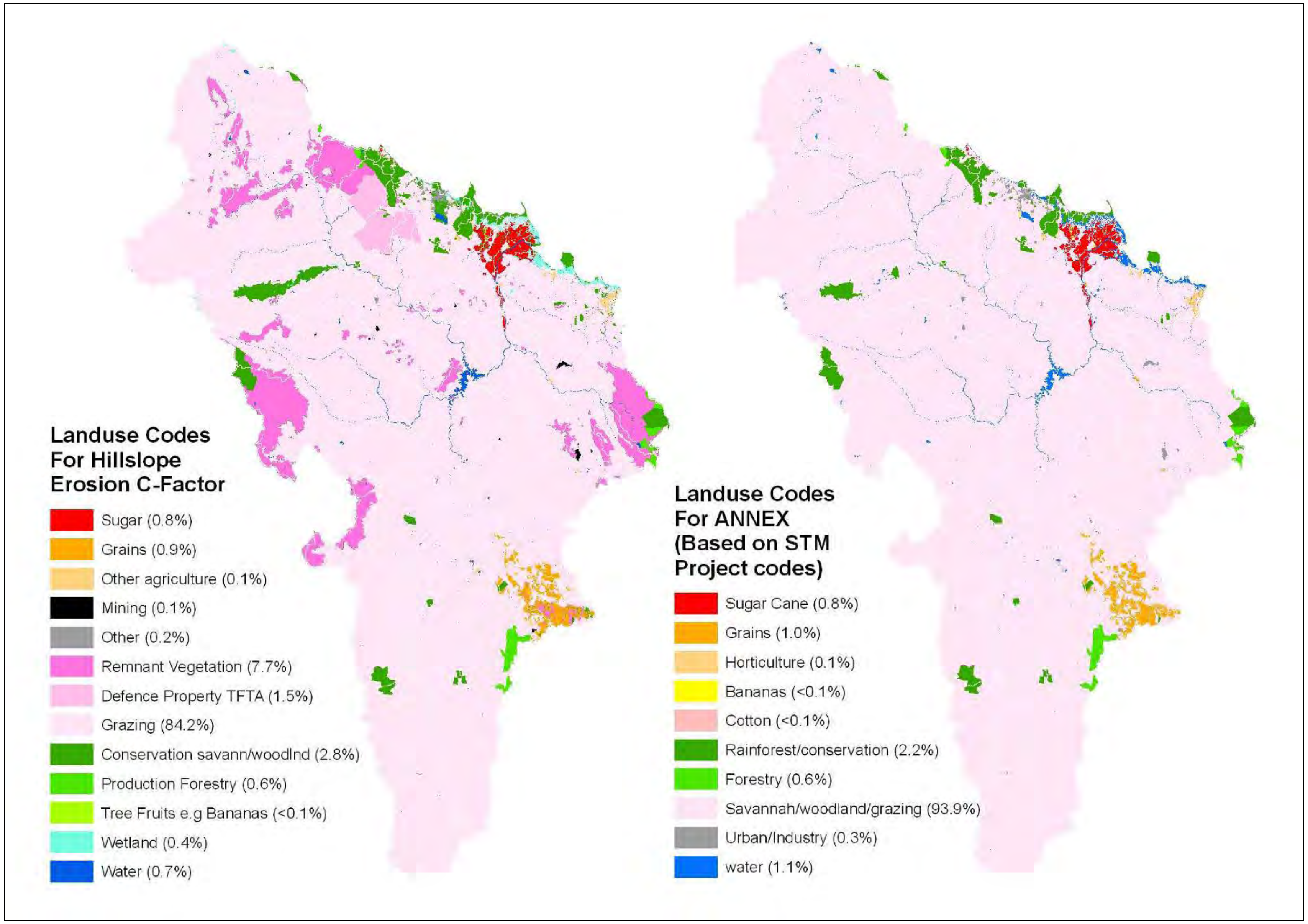


Figure 95: Landuse Classifications for Determination of C-factors and Dissolved Nutrient concentrations (ANNEX).

Hillslope Delivery Ratio (HSDR)

An additional term is used in SedNet in the calculation of hillslope erosion contributing to stream. It is the hillslope delivery ratio (HSDR). HSDR accounts for re-deposition of hillslope sediment before it reaches a stream. It is generally considered a constant by SedNet, but it may also be represented as a spatially variable grid and applied to each hillslope erosion grid cell as follows:

Total sediment delivered to stream for gridcell = Soil Loss × HSDR. Equation 4

It was originally intended to use a spatial HSDR based on work done earlier (Post, *et al*. (2006a) and Kinsey-Henderson *et al*. (2006). However, once we investigated the fitness of the 25m NRM&W DEM for purpose, we found that the derived flow paths for delineation of channel pixels down to the required 1 ha threshold was not accurate enough (see *Appendix A*). The default non-spatial (constant everywhere) HSDR was used, and as for the STM project and all other previous SedNet modelling work, is set to 10%.

Calculation of Hillslope Erosion

SedNet Version 2 asks for an RKLS grid instead of a hillslope erosion grid. It then attempts to apply a C-factor by Landuse to create it's own hillslope erosion (RKLS*C) grid. As we had a spatially variable C-factor applied to a number of landuses, we supplied a complete RKLSC grid instead of an RKLS grid and assigned a C-factor of 1 to each landuse. The landuse grid supplied to SedNet is discussed under the ANNEX section to follow, as it was supplied to comply with the dissolved nutrient landuse classification requirements.

The hillslope erosion RKLSC grid was generated at a resolution of the best available input data (i.e 25m for C-factor). The values were capped at 150 t/ha/yr, consistent with what we predict as a maximum erosion rate at that scale (150 t/ha/yr ≈ 10cm/yr loss). The percentage of grid cells above this maximum value were negligible, but had potential to distort results due to their magnitude.

For expediency, the RKLSC hillslope erosion grid was then resampled to 125m grid resolution, with each 125m grid cell containing the mean value of the 25 grid cells contained within it. This will not degrade results from the model, as the model calculates mean erosion values within each watershed anyway. Figure 96 compares the hillslope erosion estimates derived for each watershed for both the STM SedNet model and the current model (incorporating the spatially explicit C-factor and improved S-factor).

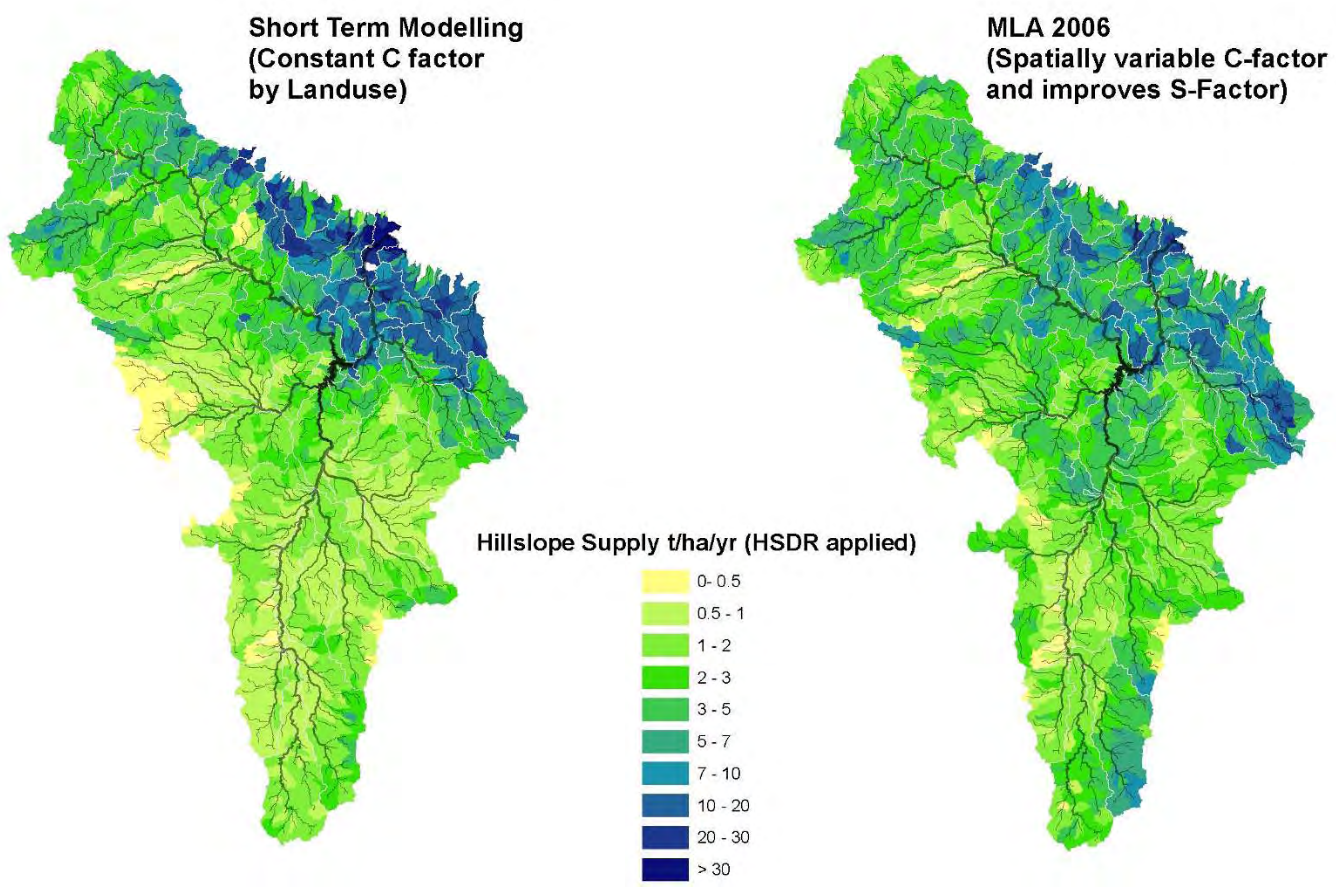


Figure 96: Comparison of hillslope erosion for STM project and this project highlighting the effect of using a spatially variable C-factor and improving the resolution of the S-factor.

Gully erosion

Gully erosion contributes equally to the suspended sediment and bedload (50:50 ratio) as well as to particulate nutrient loads (based on estimates of Soil N and P concentration). Gully erosion is estimated using a gully grid and an estimated gully cross-section. The Gully Density grid for the current model remained the same as the one used in all previous SedNet projects including the STM project:

The gully density data used in this project was sourced from the results of the National Land and Water Resources Audit. A full description of the methods used to predict gully erosion can be found in Hughes et al. (2001). Most of the gullies are located in the northern part of the Suttor subcatchment, the north-western part of the Bowen subcatchment, the East Burdekin subcatchment, the western part of the Upper Burdekin subcatchment, the northern part of the cape subcatchment, and north-western part of the Campaspe subcatchment.

It was initially planned to revise and improve the gully density maps for the Burdekin catchment, however, attempts to improve gully density mapping and subsequent predictability of gully location in SE Queensland did not provide any additional predictive capacity (Caitcheon *et al*., 2005) that could be applied to the Burdekin. The reason that the extra data did not improve the gully modelling was considered to be due the different sampling approaches employed. In the initial gully density analysis for the NLWRA and used in Prosser *et al*., (2003), gully mapping was targeted to areas 'with' and 'without' gullies. Whereas the revised mapping project by Caitcheon selected gully sites randomly. Based on the efforts in SE Queensland, it was decided that for the Burdekin SedNet project to re-use the gully density mapping presented in Prosser *et al*., (2001a) and described in Hughes *et al*., (2001) rather than attempt to improve the gully density mapping.

In the STM Project, gully cross-sectional area was set to the default value of 10 m^2. Analysis of measured field data from Heine (2002) in Table 37 below suggests that the mean cross-sectional area for a range of gully sites in two small catchments in the Granodiorite country near Charters Towers is ~5.26 m^2. It is uncertain how representative these data are of the rest of the Burdekin catchment. However, given that this estimate is based on measured data, the new cross-sectional area data were employed for this application of the SedNet model.

Table 37: Gully cross-sectional area data for Weany and Wheel Creek (Heine, 2002)

Catchment	Cross-sectional area (m)				Number of sites
	Head	Middle	Valley	Average	
Weany Creek	3.04	5.6	8.06	5.57	16
Wheel Creek	3.29	6.44	5.13	4.95	17

Bank erosion

Stream bank erosion contributes to both suspended sediment and bedload (50:50 ratio). Bank erosion is estimated from regionalised bankfull discharge rates and estimates of intact riparian vegetation and bank height within each stream link. Flow regionalisations and estimates of riparian cover were not improved upon from STM. However, as with channel width, bank height could be improved upon. The STM project assumed a constant 4m height everywhere. Field data allowed bank height to be related to catchment area (see Appendix C). The regionalisation coefficients are shown in Table 38.

Transient bedload model

In previous applications of the SedNet model in the Burdekin catchment, the bedload budget has been calculated using the approach described in (Prosser *et al*., 2001b). In this application of the model, the transient bedload budget approach was applied, which accounts for the time required for a change in sediment loads to propagate through the river network, given the transport velocity of bedload through each link. Details of the approach are described in details in Wilkinson *et al*., (2004) and Wilkinson *et al*., (2006a). The default value of 0.15 m was used to define the active depth of bedload transport in the absence of measured data from the Burdekin catchment

Scenario parameter values

Parameter values are shown in Table 38, and except where previously discussed, all parameters below are as for the STM project.

Table 38: Scenario parameter values.

Parameter	Value
Bankfull discharge recurrence interval	6
Gully age (years of elevated erosion and accumulation)	100
Gully cross-sectional area (m^2)	5.26
Gully Erosion reduction factor	1
Bedload Budget Type	Transient
Transient Bedload Storage (n)	0.15
Max bedload depth (m)	1.5
Variable bank height Coefficient	1.39
Variable bank height Exponent	0.14
Hillslope Delivery Ratio	0.1
Sediment bulk density (t/m3)	1.5
Floodplain settling velocity (m/s)	1.00E-06
Bank erosion coefficient	2.00E-05
Sediment transport capacity coefficient (k1)	560
Minimum link length (m)	2000
Proportion of suspended sediment	0.5

ANNEX

Figure 97 shows the nutrient components accounted for in each SedNet stream link using ANNEX. Spatially explicit sources of nutrients are provided to ANNEX via grids or point source data.

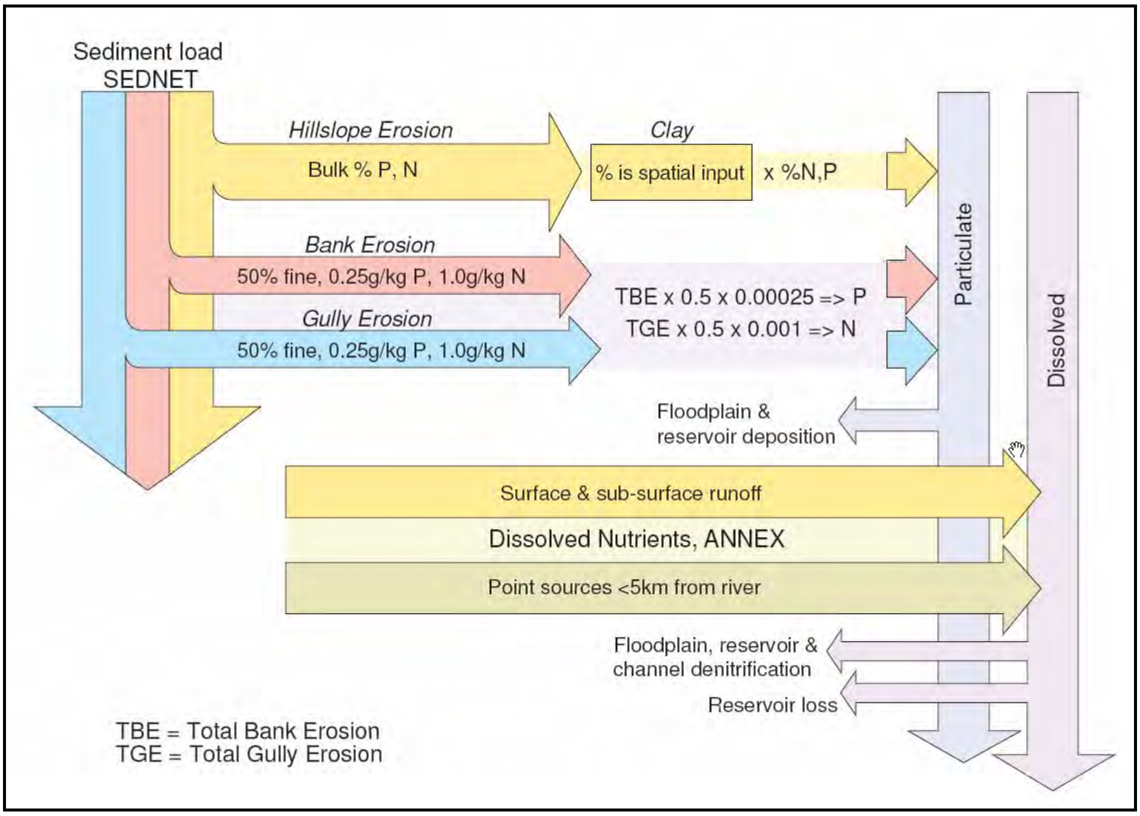


Figure 97: Conceptual model of ANNEX nutrient load modelling (from Cogle, *et al*., 2006).

Soil Nutrient and Clay concentration

Although it was noted in the STM Project report that there were serious questions regarding the soil nutrient and clay concentration grids that continue to be used for SedNet modelling work in the Burdekin (see section 2.4.9 of Cogle, *et al.* (2006)). We had no opportunity to address this issue.

Both the bulk nutrient content and clay fraction are spatially variable soil properties and are taken from the mapping of Australia by Henderson et al. (2001)

The nutrient enrichment/reduction factor which has previously been used to reduce over prediction of sediment attached nutrient estimates (see Brodie, *et al*. (2003) and the STM project) was removed in this study as it was seen as a “fudge factor” (See section 2.4.9 of Cogle, *et al.* 2006 for more discussion).

Dissolved Nutrients

ANNEX simulates dissolved nutrient loads by specifying mean annual concentrations for DIN, DIP, DON and DOP for different land use classes (Figure 95(b)). For the STM Project, the mean annual concentrations were updated from previous work such as Brodie *et al.* (2003). These values are shown below. The landuse grid to which the dissolved nutrient concentrations were applied for our current model (same as STM Project) is shown in Figure 95 (b).

Cogle et. Al (2006): Table 39 *lists the concentrations of the four dissolved nutrient species assumed for the nine land use classes for which adequate field data exist in Queensland. The values used by Brodie et al. (2003) were adopted except where more recent field data) indicated the values should be revised. The most significant changes in the current work were:*

- *A large increase in DIN for sugar cane and banana plantations*
- *A large decrease in DIN for urban land uses*
- *A decrease in DON for rainforest*
- *A decrease in FRP for sugar cane, bananas and rainforest*
- *A large increase in FRP for urban land uses*
- *A decrease in DOP for rainforest, sugar cane, bananas and urban land uses*

Table 39: Dissolved nutrient concentrations for GBR catchment land uses used by Brodie *et al*. (2003) and for this project (STM). STM values are shown as the value used. Also shown are representative upper and lower bounds for the concentrations drawn from field experiments (from Cogle *et al*., 2006).

Land use	DIN		DON		FRP		DOP	
	Brodie *et al.*	STM	Brodie *et al.*	STM	Brodie *et al.*	STM	Brodie *et al.*	STM
Savannah/ woodland grazing	100-200	160±40	100-250	200±50	20-50	20±10	10-12	10±5
Rainforest	40	40±20	150	80±40	10	6±4	10	5±3
Sugar cane	900	2000+2000-1000	250	250±50	30	10±5	25	15±5
Bananas	700	1100±300	250	250±50	100	80±20	20	14±5
Horticulture	500	500	200	200	30	30	20	20
Cotton	700	700	200	200	80	80	20	20
Grain	500	500	300	300	60	60	20	20
Forestry	150	150±75	150	150±50	8	8±2	8	8±2
Urban	1650	200±100	300	300±50	120	230±100	20	10±5

Nutrient load point sources

The EPA Point source database recommended in the STM Report Cogle *et al.* (2006) was not ready. Thus the same data as for the STM project was used. However, point source Total N and Total P were assigned more correctly to DIN and FRP instead of DON and DOP respectively as had been done was an oversight in the STM Project (Sherman, B., *Pers Comm*).

Cogle et. al (2006): Point sources of nutrient loads were taken from the National Pollutant Inventory (NPI) database. Only point sources located within 5 km of a stream channel were considered. More distant point sources are assumed to be disposed of on land and have no impact on stream water quality.

The NPI reports loads for total phosphorus, total nitrogen and ammonia. In some cases the NPI data are estimates rather than measured values where the estimates are computed following a procedure specified in the NPI documentation. A shortcoming of this approach is that the *reported nitrogen loads are occasionally inconsistent, i.e. the ammonia load may exceed the total nitrogen load. Only total nitrogen and total phosphorus load data were used in the STM project.*

NPI data for the previous 6 years 1999-2004 were assessed to identify conspicuous trends or step changes indicating the introduction of, for example, improved sewage treatment processes. In general, the average nutrient load over the 6 year period was used in ANNEX. In some circumstances the median or most recent reported load was used where it was judged to better represent the expected future contribution of the source.

It is envisioned that sometime during calendar year 2006 the Queensland EPA Point Source Database (PSD) will become available. This database will report measured loads (or concentrations) and will include smaller sources which are not included in the NPI. We recommend that in the future the PSD values be used in preference to NPI data.

All point source nutrient loads were assigned to the dissolved organic nitrogen (DON) and phosphorus (DOP) fractions. In fact most point sources consist of a mixture of organic and inorganic nitrogen and phosphorus. The main implication of this simplification is that point source contributions to the dissolved nitrogen load will not suffer any losses through denitrification. The significance of this simplification is discussed in each of the regional reports.

ANNEX parameter settings

The ANNEX parameter settings were the same as for the STM project Table 40). Setting dissolved reservoir trapping to “loss” assumes dissolved nutrients in the reservoir stored water can transform to other forms and either settle out of the water body or be lost to the atmosphere. Subsoil P and N concentrations are used in conjunction with gully and bank erosion to determine sediment attached nutrient loads from these sources.

Table 40: ANNEX parameter settings used based on STM

Parameter	Value
Dissolved Reservoir Trapping	Loss
Subsoil Phosphorus Concentration (g/kg)	0.25
Subsoil Nitrogen Concentration (g/kg)	1

Appendix C: Channel width and depth estimates

The SedNet model requires estimates of channel width and corresponding active channel depth (or bank height) to estimate sediment transport capacity and bank erosion, respectively. Channel width and depth can be calculated using bankfull discharge values based on empirical rules of hydraulic geometry. Hydraulic geometry was first introduced by Leopold and Maddock (1953) and provides a set of relationships that describe river behaviour in terms of discharge (Q) and the dependent variables width (*w*), mean depth (d) and mean velocity (*v*). The relationship between discharge (Q) and channel width and depth are known to form a power function for most stream systems (Knighton, 1977). In the absence of known discharge values, or due to the diverse hydrologic regimes in many catchments in Australia, a number of studies have used catchment area as a surrogate for discharge to predict channel width and depth (Prosser *et al*., 2001b; Wilkinson *et al*., 2006a).

For the Burdekin catchment, a total of 39 cross-section sites were used to develop a relationship between catchment area and channel width and depth. Nineteen of the sites were measured on the Burdekin River between Greenvale and Macrossan Bridge (Bainbridge, 2004). The catchment areas of these sites ranged between 9,500 – 36,100 km^2. Eight sites with catchment areas between 0.12-14 km^2 were measured in Weany Creek near Mingela (Bartley *et al*., 2007). The remaining 12 sites had catchment area of 193-7100 km^2 and were measured from DNR&M gauge sites around the Burdekin Catchment that had distinct bankfull features (note: some of these gauges are no longer active). No data from downstream of the Burdekin falls dam were used due to the potential for changed channel characteristics due to regulated flow. The sites measured provide a range of catchment areas, and a list of the data is given in Table 42.

Bankfull width and corresponding depths were determined visually for all cross-sections using break of slope changes and the location of bench and bar features (see Figure 98) (Wharton, 1995; Woodyer, 1968). It is acknowledged that there are more rigorous methods for estimating bankfull, such as using manning's equation and/or 2D flow modelling (e.g. HecRas, http://www.hec.usace.army.mil/software/hec-ras/), however, due to the problems associated with defining bankfull in semi-arid rivers, and the size and variability of rainfall and runoff in the Burdekin Catchment, visual estimates for determining bankfull morphology were considered just as rigorous. As long as the method used for defining bankfull width and depth is pre-defined, and is used consistently by a single person, then the method is considered appropriate.

Prosser *et al*., (2001b) developed a relationship for the Burdekin catchment to predict channel width based on aerial photo analysis (Equation 5). Prosser *et al*., (2001b) found that discharge was a poor predictor of channel width, and therefore they used multiple regression to estimate channel width (w) based on catchment area (A), floodplain width (F) and channel slope (S).

$$w_x = 0.092A_x^{0.34}F_x^{0.5}S_x^{0.29} \quad (r^2 = 0.64,\ n = 180)$$ Equation 5

The revised data set presented in this document represents a simplified relationship, however, we consider that this is actually an improvement on the width estimates in Equation 5 for a number of reasons:

- These revised data are from 'measured' cross-sections rather than from aerial photography, and we were able to isolate the 'active' channel, rather than measure the total channel width, which is an important consideration with regard to sediment transport as it is rare that the entire channel is actively mobile;

- It was possible to obtain corresponding width and depth data from individual cross-sections. It is not possible to determine channel depth from aerial photo analysis;
- This data set includes estimates from a headwater catchment (Weany Creek). Small headwater catchments are often seen as important sources of sediment to downstream areas due to the high connectivity between hillslopes and the channel network (Walling *et al*., 2002). These sites often don't have well developed floodplains, and therefore it is not appropriate to use floodplain width as a predictor of channel width at these sites;
- The slope estimates derived from the DEM are known to out by up to an order of magnitude (Stewardson *et al*., 2005), and therefore slope was not included in the revised analysis.

When the revised width and depth data for the Upper Burdekin were plot against catchment area (Figure 99 and Figure 100) strong relationships, in terms of the correlation coefficients, were obtained (Table 41). There are relatively large standard errors associated with the relationships in Table 41, particularly for channel width, however, this reflects the range of catchment sizes and channel widths measured.

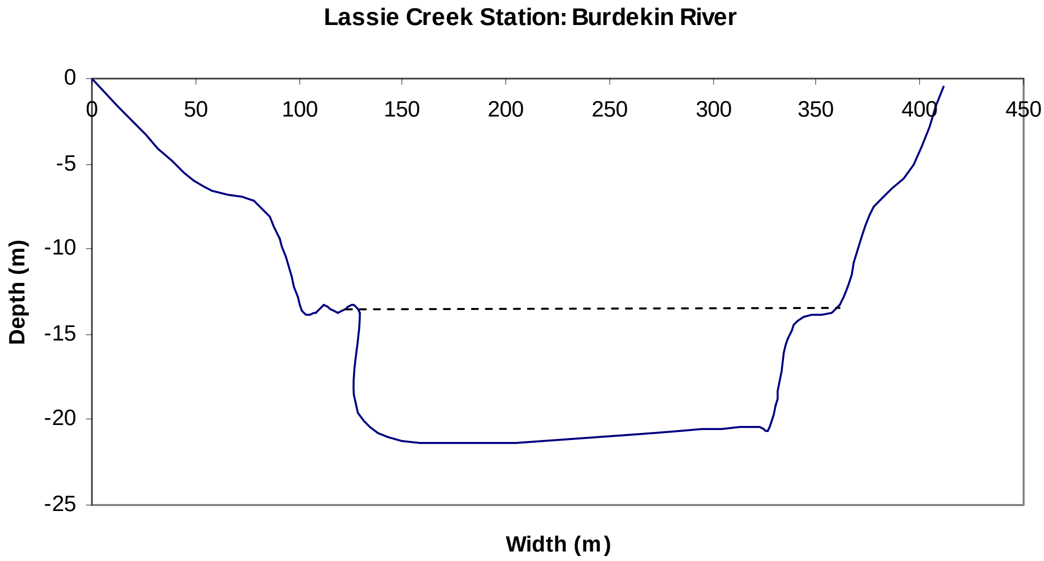


Figure 98: Cross-section from Lassie Creek Station on the Burdekin River. Example of how using break of slope changes and the location of benches were used to define channel width and depth on the Upper Burdekin

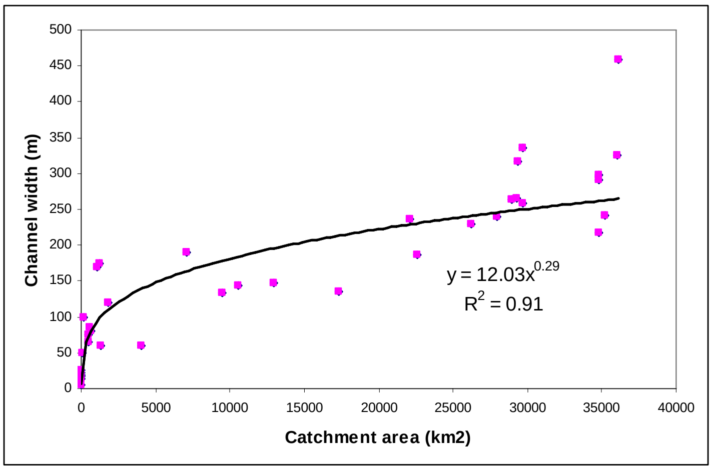


Figure 99: Catchment area against channel width for the Upper Burdekin

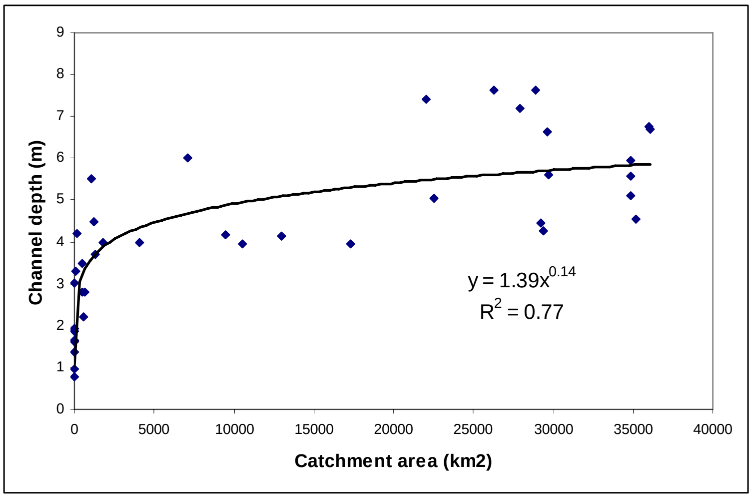


Figure 100: Catchment area against channel depth for the Upper Burdekin

Table 41: Revised values for estimating channel width and depth for the Burdekin Catchment

Equation form	Constant (b)	Exponent (c)	Correlation coefficient	Standard error of estimate	N
Width $=bArea^c$	12.03	0.29	0.90	50.34	29
Depth $=bArea^c$	1.39	0.14	0.75	1.29	29

Table 42: Data used to develop the relationships between catchment area and channel width and depth

	Site #	Name	Catchment area (km2)	Width (m)	Depth (m)
Upper Burdekin	42	Macrossan Bridge	36090.23	459.22	6.68
	51	Fanning Junction	36036.92	325.44	6.75
	17	Acacia Vale	35202.58	240.59	4.56
	44	Basalt St#2	34844.00	298.58	5.58
	62	Basalt St	34844.00	290.42	5.96
	43	Riverview St	34844.00	217.10	5.12
	18	Dalrymple NP	29684.66	336.17	5.60
	4	Dalrymple NP#2	29668.99	257.87	6.62
	45	Dalrymple NP#3	29364.89	316.81	4.27
	30	Gainsford St	29244.60	265.73	4.44
	24	Bridgewater	28929.48	262.88	7.64
	26	Eumara Springs	27925.50	239.47	7.19
	7	Hillgrove	26262.16	229.33	7.63
	56	Starbright	22567.82	186.88	5.05
	38	Lassie Ck Station	22068.39	235.52	7.42
	71	Mt Fullstop St	17299.00	136.00	3.94
	16	Blue Range #2	12976.74	146.42	4.14
	21	Blue Range	10528.00	143.17	3.94
	67	Chrismas Ck St	9496.05	132.84	4.16
Weany Creek	1	Weany Creek	13.48	22.33	3.01
	2	Weany Creek	12.72	16.38	1.93
	3	Weany Creek	12.54	13.66	1.65
	4	Weany Creek	3.55	25.93	0.79
	5	Weany Creek	0.88	19.14	0.97
	6	Weany Creek	3.36	13.14	1.63
	7	Weany Creek	2.34	18.23	1.37
	8	Weany Creek	0.12	5.72	1.87
QNR&M Gauge sites	120102A	Keelbottom Creek@Keelbottom	193.00	100.00	4.20
	120114A	Douglas Creek@Kangaroo Hills	663.00	80.00	2.80
	120106A	Baslt River@Bluff downs	1301.00	60.00	3.70
	1200112a	Star River @Laroona	1212.00	175.00	4.50
	120019A	Fanning River@Fanning River	498.00	75.00	2.80
	120120A	Running River@Mt Bradley	490.00	65.00	3.50
	120205A	Bowen River@Myuna	7104.00	190.00	6.00
	120216A	Broken River@Racecourse	100.00	50.00	3.30
	120005B	Bogie River@Strathbogie	1087.00	170.00	5.50
	120305A	Native Companion Creek@Violet Grove	4065.00	60.00	4.00
	120206A	Pelican Creek@ Mt Jimmy	545.00	85.00	2.20
	120113A	ClarkRiver @Wandonvale	1802.00	120.00	4.00

Appendix D: Seasonal end of wet and end of dry season trends in key metrics for Virginia Park study paddocks

Variable	Unit of measure	Year	Bottom Aires	se	Top Aires	se	Black fellas	se	Stud	se
EOW Total biomass	Kg/ha dry matter	EOW_03	NA	NA	NA	NA	NA	NA	NA	NA
EOW Total biomass	Kg/ha dry matter	EOW_04	791	41.46	624	35.45	624	35.45	1031	75.47
EOW Total biomass	Kg/ha dry matter	EOW_05	659	33.19	610	32.21	610	32.21	651	94.31
EOW Total biomass	Kg/ha dry matter	EOW_065	1680	90.68	1838	98.92	2157	118.02	1504	194.77
EOW 3P %	%	EOW_03	NA	NA	NA	NA	NA	NA	NA	NA
EOW 3P %	%	EOW_04	29.0		44.1		29.0		26.5	
EOW 3P %	%	EOW_05	17.4		30.9		17.4		37.8	
EOW 3P %	%	EOW_065	13.0		17.6		7.7		26.8	
EOW 3P Frequency	%	EOW_03	NA	NA	NA	NA	NA	NA	NA	NA
EOW 3P Frequency	%	EOW_04	68.5		80.0		67.4		64.2	
EOW 3P Frequency	%	EOW_05	48.3		58.1		43.1		54.8	
EOW 3P Frequency	%	EOW_065	51.0		51.0		41.4		47.0	
EOW Defoliation	%	EOW_03	NA	NA	NA	NA	NA	NA	NA	NA
EOW Defoliation	%	EOW_04	8.1	1.22	13.0	1.79	6.2	1.10	11.4	2.90
EOW Defoliation	%	EOW_05	0.2	0.15	16.1	1.84	15.0	1.78	19.6	3.21
EOW Defoliation	%	EOW_065	11.3	1.57	9.0	1.40	1.2	0.82	9.4	2.21
EOW Ground cover	%	EOW_03	NA	NA	NA	NA	NA	NA	NA	NA

EOW Ground cover	%	EOW_04	39.6	1.58	36.2	1.29	37.1	1.47	43.0	3.13
EOW Ground cover	%	EOW_05	52.4	1.94	54.2	1.91	56.4	1.97	51.0	3.52
EOW Ground cover	%	EOW_065	59.0	16.81	72.1	2.08	66.2	2.02	61.5	3.25
EOW Litter cover	%	EOW_03	NA	NA	NA	NA	NA	NA	NA	NA
EOW Litter cover	%	EOW_04	9.7	1.00	9.8	0.74	14.6	1.33	15.9	2.66
EOW Litter cover	%	EOW_05	20.1	1.60	21.4	1.24	31.2	1.92	26.5	3.57
EOW Litter cover	%	EOW_05	13.9	1.38	10.9	1.15	13.45	1.17	14.7	2.82
EOD Total biomass	Kg/ha dry matter	EOD_02	229	19.12	242	12.98	279	20.12	NA	NA
EOD Total biomass	Kg/ha dry matter	EOD_03	43	2.45	77	5.03	40	1.99	85	13.47
EOD Total biomass	Kg/ha dry matter	EOD_04	270	27.01	410	29.56	242	26.92	748	96.57
EOD Total biomass	Kg/ha dry matter	EOD_05	529	31.18	504	32.08	337	20.95	511	59.69
EOD 3P %	%	EOD_02	5.7		23.5		21.5		NA	NA
EOD 3P %	%	EOD_03	16.5		35.1		19.9		53.2	
EOD 3P %	%	EOD_04	20.8		46.8		33.1		44.1	
EOD 3P %	%	EOD_05	33.4		29.3		17.1		27.7	
EOD 3P Frequency	%	EOD_02	64.5		77.3		53.1		NA	NA
EOD 3P Frequency	%	EOD_03	46.4		72.1		46.4		56.2	
EOD 3P Frequency	%	EOD_04	53.2		79.9		61.9		73.8	
EOD 3P Frequency	%	EOD_05	68.6		45.6		46.1		56.7	
EOD Defoliation	%	EOD_02	80.5	1.35	83.2	0.93	78.2	1.54	NA	NA
EOD Defoliation	%	EOD_03	65.3	1.76	66.3	1.68	76.7	1.36	76.1	
EOD Defoliation	%	EOD_04	57.7	2.45	46.0	2.18	47.4	2.20	41.5	
EOD Defoliation	%	EOD_05	12.3	1.63	17.6	1.96	21.8	2.02	14.2	2.98

EOD Ground cover	%	EOD_02	62.1	1.99	73.1	1.63	71.3	2.63	NA	NA
EOD Ground cover	%	EOD_03	32.1	1.21	33.7	1.22	39.6	1.29	33.6	2.43
EOD Ground cover	%	EOD_04	43.9	2.38	48.1	1.86	50.5	1.95	51.9	3.62
EOD Ground cover	%	EOD_05	47.8	2.09	52.0	2.52	46.5	1.87	49.6	3.45
EOD Litter cover	%	EOD_02	22.2	1.20	23.3	1.30	30.0	1.99	NA	NA
EOD Litter cover	%	EOD_03	21.5	1.06	18.8	1.05	27.9	1.23	21.9	2.13
EOD Litter cover	%	EOD_04	24.6	1.92	24.4	1.59	32.1	1.68	27.6	2.29
EOD Litter cover	%	EOD_05	22.0	1.63	22.9	2.10	23.1	1.64	22.9	3.05

Appendix E: Measured and derived landscape and hydrological function values for the range of crusting soil types and vegetation/land types in the upper Burdekin

SITE	LANDTYPE	VEGTYPE	SOILTYPE	VARIABLE	Unit of measure	ABCD Land condition Class							
						A	s.e	B	s.e.	C	s.e.	D	s.e.
Virginia Park	grano-diorite	ironbark/bloodwood	neutral red duplex	ground cover	%	na	na	79.2	3.39	40.9	5.04	5.3	1.41
Virginia Park	grano-diorite	ironbark/bloodwood	neutral red duplex	LFA stability	% of maximum	na	na	69.2	1.84	59.6	0.96	45.7	2.36
Virginia Park	grano-diorite	ironbark/bloodwood	neutral red duplex	LFA infiltration	% of maximum	na	na	30.9	0.94	25.3	1.20	24.1	1.44
Virginia Park	grano-diorite	ironbark/bloodwood	neutral red duplex	LFA nutrient cycling	% of maximum	na	na	27.3	1.59	19.3	1.19	15.4	1.51
Virginia Park	grano-diorite	ironbark/bloodwood	neutral red duplex	predicted infiltration	mm/hr	na	na	237.8	17.21	109.4	18.5	10.6	0.78
Virginia Park	grano-diorite	ironbark/bloodwood	neutral red duplex	predicted respiration	mg CO2/m/hr	na	na	374.5	20.91	220.4	22.89	115.9	1.28
Virginia Park	grano-diorite	ironbark/bloodwood	neutral red duplex	predicted DLI	zero -1 = NL to L	na	na	0.21	0.023	0.56	0.044	0.92	0.078
Blue Range	sedimantary	ironbark/bloodwood	Brown – yellow chromosol	ground cover	%	91.0	1.71	88.8	1.79	63.9	3.05	0.8	0.41
Blue Range	sedimantary	ironbark/bloodwood	Brown – yellow chromosol	LFA stability	% of maximum	75.7	0.48	74.4	0.48	63.5	0.94	43.2	0.68
Blue Range	sedimantary	ironbark/bloodwood	Brown – yellow chromosol	LFA infiltration	% of maximum	37.8	1.34	36.0	0.70	28.0	0.70	20.5	0.21
Blue Range	sedimantary	ironbark/bloodwood	Brown – yellow chromosol	LFA nutrient cycling	% of maximum	30.3	1.83	31.8	0.74	23.3	0.88	13.8	0.54
Blue Range	sedimantary	ironbark/bloodwood	Brown – yellow chromosol	predicted infiltration	mm/hr	66.1	2.48	63.5	2.30	36.3	2.88	10.8	0.03
Blue Range	sedimantary	ironbark/bloodwood	Brown – yellow chromosol	predicted respiration	mg CO2/m/hr	na	na	na	na	na	na	na	na
Blue Range	sedimantary	ironbark/bloodwood	Brown – yellow chromosol	predicted DLI	zero -1 = NL to L	na	na	na	na	na	na	na	na
Wambiana	cainazoic	box	Brown – yellow sodosol	ground cover	%	80.9	3.91	37.5	4.28	21.5	2.84	14.4	2.35
Wambiana	cainazoic	box	Brown – yellow sodosol	LFA stability	% of maximum	68.9	1.50	66.2	0.62	55.6	0.63	55.3	1.08
Wambiana	cainazoic	box	Brown – yellow sodosol	LFA infiltration	% of maximum	35.0	0.84	28.5	0.65	23.7	0.48	22.4	1.38
Wambiana	cainazoic	box	Brown – yellow sodosol	LFA nutrient cycling	% of maximum	28.3	0.97	23.1	0.57	17.4	0.40	18.0	0.98
Wambiana	cainazoic	box	Brown – yellow sodosol	predicted infiltration	mm/hr	na	na	na	na	na	na	na	na
Wambiana	cainazoic	box	Brown – yellow sodosol	predicted respiration	mg CO2/m/hr	na	na	na	na	na	na	na	na
Wambiana	cainazoic	box	Brown – yellow sodosol	predicted DLI	zero -1 = NL to L	na	na	na	na	na	na	na	na
Wambiana	cainazoic	brigalow/claysoils	grey vertosol	ground cover	%	65.8	7.79	29.2	3.46	11.6	3.47	1.6	0.17
Wambiana	cainazoic	brigalow/claysoils	grey vertosol	LFA stability	% of maximum	65.2	1.24	57.4	0.45	53.3	0.51	52.9	0.56
Wambiana	cainazoic	brigalow/claysoils	grey vertosol	LFA infiltration	% of maximum	41.2	1.39	33.5	0.38	32.0	0.56	30.6	0.29
Wambiana	cainazoic	brigalow/claysoils	grey vertosol	LFA nutrient cycling	% of maximum	30.4	2.02	20.9	0.46	17.3	0.96	15.6	0.54
Wambiana	cainazoic	brigalow/claysoils	grey vertosol	predicted infiltration	mm/hr	na	na	na	na	na	na	na	na
Wambiana	cainazoic	brigalow/claysoils	grey vertosol	predicted respiration	mg CO2/m/hr	na	na	na	na	na	na	na	na
Wambiana	cainazoic	brigalow/claysoils	grey vertosol	predicted DLI	zero -1 = NL to L	na	na	na	na	na	na	na	na
SITE	LANDTYPE		SOILTYPE	VARIABLE	Unit of measure	A	SE	B	SE	C	SE	D	SE

Wambiana	cainazoic	silverleaf ironbark	yellow kandosol	ground cover	%	na	na	88.5	6.30	47.3	3.85	36.9	2.57
Wambiana	cainazoic	silverleaf ironbark	yellow kandosol	LFA stability	% of maximum	na	na	67.0	1.22	57.9	0.65	56.5	0.60
Wambiana	cainazoic	silverleaf ironbark	yellow kandosol	LFA infiltration	% of maximum	na	na	33.2	1.14	24.7	0.34	26.0	0.57
Wambiana	cainazoic	silverleaf ironbark	yellow kandosol	LFA nutrient cycling	% of maximum	na	na	24.8	1.51	16.3	0.31	17.6	0.55
Wambiana	cainazoic	silverleaf ironbark	yellow kandosol	predicted infiltration	mm/hr	na	na	na	na	na	na	na	na
Wambiana	cainazoic	silverleaf ironbark	yellow kandosol	predicted respiration	mg CO2/m/hr	na	na	na	na	na	na	na	na
Wambiana	cainazoic	silverleaf ironbark	yellow kandosol	predicted DLI	zero -1 = NL to L	na	na	na	na	na	na	na	na

Note: These are all mid-late dry season measurements base on detailed patch dynamics studies at Virginia Park and Blue Range stations and the Wambiana grazing trial site conducted during 2004-05. As such, they should be used as guidelines only for the purpose of assessing

Appendix F: Development of the PATCHKEY patch classification framework

(Extract from Milestone 5 report NBP.314)

There were four key guidelines in the development of the patch classification scheme:

1) to facilitate patch profiling and distribution studies and to assist in identifying key thresholds in patch landscape function and land condition which relate to leakiness potential, we required a framework for rapid field identification and classification of grazing induced patch types;
2) to relate patch function and distribution to land condition, as defined by the now widely adopted ABCD land condition framework, such a patch classification scheme needed to relate directly to key pasture condition criteria used in that framework;
3) to relate patch condition and function (and by inference ABCD land condition) to potential leakiness it also needed to embrace key drivers of landscape function/soil surface condition;
4) the classification criteria used needed to be easily identifiable and repeatable in the field and have the potential for identification by remote sensing (or relate closely to remote sensed surrogates).

The existing patch classification framework developed by Christian Roth (Roth, 2004) provides robust linkages between soil surface condition, ground cover and infiltration/run-off, however, it does not link easily into other main ABCD pasture and land condition criteria such as pasture form, composition and perennial grass basal area. Moreover, its use of total projected ground cover (TPGC) as a primary classifier, does not take account of differential impact of cover source and type, where TPGC can be 0-100% foliar, 0-100% ephemeral litter or any combination of both. Whilst Roth developed reasonably robust relationships between TPGC and infiltration, especially at high (>75%) and low (<25%) levels, relationships at moderate cover levels (25-75%) were less well defined by TPGC alone (Roth, 2004). This accords with findings from our own previous hillslope and paddock scale studies (see NAP 3.224 final report) that relationships between TPGP and herbage biomass and basal area (directly linked to foliar cover) are often poor, especially where a range of pasture forms (tussock and stoloniferous) are present.

In developing the new patch classification system, we attempted to address these deficiencies whilst keeping the classification criteria as simple as possible. Linkages to ABCD land condition criteria are achieved through inclusion of:

- *pasture form, composition, basal area and total projected cover criteria*

whilst linkages to soil surface condition are achieved through inclusion of:

- *separate foliar and litter cover components and LFA surface erosion and deposition criteria (these represent key drivers of LFA soil surface condition indices)*

The PATCHKEY framework is hierarchical, allowing users to drill down from primary classifiers (pasture form, 3P contribution, PG basal area) to secondary classifiers such as TPGC, foliar and litter cover contribution and erosion/deposition status as follows. It also spans the range of patch resource accumulating) and inter-patch (resource shedding) categories used in both LFA and landscape leakiness approaches.

Primary classifiers – criteria and levels derived from ABCD framework

Parameter	**Level or class**
Dominant pasture form	- tussock, stoloniferous, annual, nil
Dominant pasture component	- 3P, 3P+other pgs, exotic grasses, annuals, nil
Perennial grass basal area	- high, medium, low, nil
Total projected cover	- high, medium, low, nil

Secondary classifiers – criteria and levels derived from LFA SSCA framework

Folia contribution	- high medium, low, nil
Litter contribution	- high, medium, low, nil
Erosion status	- high, medium, low nil
Deposition status	- high, medium, low, nil

Table 43: Conceptual PATCHKEY patch classification – April 2004

Primary (ABCD land condition)				**Secondary (SSC) classifiers**					
Pasture Form	**Dom Group**	**Basal area**	**Total cover**	**Folia contrib.**	**Litter contrib.**	**Erosion extent**	**Deposition extent**	**Patch ID**	**Patch /inter-patch**
Tussock	3P	H	H	H	L	N	N	A1	P
Tussock	3P	H	H	M	M	N	N	A2	P
Tussock	3p+opg	M	H	M	M	N	N	B1	P
Tussock	3p+opg	M	M	M	L	L	L	B2	P
Stolon	exotic	H	H	H	H	N	N	B3	P
Stolon	exotic	H	H	M	M	N	N	B4	P
Stolon	exotic	M	M	M	M	L	L	B5	P
Stolon	exotic	M	M	M	L	L	L	B6	P
Tussock	opg+3p	L	H	L	H	L	L	C1	I/P
Tussock	opg+3p	L	M	L	M	L	L	C2	I/P
Tussock	opg+3p	L	L	L	L	H	M	C3	I
Stolon	exotic	L	H	L	H	M	H	C4	I/P
Stolon	exotic	L	M	L	M	M	M	C5	I
Stolon	exotic	L	L	L	L	H	M	C6	I
Annual	ann+pg	L	H	M	M	M	M	C7	I
Annual	ann+pg	L	M	M	L	M	M	C8	I/P
Annual	ann+pg	L	H	L	H	M	M	C9	I
Annual	ann+pg	L	M	L	M	M	M	C10	I
Annual	ann+pg	L	L	L	L	H	L	C11	I
Annual	anns	N	H	M	H	L	H	D1	I
Annual	anns	N	M	L	M	M	M	D2	I
Annual	anns	N	L	L	L	H	M	D3	I
Nil	nospec	N	N	N	H	M	H	D4	I
Nil	nospec	N	N	N	M	H	H	D5	I
Nil	nospec	N	N	N	N	H	H	D6	I
Nil	nospec	N	N	N	N	H	L	D7	I
Carissa	3P/ ogs	M	H	M	H	N	N	D8	P
Carissa	3P/ ogs	L	M	L	M	N	N	D9	P
Carissa	none	N	H	N	H	L	L	D10	P
Carissa	none	N	M	N	M	L	L	D11	P

For a detailed description and justification of the class values and ranges associated with each classification parameter see the PATCHKEY description document (available from Jeff Corfield at CSIRO). If every permutation and combination within this classification system was allowed for in practice, the number of possible patches would be overwhelming. However, many such combinations and permutations are mutually exclusive. For instance patches with high 3P contribution, PG basal area and TPGC are unlikely to have low foliar cover or high erosion and deposition and vice versa. The hierarchical nature of the classification framework also allows quick elimination of most combinations at the primary, then secondary level. Even so, to keep the number of potential patches at a management level, existing field based knowledge has been used to select the most commonly occurring patch types, especially those representing, key land condition or landscape function thresholds or transitions identified in previous studies.

If we substitute percentage 3P contribution for the pasture form and functional group categories, we can then substitute simple 1-4 values for the nil, low, medium and high categories (where 1-nil/insignificant, 2=low, 3=medium and 4=high) in a similar way to the method used by David Tongway (Tongway and Hindley, 1995) though without the weightings assigned to particular parameters, as is the case for LFA infiltration and nutrient cycling (**Table 44**)
.

Table 44: Conceptual PATCHKEY table with values assigned

PATCH	3P%	PG basal %	Foliar%	Litter%	Erosion	Deposition	Total
A1	4	4	4	3	4	4	19
A2	4	4	3	3	4	4	18
B1	3	3	3	3	4	4	16
B2	3	3	3	2	4	4	15
C1	2	2	2	4	4	4	14
C2	2	2	2	3	3	3	11
C3	2	2	2	2	2	3	9
B3	2	4	4	2	4	4	16
B4	2	4	3	2	4	4	16
B5	2	2	3	2	3	3	12
B6	2	3	3	2	3	3	12
C4	2	2	2	4	3	1	10
C5	2	2	2	3	2	2	9
C6	2	2	2	2	2	2	8
C7	2	2	3	3	3	3	12
C8	2	2	3	2	3	3	11
C9	2	2	2	4	3	3	12
C10	2	2	2	3	2	2	9
C11	2	2	2	2	2	2	8
D1	1	1	3	4	3	2	10
D2	1	1	2	3	2	2	7
D3	1	1	2	1	2	2	6
D4	1	1	1	4	3	2	8
D5	1	1	1	3	2	2	6
D6	1	1	1	2	1	2	4
D7	1	1	1	2	1	1	3
D8	3	3	3	4	4	4	21
D9	2	2	2	3	4	4	17
D10	1	1	1	4	4	4	15
D11	1	1	1	3	3	3	12

This allows a simplistic quantitative conceptual representation of the differences between the various patch types (**Figure 101**), which can be compared to actual measured field values, in order to compare trends.

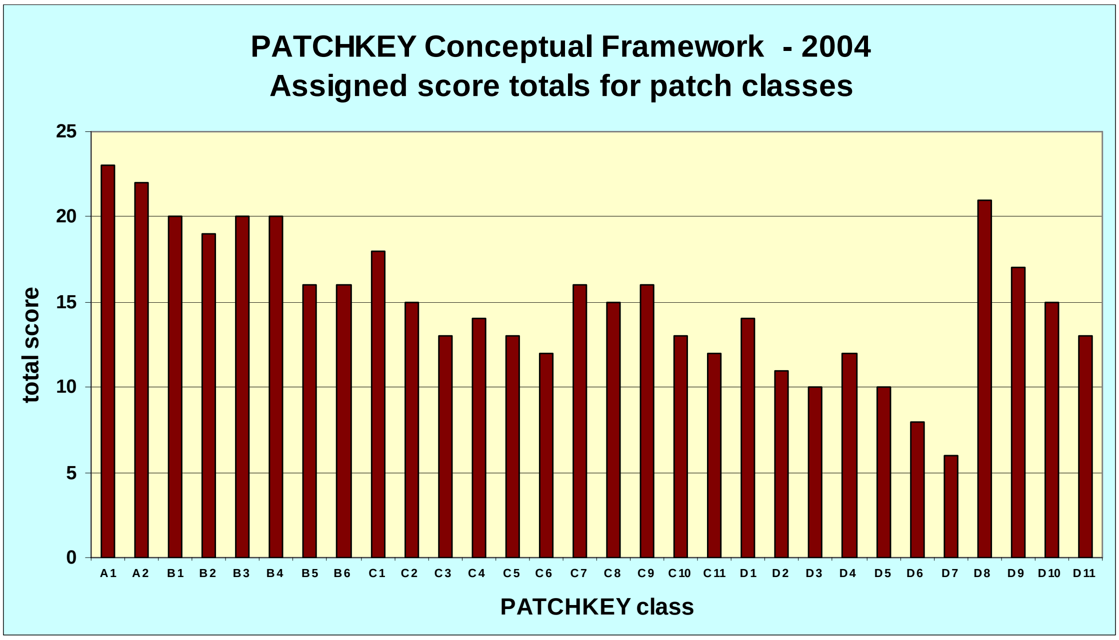


Figure 101: Graphical representation of assigned patch parameter total scores for conceptual PATCHKEY classes.

Field testing and refinement of PATCHKEY framework

A draft version of the conceptual framework was circulated to colleagues within CSIRO and QDPIF for review and comment in early 2004. Subsequent adjustments to both the framework criteria and concepts were made in response to this.

At the same time, field testing and refinement commenced in the following forms

1. *Identification and profiling of a range patches selected from different stocking rate*soil type combinations on the Wambiana grazing trial and existing study sites at Virginia Park.*
2. *Incorporation of PATCHKEY criteria into existing pasture sampling/survey criteria on both the grazing distribution model survey paddocks and Virginia Park flume catchments and study paddocks*
3. *Post-hoc application of PATCHKEY criteria to previously collected data sets from the above sources.*

Patch classification and profiling – Virginia Park and Wambiana

The aim was to test how well the PATCHKEY criteria identified actual represented differences in pasture and landscape function for various patch/soil type/landscape position combinations and to determine whether the existing conceptual array of patch classes needed to be expanded or (hopefully) concatenated.

Replicate patches, covering the range of extant patch types and land conditions, were identified within existing grazing treatment * soil type monitoring sites at Wambiana and within landscape position*soil/vegetation units at Virginia Park flume sites in early-mid 2004. Belt transects (oriented down-slope where applicable) were established across each patch and pasture and soil surface condition data were recorded in 1m^2 contiguous quadrats along each belt transect. This data was then used to derive mean and standard deviation/standard error values for each patch type * soil * landscape position (where applicable). These identified patches are also being used for both on-going monitoring of patch dynamics and more detailed examination of relationships between PATCHKEY type and other measures of landscape health, function and leakiness (including soil respiration, infiltration, ground based digital directional leakiness and infiltration).

Results – Virginia Park patch characterisation Study Site

The charts in **Figure 102** and **Figure 103** indicate the range of LFA derived stability and infiltration values recorded for all patches averaged across all landscape positions. The pattern of values broadly mirrors that shown in the conceptual framework above, with the main variation occurring with the *Carissa* patches[1], due to discount for low 3P % within the conceptual framework. Of the three LFA indices, soil surface stability represents the best comparison (**Figure 104**) , as the SSC component litter and surface resistance values for stability calculation are not weighted, as they are in both infiltration an nutrient cycling calculations.

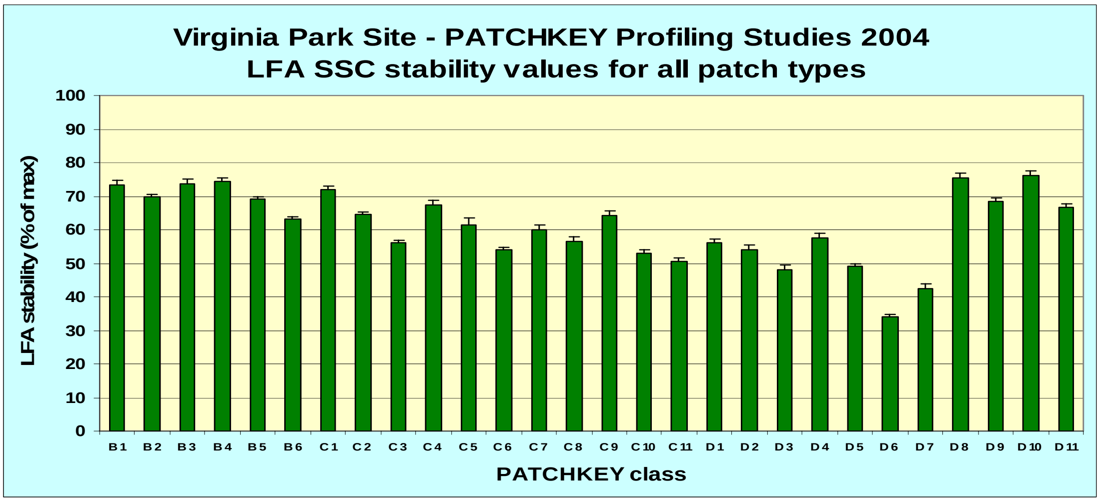


Figure 102: LFA stability values obtained for all PATCHKEY types present at Virginia Park study site, November 2004

1 Though PATCHKEY is an essentially herbage level patch classification framework, all grazed landscapes within the Burdekin catchment contain patches dominated by the native shrub *Carissa*, which, more than any other shrub complex (except for exotic woody weeds such as *Cryptostegia, Parkinsonia and Zyziphus*) forms an integral component of the pasture layer. These patches do not fit easily into this hybrid classification system, but need to be taken account of if we are to develop a predictive relationship between land condition, grazing preference, landscape and leakiness. From the ABCD land condition productivity perspective *Carissa* patches would be indicative of D condition, especially where they are increasing in response to grazing and lack of fire. However, from a landscape function/ biodiversity perspective, such patches are invariable resource accumulating refugia which can sit anywhere between A and C condition. Within PATCHKEY, four *Carissa* patch categories have been included, nominally under condition D, for convenience.
The four *Carissa* categories represent *Carissa* with and without a perennial grass component, with medium-high TPGC and low TPGC.

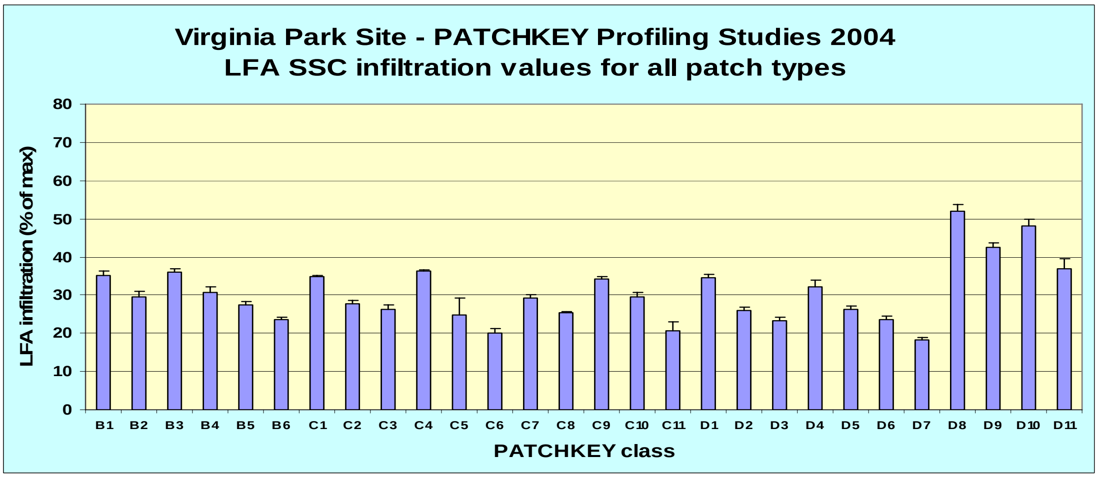


Figure 103: LFA infiltration scores obtained for PATCHKEY types present at Virginia Park study site November 2004

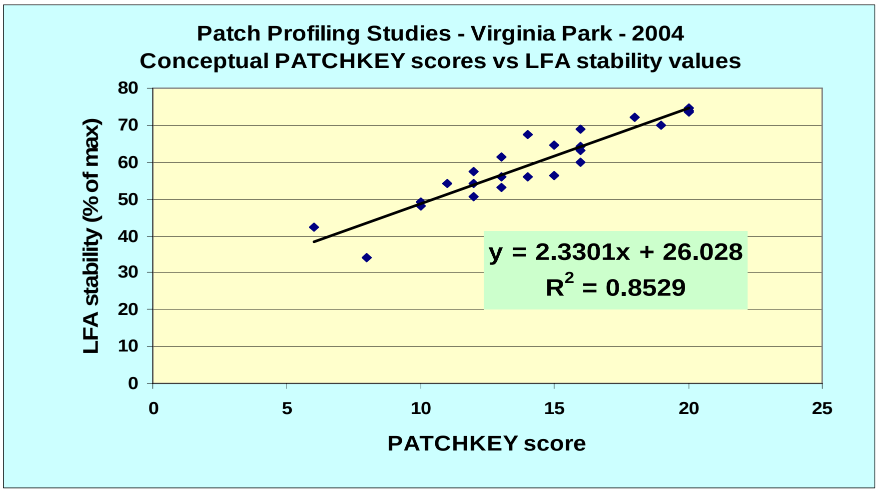


Figure 104: Relationship between conceptual PATCHKEY scores and recorded LFA stability scores from marked patches at Virginia Park study site – November 2004.

Results – Wambiana characterisation study site

The following charts (**Figure 105**) indicate the range soil surface condition values recorded across the range of patch types studied at Wambiana in mid-2004 (data pooled across soil types) The first set of graphs indicate levels of total cover and litter cover.

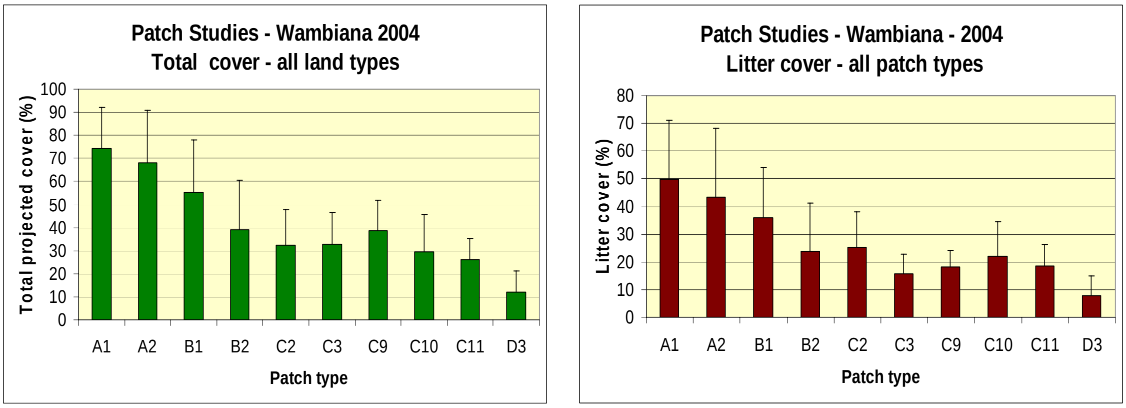


Figure 105: Total projected cover (left) and litter cover values for key patch types in Wambiana patch study, June 2004 (mean and s.d.).

Note that whilst cover generally declines from A to D condition, individual patch types within those classes may vary in terms of component cover levels. Note also the considerable variation in cover levels for individual patch types – a reflection of the fact that patch classification cover criteria (nil, low, medium, high) represent fairly broad ranges. Even so, the calibrated cover levels reflect the PATCHKEY criteria quite well.

The next set of charts (**Figure 106**) indicates LFA derived stability and infiltration values derived from soil surface condition data on these same patches.

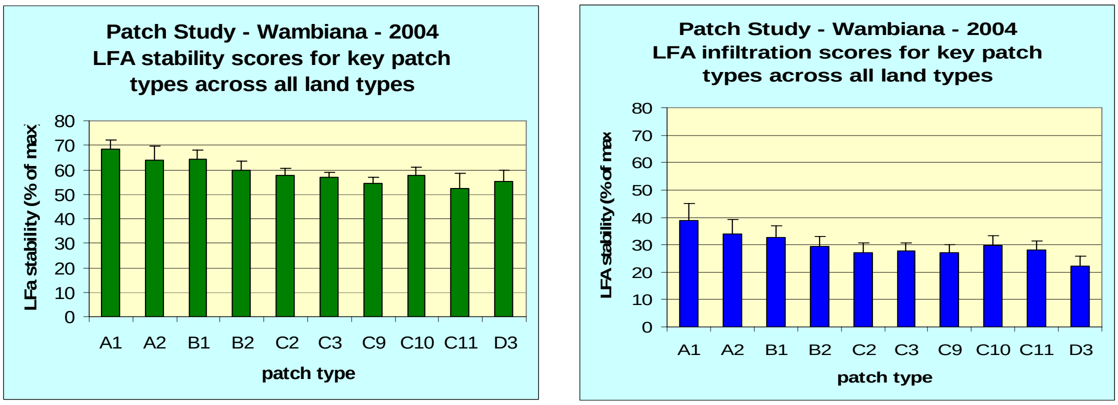


Figure 106: LFA stability and infiltration values (mean and s.d.) for key patch types at Wambiana, June 2004.

Note that with LFA stability, the overall amplitude of patch values and differences between individual patch are less at Wambiana, despite wider separation of patch types indicated by recorded cover values. This reinforces the point that cover alone is not a good indicator of inherent landscape stability, especially in relatively flat topographic environments such as Wambiana. Previous LFA studies at Wambiana have also found that soil surface condition on these soils and topographic environments can remain relatively stable, despite loss of cover, at least in the medium term. LFA derived infiltration (and nutrient cycling) indices do show a greater range, being heavily driven by cover source, level and degree of incorporation. The interaction of soil type and patches on patch values can be seen in the following charts (**Figure 107** and **Figure 108**).

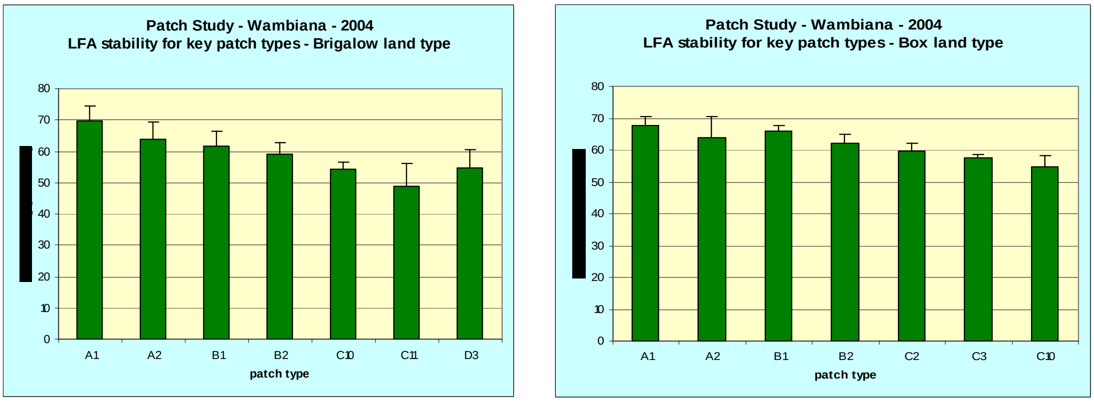


Figure 107: LFA stability values (mean and s.d.) for similar patch types on Brigalow and Box soil/vegetation units at Wambiana Grazing Trial, June 2004.

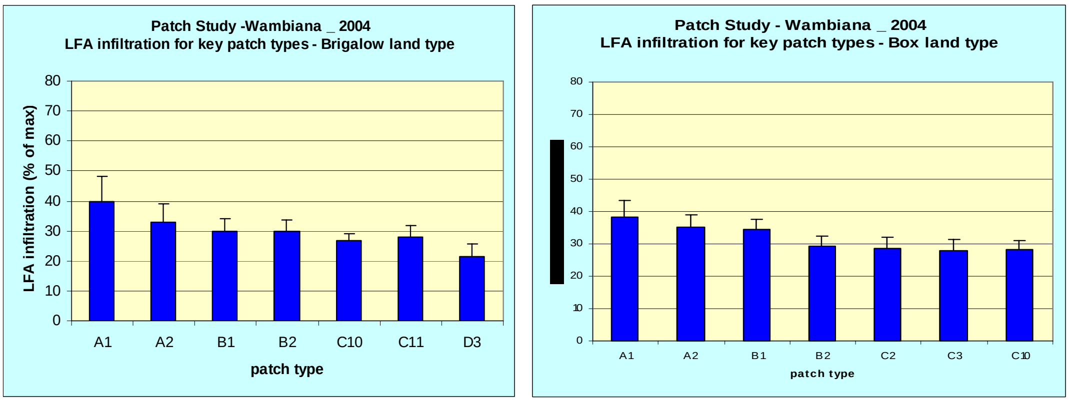


Figure 108: LFA infiltration values (mean and s.d.) for similar patch types on Brigalow and Box soil/vegetation units at Wambiana, June 2004.

At Virginia Park study site, the interaction of landscape position with patch type was examined in a study in February 2004. The following charts (**Figure 109**) illustrate the results obtained. Only small and mostly non-significant differences were recorded between hillslope positions for variables measured in this study, whilst the pattern of LFA infiltration scores across PATCHKEY types broadly mirrored that obtained by Christian Roth in previous studies (Roth, 2003).

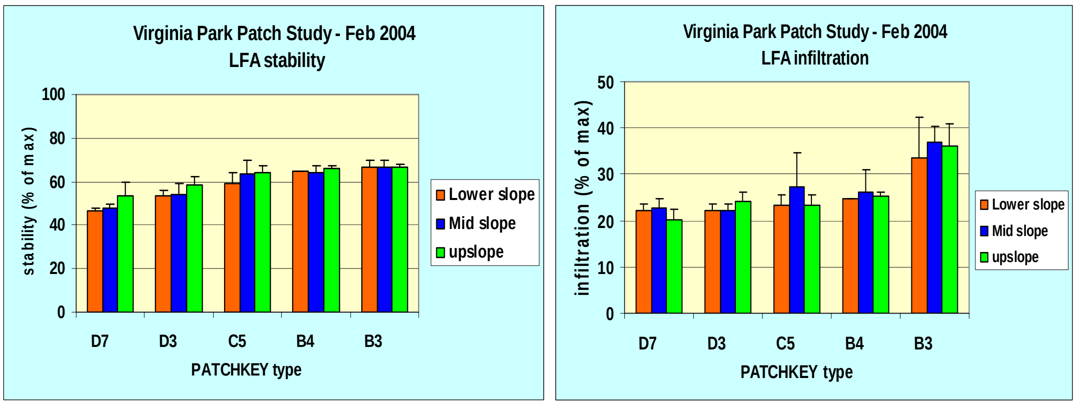


Figure 109: Effect of hillslope position on LFA stability (left) and infiltration (right) values for the same patch types at Virginia Park, February 2004 means and standard errors)

Developing predictive relationships between patch classes and measured infiltration

The above patch profiling and field testing studies indicate that, in terms of landscape function (LFA) values, there was little significant difference (and in some cases overlap) between some of the conceptual PATCHKEY classes within the range of soil types, vegetation communities an landscape positions covered by the study. Whilst further patch profiling on other soil types and vegetation communities will be needed, the prospect of identifying a smaller subset of key patch types representing critical thresholds is promising.

Such a subset of patch types was selected at both Virginia Park and Wambiana for a series of more detailed profiling, conducted from mid 2003 to late 2004, using independent measures such as soil respiration, ground based digitally derived directional leakiness and infiltration. The aim was to develop robust predictive relationships between LFA derived measures of patch condition with various other measures of soil health and hydrological function, to enable calculation of likely patch contribution to leakiness or measured run-off at the hillslope and sub-catchment scale.

The first of these studies involved comparison of LFA, soil respiration and digital leakiness measures of patch condition for a replicated set of marked patches spanning key PATCHKEY thresholds across the range of patches present on the hillslope adjacent to the scald flume site at Virginia Park. The second study involved a repeat of these measurements (plus additional penetrometer and soil nutrient measures) on an expanded set of patches, stratified into three hillslope positions (upslope, mid-slope and lower slope). A third study, conducted on the same site in November 2004, compared both LFA soil surface condition values with measured infiltration for an expanded set of PATCHKEY types, using both ring infiltrometer and hood permeameter. Details of this latter work, conducted in association with CSIRO Land and Water colleagues will be reported in a forthcoming paper by Bartley et al. (2005 in prep.). Similar studies comparing LFA, soil respiration and directional leakiness measures of patch condition have been conducted at Wambiana in 2003-04, whilst a recent study comparing probe measured rainfall infiltration with LFA indices on selected patch types is currently in progress at this site.

For the purpose of this report, results of these studies can be considered together, as they compliment each other and enhance development of the sought-after predictive relationships.

Relationships between LFA indices, total projected cover and soil respiration

Two studies were undertaken during 2003-04 on a range of key patch types existing within the grano-diorite texture contrast hillslopes at Virginia Park. Both examined the relationship between TPGC, LFA derived stability, infiltration and nutrient cycling, soil respiration (a measure of soil biological activity and ground based digitally derived directional leakiness.

The first study was conducted on replicate patches covering the critical points in range of PATCHKEY types existing on the Virginia Park study site (see **Table 45**).

Table 45: Descriptions, PATCHKEY classes and LFA indices for patch types in study

Patch	Description	Rep	stability	infiltration	nutrients
D11	Carissa+bare – med cover , low foliar, med litter	1	51.8	32.4	23.9
D11	Carissa+bare – med cover , low foliar, med litter	2	51.0	32.1	22.8
D7	Bare scald - low cover, high erosion, low deposit	1	40.7	20.1	16.3
D7	Bare scald - low cover, high erosion, low deposit	2	35.0	26.4	14.5
D6	Bare eroded - low cover high erosion/deposition	1	42.9	23.3	18.4
D6	Bare eroded - low cover high erosion/deposition	2	34.7	26.8	13.5
C6	B. pertusa low foliar and litter cover	1	46.0	25.6	20.9
C5	B. pertusa low foliar and litter cover	2	46.0	26.0	20.4
B6	B. pertusa medium foliar and litter cover	1	55.5	27.3	22.5
B5	B. pertusa medium foliar and litter cover	2	57.5	26.7	21.6
B3	B.pertusa high TPC high foliar, med litter cover	1	76.7	32.2	29.0
B4	B. pertusa high TPG med foliar high litter cover	2	71.3	40.5	39.2

Relationship between total projected and LFA stability

Whilst relationships between total projected ground cover and LFA infiltration and nutrient cycling indices have been variable where a range of pasture forms are present, relationship between TPGC and stability have usually been robust, as was the case here. The following charts (**Figure 110**) show the relationship derived from this patch study in 2004 and compares it with the relationship derived from November 2003 paddock survey data at Virginia Park.

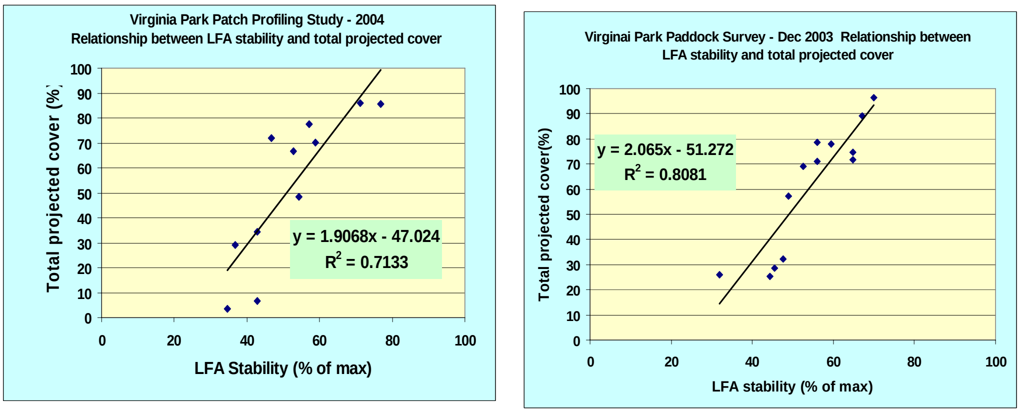


Figure 110: Relationship between LFA derived stability values and total projected cover (left) in patch studies and (right) in paddock studies at Virginia Park

Relationships with soil respiration

Robust relationships between LFA indices, total projected cover and soil respiration (**Figure 111**) were also developed from Virginia Park Studies conducted in 2003-04. The best relationships for soil respiration were obtained with both total projected ground cover and LFA soil surface stability. Relationships with LFA infiltration and nutrient cycling were less robust, probably due to the litter cover and surface hardness weightings used to calculate these indices.

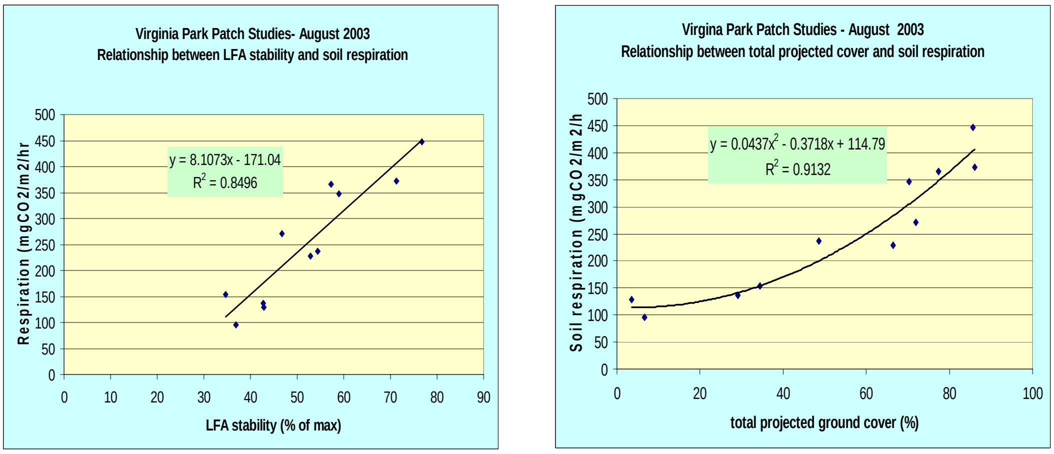


Figure 111: Relationships between measured soil respiration and LFA derived stability (left) and calibrated total projected ground cover (right) obtained at Virginia Park patch study site, August 2003

Relationships with ground based directional leakiness index

Measures of ground based directional leakiness, obtained using a quad bike mounted digital camera were also calculated for key patch types under study at Virginia Park. These measures, taken from 1m belt transects running downslope on each patch, provide a 0-1 index between 0=non-leaky and 1=maximum leakiness. These were also compared with total projected ground cover and LFA stability values obtained for the same patches (**Figure 112**).

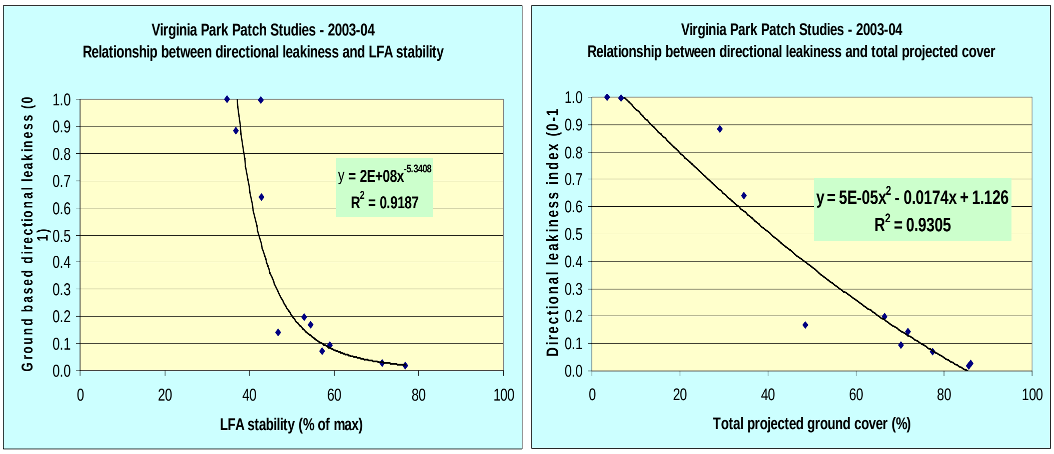


Figure 112: Relationship between ground based directional leakiness and LFA stability (left) and total projected ground cover (right) obtained at Virginia Park patch study site August 2003) Note, leakiness index is a 0-1 scale where 0=non-leaky and 1=very leaky).

Similar results were obtained in the more detailed patch study conducted in February 2004, though overall comparisons were slightly confounded by stratification of replicate patches across landscape positions. Whilst these relationships appear robust for the grano-diorite hillslopes of Virginia Park and similar environments, this work needs to be repeated at other sites before it can be extrapolated across the range of soil types and vegetation communities existing in the catchment.

Relationships between measured infiltration, LFA and cover

The relatively poor relationships derived between LFA infiltration and measured variables such as soil respiration and leakiness, led us to conduct specific infiltration studies on a selection of PATCHKEY types representing critical thresholds, in November 2005, in order to develop a predictive relationship between patch scale infiltration and measured hillslope run-off. Two infiltration measures (ring infiltrometer and hood permeameter) were used to measure potential infiltration in two replicates within each patch. LFA soil surface condition assessment was made of areas immediately surrounding each sampling site by Aaron Hawdon (CSIRO LW) and digital photos were taken to determine total projected cover. In addition, a 1m belt transect was established across each patch in a downslope direction, intersecting the sampling sites. Herbage composition and biomass, TPGC and soil surface condition data were obtained (by Jeff Corfield (CSIRO SE) for each sub-patch area within belt transects, to obtain composite LFA index values for the whole of each patch. This was done for comparison of the relationship between whole patch characteristics and immediate sampling sites.

Results obtained

The combinations of ring infiltrometer and hood permeameter values provided the best relationships with both whole patch and sampling sites (**Figure 113**). The relationship between whole plot SSC infiltration values and sample site SSC infiltration values (**Figure 114**a) was also robust. Differences in slope between the two infiltration relationships are likely brought about by the fact that whole patch values are usually an aggregate of several subtle sub-patch component values, whereas sample site values reflect the immediate area sampled by the infiltrometers. Both relationships are important in helping us understand the impact of surrounding patch conditions, especially upslope conditions, on infiltration potential.

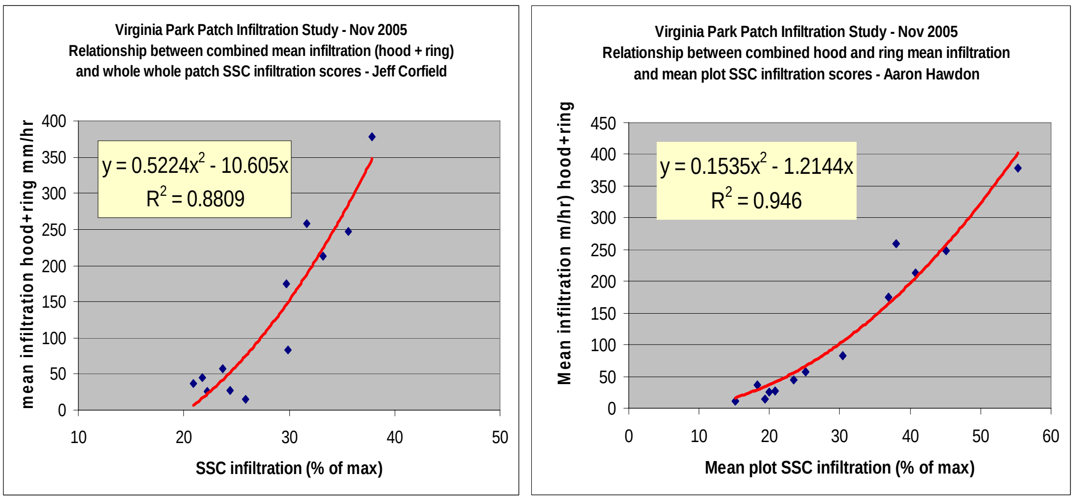


Figure 113: Relationship between measured infiltration (combined ring infiltrometer and hood permeameter) and LFA SSC infiltration values for whole of patch (left) and immediate sampling site (right).

At the Virginia Park study site the relationship between total projected ground cover and measured infiltration was also good compared with previous results from Fanning River and other sites. This was probably assisted by the fact that the site has a fairly uniform soil type (neutral red duplex), vegetation over-story (Ironbark-bloodwood) and pasture type dominated by *Bothriochloa pertusa* over the hillslope sites studied.

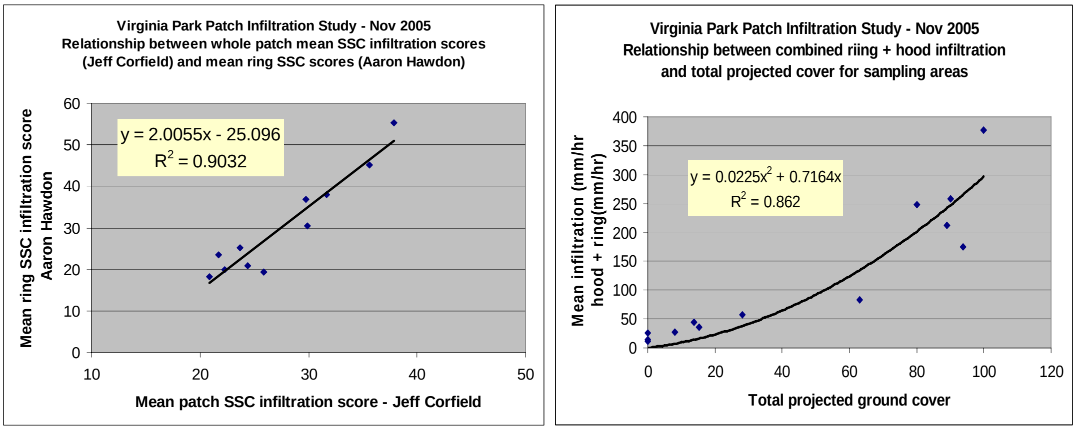


Figure 114: (a) Relationship between whole of patch (Jeff Corfield) and sampling site specific (Aaron Hawdon) LFA SSC infiltration scores on Virginia Park patch infiltration study – Nov. 2005. (b) Relationship between total projected cover infiltration for patch sample sites.

Applying derived relationships to flume and paddock data

Deriving such relationships allows us to apply them to patch types present on the Virginia Park study site in the first instance, and to similar grano-diorite landscapes in the Burdekin catchment. Further studies at other sites will help determine whether such relationships can be applied more broadly across other surface crusting texture contrast soils in the region. The following chart (**Figure 115**) shows calculated infiltration values for PATCHKEY types present at the Virginia Park study site. The above relationships are currently being tested and applied to existing flume hillslope data from the Virginia Park study site, in order to develop relationships between predicted patch infiltration and patch distribution at hillslope scale and measured run-off at flume mouths.

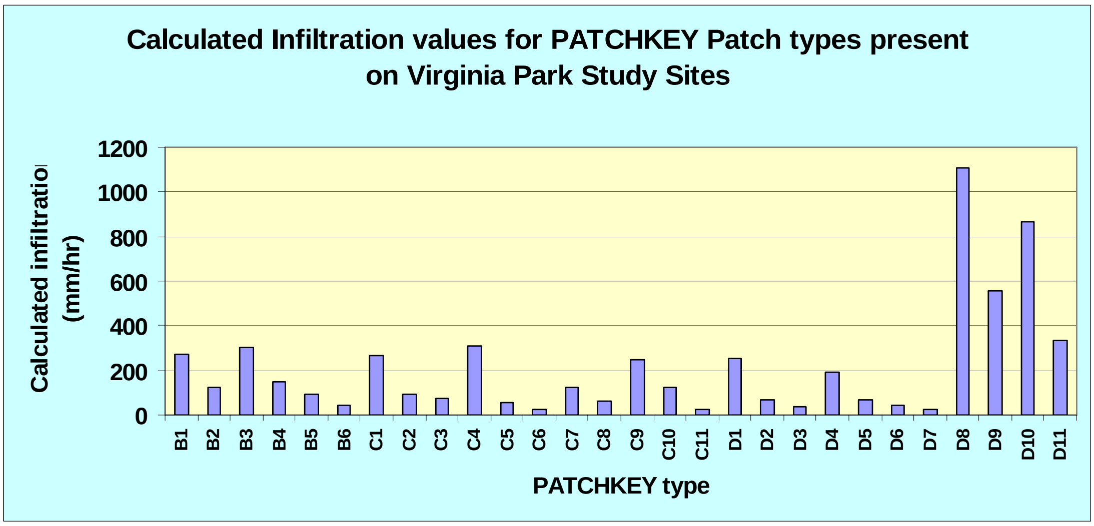


Figure 115: Calculated infiltration rate values for PATCHKEY patch types present on hillslopes at Virginia Park study site.

Appendix G: Detailed descriptions of methods and metrics used in Virginia Park and other grazing / vegetation surveys

Virginia Park paddock grid surveys

Survey grids were established in each of the 4 Virginia Park study paddocks (Aires Top, Aires Bottom, Blackfellas and Stud paddocks) used for testing Ecograze grazing management strategies between 2002 and 2006. In Aires and Blackfellas paddocks paddocks north-south running transects were located at 400m intervals from east to west along the length of the fences. In Stud paddock the transects ran roughly east-west. Sampling points were located every 100m along the length of each transect. Both transect start and end points and sampling points were located each time using a Garmin 12 or 76 GPS. Accuracy of re-locating sampling points was +- 5m in most cases. Paddock surveys were conducted twice yearly at end of wet and end of dry season.

Virginia Park flume hillslope catchment survey grids

A 4m*4m sampling grid was established over each of the three flumes in December 2002. Grid boundaries were located to encompass catchment boundaries identified by initial coarse DEM surveys conducted by CSIRO LW colleagues in October 2002. An adaptive sampling technique was used, whereby sampling density was increased at the edges of patches to better define patch boundaries within the flume catchments. This amounted to 835 points in the large flume, 217 and 461 points in the grassed and scald sites, respectively. Grid boundaries were recorded using a differential GPS and geo-referenced to aerial photographs and preliminary D.E.Ms of each site, to overlay topographic information on the resultant GIS for each hillslope. Maps indicating patterns of biomass cover and other key variables were then generated. This design was used because the areas were relatively small, and the rather dense grid of points provided an excellent database for constructing maps through the process of prediction kriging. We explicitly included sampling points outside the catchment boundary because the measurement error increases dramatically when points are extrapolated (vs. interpolated). Pasture composition, biomass, cover, defoliation and dominant LFA patch type were the key variables recorded. In addition, key individual elements contributing to LFA soil surface condition index (erosion type and severity, deposition type and severity, surface hardness, cryptogam cover, folia cover etc. were scored as a cross-check against assigned LFA patch type categories, derived independently from LFA patch transects.

Flume hillslope grids were modified from 2003-04 on to accommodate refined DEM surveys of catchment boundaries. From 2004 on the survey grid was reduced to transects at 8m intervals from lower to upper slope, but quadrat sampling points remained at 4m centres across the slope along each transect. Adaptive sampling to define patch boundaries was also substituted for recording start and end locations of each patch along transects. The original patch LFA patch descriptions were replaced by PATCHKEY classes after 2004 and previous data re-aligned to PATCHKEY classes. After 2003 only ground cover, litter cover, biomass and PATCHKEY class data were regularly scored.

Table 46: Virginia Park paddock surveys - variables recorded for each quadrat

VARIABLE	METHOD/REFERENCE	UNIT
GPS location		UTMs in WGS84 datum
Calibrated comparative yield estimates	BOTANAL Tothill et al (1978)	Kg/ha dry matter.
3 dominant species/groups in dry weight rank order	BOTANAL Tothill et al (1978)	Species ID number
Composition estimates for 3 dominant species	BOTANAL Tothill et al (1978)	Percentage
Calibrated estimates of foliar +		Percentage
Calibrated estimates of litter cover only		Percentage
Visual rating of defoliation within quadrat, using an un-calibrated 0-5 rating scale	Andrew (1986)	0-5 scale 0=nil, 1=<5% 2=5-25% 3=25-50% 4=50-75% 5=>75%
Classify each quad into one of four basal area classes. Note B. pertusa BA not included in this as not a tussock grass		0-3 scale 0=nil 1=<1% ba 2=1-2.5% 3=>2.5%
Classify quads into one of four dominant erosion types. Erosion feature must affect >25% of quadrat	Tongway and Hindley (1995)	0-3 ID code 0=nil 1=sheet 2=rill 3=gully
Classify erosion into one of four types. Record the most dominant severity present	Tongway and Hindley (1995)	1-4 scale 1=severe 2=moderate 3=slight 4=insignificant
Classify quads into one of four dominant erosion types. Erosion feature must affect >25% of quadrat	Tongway and Hindley (1995)	1-3 ID code1=sand 2=gravel 3=rocks
Classify deposition into one of four types. Record the most dominant severity present	Tongway and Hindley (1995)	1-4 scale 1=severe 2=moderate 3=slight 4=insignificant
Dominant veg community within a 10m radius of each quad location		Numeric ID code 1= IBBW, 2=Carissa/Eromophola 3=riparian 4=box, 5=mixed Euc/shrubby 6=other
Dominant soil or topographic feature within 10m radius of quad		ID number
PATCHKEY class (after 2003)	Corfield and Abbott (2006)	Alpha-numeric ID code

Table 47 species list for paddock and flume hillslope pasture surveys

ID Number	SPECIES
1	Aristida sp (perennial)
2	Bothriochloa decipiens
3	Bothriochloa ewartiana
4	Chrysopogon fallax
5	Dichanthium sp
6	Enneapogon spp
7	Heteropogon contortus
8	Heteropogon triticeus
9	Themeda triandra
10	Sorghum plumosum
11	Other native perennial grasses
12	Bothriochloa pertusa
13	Melenis repens
14	Cenchrus ciliaris
15	Urochloa mosambicensis
16	Other exotic perennial grasses
17	Dactyloctineum spp.
18	Sporobolus spp.
19	Tragus spp.
20	Other annual grasses
21	Legumes
22	Sedges
23	Forbs
24	Panicum spp.
25	Eulalia aurea
26	Dichanthium aristatum
27	Astrebla sp.
29	Digitaria brownii
30	stylo
31	Oxychloris scariosa
32	
33	Eriachne sp
34	Chloris sp
35	Setaria sp
36	

Table 48: Variables recorded for flume hillslope surveys – 2002-05.

VARIABLE	DESCRIPTION / METHOD	REFERENCE	UNIT
FLUME	1=large flume, 2=grassed flume, 3=scald flume		
TRANSECT	in 4m intervals numbered from flume apex upslope		0-240m in 4m intervals
QUADRAT	Quadrat number 1-n numbered from LHS of each flume catchment looking upslope		1-n
SP1	First herbage species in rank order	Botanal percentage rank method (Tothill & Hargreaves, 1978)	Integer 1-26
SP2	Second herbage species in rank order		Integer 1-26
SP3	Third herbage species in rank order		Integer 1-26
SP4	Fourth herbage species in rank order		Integer 1-26
SP1_PC	First species percentage composition		0-100 percent
SP2_PC	Second species percentage composition		0-100 percent
SP3_PC	Third species percentage composition		0-100 percent
DISTANCE	Quad location (placed upslope with LH corner on 4m mark)		metres
YE	Yield estimate of total standing biomass (1-100 rating scale)	Botanal (Tothill & Hargreaves, 1978)	0-100 range
KG_HA_DM	Calibrated dry matter yield		kg/ha D.M.
TOTCOV	Total projected cover (folia+litter+rocks)		0-100 range
LITCOV	Litter cover		0-100 range
CRYPTO	Cryptogam cover		0-100 range
BASAL	Perennial grass basal area category (including pertusa) - 0=nil, 1=0-1%, 2=1-2.5%, 3=2.5-5%, 4=4=5-10%, 5=>10%	Tongway LFA soil surface condition criteria (Tongway et al 1995)	0-5 categorical
HARDNESS	Surface hardness 1=soft sandy; 2=breaks with finger pressure 3=breaks with pen pressure; 4 needs metal implement		1-4 categorical
ERTYPE	Dominant erosion type 0=nil, 1=sheet, 2=rill, 3=gully, 4=pedistal, 5=teracette, 6=scald, 7=hummock		1-7 categorical
ERSEV	Erosion severity 1=extensive, 2= moderate, 3=slight, 4=insignificant		1-4 categorical
DEPTYPE	Dominant deposition type 0=nil 1=sand, 2=gravel, 3=rocks		0-3 categorical
DEPEXT	1=extensive, 2= moderate, 3=slight, 4=insignificant		0-4 categorical
PATCH TYPE	LFA patch type 1=bope1, 2=bope2, 3=bope3, 4=bope4, 5=bope5, 6=ss, 7=sand, 8=ss+sand, 9=litter, 10=ss+litter, 11=Carissa+bope, 12=ss+gravel 13=Carissa+litter * replaced by PATCHKEY class after 2004 – see PATCHKEY description appendix 13		1-15 categorical
CAN_PRES	Status of canopy cover 1=nil, 2=under canopy		1-2 categorical
CAN_TYPE	1=no canopy, 2=live trees, 3=dead trees, 4=live shrubs, 5 dead shrubs (NB. Trees generally Eucs, shrubs includes Carissa, Eremohola, cryptostegia, Acacia and Melaleuca		1-5 categorical
SHRUBS	Presence of shrubs or tree seedlings/suckers rooted in quadrat 1=no shrubs present, 2=shrubs present		1-2 categorical
LOGS	Presence of logs or fallen tree branches within quadrat, which might cause flow obstruction or provide cover 1=no logs, 2=logs present		1-2 categorical
ROCKCOV_PC	Presence of significant rock cover as percentage cover NB rocks defined as greater than 5cm in diameter		percentage
VEG	1= IBBW, 2=Carissa/Eremophola		1-2 categorical
COMMENTS	any additional comments		text

Landscape Leakiness – digital imagery studies

As previously mention a significant effort has been made to develop an efficient ground based digital imagery technique for obtaining quantitative measures of landscape leakiness, which can relate directly to both LFA and hydrological measurements of infiltration, run-off and soil and nutrient loss. This technique has been adapted from a technique developed by Dr. John Ludwig, and others for use in calculating landscape leakiness from satellite imagery (Ludwig et al 2002). Digital photographs are collected using a quad bike to which is fixed an extended boom and remotely operated digital camera, to take photo-quadrats of 4.6m x 3.5m along both intermediate scale transects at Fanning River and LFA patch and transition zone transects at Virginia Park and Wambiana.

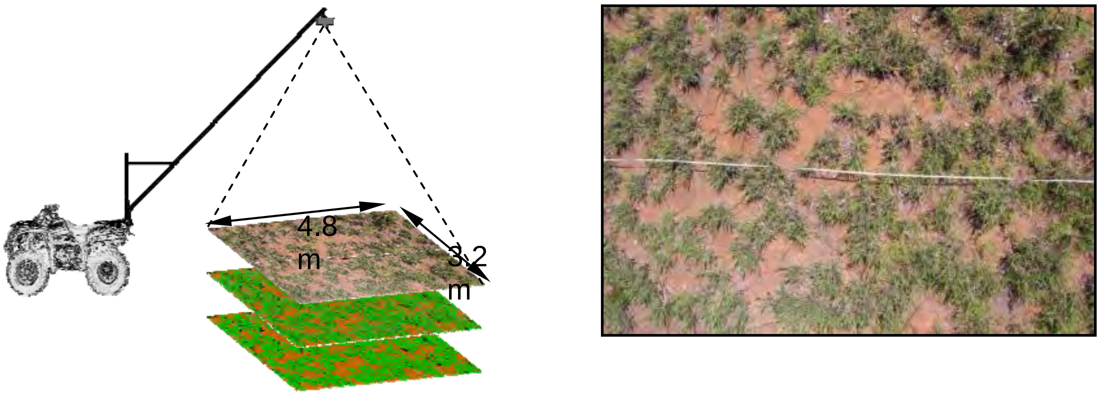


Figure 116: Diagram of procedure for collecting ground based digital imagery (left) and raw image (right).

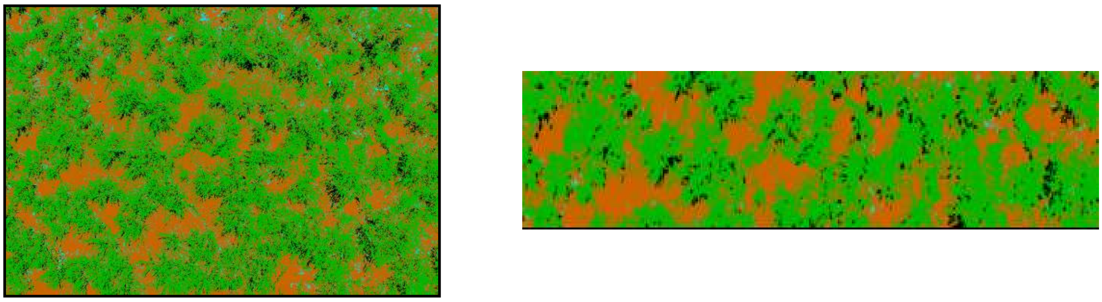


Figure 117: Classified full image (left) and 1m band extracted from that image (right).

Imagery is classified into green foliage, cover and bare ground elements using standard image processing methodology such as ER Mapper supervise maximum likelihood technique. Patterns of bare ground are described quantitatively using statistical distributions and landscape metrics (APACK and FRAGSTATS software packages) to evaluate “leakiness” and ecological function in terms of parameters such as lacunarity, percolation and connectance.

Table 49: Details of analysis procedures for leakiness determination.

VARIABLE	METHOD /DEFINITION	REFERENCE	UNIT
Classification	Supervised maximum likelihood	ER Mapper 6.0	
Green foliage	Foliage greenness		% of image
Cover	Any grass (including green foliage) or litter element.		% of image
Bare ground	Bare earth not covered by a grass or litter element		% of image
Statistical distributions			
Mean, variance etc	Computed from the number of patches (soil and cover) and patch sizes		
Landscape analysis			
Leakiness	Measure of leakiness of a landscape unit	Ludwig et al (2002)	Directional leakiness index (DLI)
Patch metrics	Various descriptive metrics used to describe landscapes. lacunarity, percolation and connectance are a few examples	APACK and FRAGSTATS software packages Descriptive indices	Descriptive indices

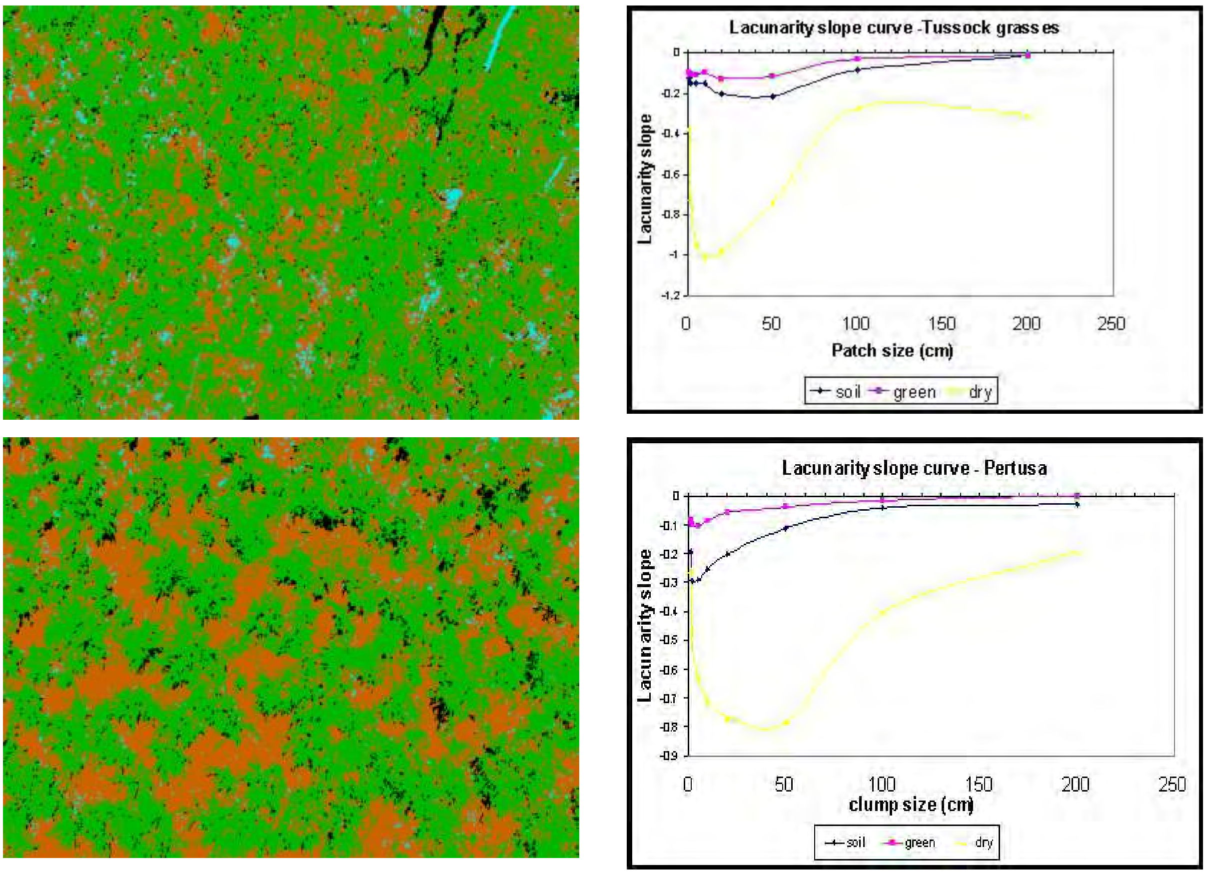
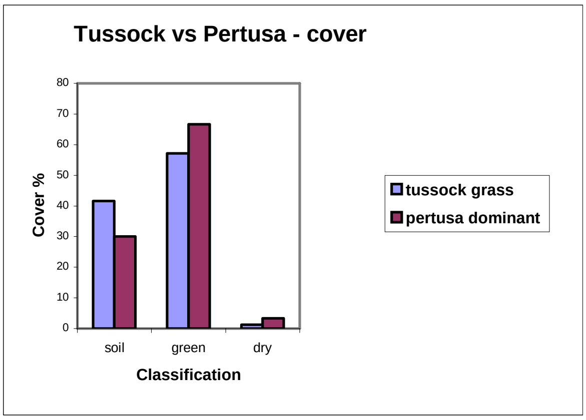
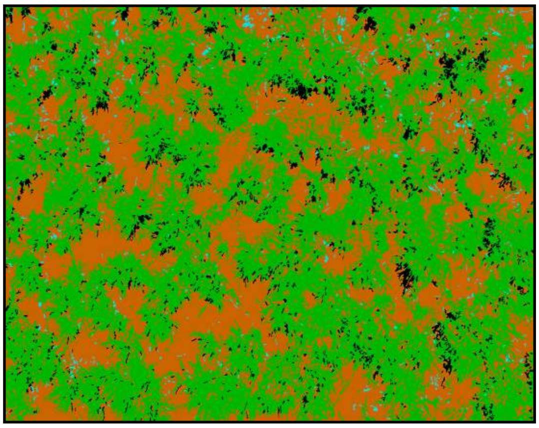


Figure 118: Classified images of Indian couch (B. pertusa) dominated quadrat (top left) and tussock grass dominated quadrat (bottom left), with corresponding lacunarity slope curves (bottom and top right). Shallower slopes for tussock grass images indicate likely homogeneous (and thus more stable) pattern at larger scales, than for the Indian couch. Note: Patch size is expressed in cm of box length for lacunarity.

Patterns of cover at the small-scale can then be related to LFA indices, vegetation type, soil characteristics, defoliation and topography.





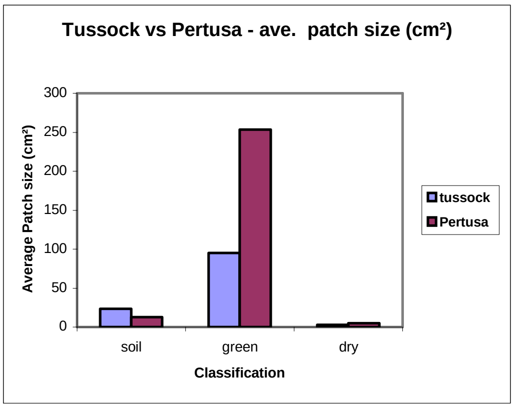


Figure 119: Graphs (right) showing calculated mean patch size for Indian couch (top right) and tussock grass (bottom right) from classified images (left) of Fanning River intermediate scale transects, 2002.

Such classifications can also be used to compare visual estimates of cover obtained from intermediate scale and LFA patch transects and flume catchment sampling grids, providing further cross-scale calibration opportunities.

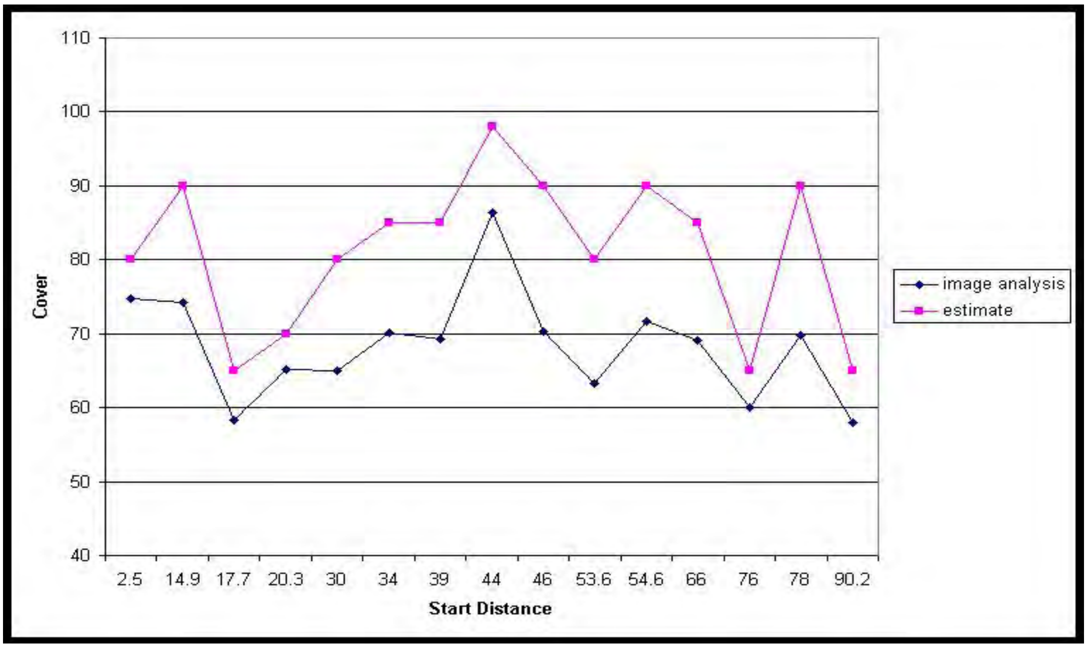


Figure 120: Comparison of cover estimates obtained from digital image analysis vs. visual estimation for the same intermediate transect section at Fanning River, 2002.

Similar techniques were also used to compare digital image derived cover and leakiness scores with LFA derived stability scores for the same key patch types at the Virginia Park flume sites in August 2003. Again good relationships were obtained between digital image derived classified cover and landscape leakiness scores, LFA stability scores and measured soil respiration from the same patch types at Virginia Park. Though much more work needs to be done to develop these relationships, early results are promising.

Component B Paddock scale grazing distribution studies
John Gross model testing and refinement strategies 2004-05

Original component B objective

To verify and refine the ability to forecast the spatial distribution of grazing impacts at paddock scales

This component of the project requires us to address 2 issues:

Test the current model of grazing distribution at the paddock level.
Refine the current model of grazing distribution at the paddock level.

a.) Test the current model of grazing distribution at the paddock level.
This requires a rather low level broad scale survey. 6-8 paddocks will be sampled in the first instance, commencing in wet season 2003/04

A sampled paddock needs to be accessible, large enough to exhibit some reasonable degree of heterogeneity in use (1000ha and above). Some record of previous utilisation rate, which could be derived from information on stocking rates, is necessary. It will be necessary to get information on the location of fence lines, watering points, and other features (areas burned recently, roads, etc.), from paddock maps or aerial survey. Paddocks to be included in grazing distribution studies are listed in **Table 50**.

Table 50: Paddocks identified to date for probable inclusion in the sample set

PROPERTY	PADDOCK	SOIL/GEOLOGY	AREA (HA)
Hillgrove	Plain	basalt	
The Brook	Allingham	basalt	3849 *
Trafalga	Rocky	cainozoic	1375 *
Milray	River	cainozoic	4695 *
Cameron Downs	Spring Creek	grano-diorite	1793 *
Kirkland Downs	Boon Boon	grano-diorite	2700
Hillgrove	Halers	sedimentary	
Blue Range	Springs	sedimentary	2000-3000

* These paddocks are also part of the SCALE project

The main variables in the John Gross' model are burned/unburned, distance to water, distance to a fence, and topography (distance to drainage). So each of the sample points should be GPS referenced & digitised.

For each paddock, there are 6 randomly selected transects from water points and 6 from fences. At each transect initiation point the direction of the transect should be chosen from the pool of 6 x 60^o angles (i.e. 0^o, 60^o, 120^o, 180^o, 240^o, 300^o), ensuring that each angle is drawn no more than once per paddock [water point / fence line] combination. To sample distance from water, sample the response variables (cover, biomass, dominant species composition, erosion attributes, defoliation) at distances of, 10, 20, 50, 70, 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200, 1400, 1600, 1800 & 2000m. If there has been a burn near a watering point, sample at similar distances in both burned and unburned areas. The effect of fences is likely to be much smaller. So for fences, sample as distances of about 2, 5, 10, 15, 20, 30, 50, 100, 200, 400, 500 m from fences. This sampling should be repeated early wet (Nov., Dec.), late wet (Apr., May), mid dry (Jul., Aug.) & late dry (Oct.). Variables to be recorded at each sampling are listed in **Table 51**.

Table 51: Variables to be recorded at each sampling

VARIABLE	DESCRIPTION	TYPE
Paddock ID	Property / paddock code	alpha text
Transect ID	Transect number	alpha-numeric
Sample point	Sample no / distance indicator	numeric
GPS location	Either direct acquisition into palmtop or as waypoint number.	eastings/northings WGS84 datum
Vegetation unit	Broad scale descriptive veg community type	categorical
Soil type unit	Broad scale sol type	categorical
Landscape position	Broad scale location in landscape e.g. ridge/hill top, upper slope, mid-slope, lower slope, riparian	categorical
Slope / aspect	Slope class and aspect descriptor	categorical
Burn status	Record whether recently burnt	Binary/categorical
Herbage biomass	Comparative yield estimate (Botanal)	calibrated visual estimate
Species composition	Dominant 4 species in percent rank order	visual estimate
Defoliation	Visual defoliation rating for dominant species and whole quadrat on 0-5 scale (Andrew, 1986)	visual rating
Basal area	Direct estimate of perennial grass basal area	Calibrated visual estimate
Total projected cover	Direct estimate of total cover (compliment of bare ground)	calibrated visual estimate
Litter cover	Direct visual estimate of litter cover	calibrated visual estimate
Soil surface condition key variables	Score key descriptors of LFA soil surface condition (Tongway & Hindley, 1995) including litter source and incorporation, soil surface resistance, erosion & deposition type and extent	Visual rating as per Tongway & Hindley (1995)

b.) <u>Refine the current model of grazing distribution at the paddock level.</u>
This requires a more detailed survey to assess the factors affecting the distribution of cattle at the landscape level. Again at least 6 paddocks will be required; these can be the same as those surveyed for component a. of this objective. A sampled paddock needs to be accessible, large enough to exhibit some reasonable degree of heterogeneity in use (1000ha and above). Some record of previous utilisation rate, which could be derived from information on stocking rates, is necessary. It will be necessary to get information on the location of fence lines, watering points, and other features (areas burned recently, roads, etc.), from paddock maps or aerial survey. The paddocks should cover a range of climatic (i.e. rainfall) & soil types.

Over each paddock a 1 km x 1 km grid would be drawn. In each paddock, there would be 12 transects. Each of these transects would be randomly drawn from the grid intersections as a starting point. At each transect initiation point the direction of the transect should be chosen from the pool of 6 x 60^o angles (i.e. 0^o, 60^o, 120^o, 180^o, 240^o, 300^o), ensuring that each angle is drawn no more than once per paddock [water point] combination. Each transect should run until it hits a fence. Sampling points on the transect should be occur every 50m and located with a GPS with the broad vegetation community, slope, aspect described. Within the sampling point a 2m*2m quadrat should be randomly placed to the left or right of the transect with the random selection of the upper or lower corner at the point at the 50m mark on the transect. The data measured within each quadrat would include herbage biomass composition, cover, vegetation height, grazing intensity and LFA soil surface condition attributes (see list below). Around each sampling point a 10m radius quadrat should be located to record tree and shrub composition, numbers, cover and breast height girth classes. Data will be scored using a single spreadsheet format as nested quadrats are listed in **Table 52**.

Table 52: Paddock grazing survey data recorded on spreadsheet

VARIABLE	DESCRIPTION	TYPE
A. Common Descriptors		
Paddock ID	Property / paddock code	alpha text
Transect ID	Transect number	alpha-numeric
Sample point	Sample no / distance indicator	numeric
GPS location	Either direct acquisition into palmtop or as waypoint number.	eastings/northings WGS84 datum
Vegetation unit	Broad veg community type	Categorical
Soil type unit	Broad scale soil type	categorical
Landscape position	Location in landscape e.g. ridge/hill-top, upper slope, mid-slope, lower slope, riparian	categorical
Slope / aspect	Slope and aspect descriptor	categorical
Burn status	Record whether recently burnt	Binary/categorical
B. Herbage layer		
Herbage biomass	Comparative yield estimate (Botanal)	calibrated visual estimate
Species composition	Dominant 4 species in percent rank order	visual estimate
Defoliation	Visual defoliation rating for dominant species and whole quadrat on 0-5 scale (Andrew, 1986)	visual rating
Basal area	Direct estimate of perennial grass basal area	Calibrated visual estimate
Total projected cover	Direct estimate of total cover (compliment of bare ground)	calibrated visual estimate
Litter cover	Direct visual estimate of litter cover	calibrated visual estimate
Soil surface condition key variables	Score key descriptors of LFA soil surface condition (Tongway & Hindley, 1995) including litter source and incorporation, soil surface resistance, erosion & deposition type and extent	Visual rating as per Tongway & Hindley (1995)
C. Tree/shrub layer		
Tree and shrub species	Number of each tree an shrub species present	presence/ count
Tree canopy cover	Visual rating of shrub cover class	categorical
Shrub canopy cover	Visual rating of shrub cover class	categorical
Tree basal area	Visual rating of tree basal area class	categorical

This sampling should be repeated early wet (Nov., Dec.), late wet (Apr., May), mid dry (Jul., Aug.) & late dry (Oct.).

Patch studies - details of methods and metrics

Component B objective 2: *Develop a predictive understanding of patch formation and structure at hill-slope scale*

This component of the project requires us to address 2 issues:

1. Measure the patches and relate this to the drivers of the formation of these patches.

2. Describe patch structure on the hill-slope. In order to develop a predictive understanding, we need to be able to determine what biotic and abiotic variables best describe patch structure

1. Measure the patches and relate this to the drivers of the formation of these patches.

The emphasis of Component B of the MLA project is to understand how grazing interacts with biotic and abiotic variables in space and time to affect patch formation. This will require a much greater understanding of the dynamics of individual patch types. At the top level it is necessary to determine the change of a patch from one state to another. This would mean the comparison of the fate of patches within the same context, i.e. which have received the same treatment.

A patch is defined as a clearly defined vegetation unit, which is homogeneous. It is bounded by patches of vegetation, which differ from it in state. The homogeneity could be on the basis of species composition, biomass or height (or an interaction between these, obviously if it is an interaction then we increase the number of patch types we have). Homogeneity will be characterised by features which link landscape structure with landscape leakiness. From previous work the main determinant of landscape leakiness appears to be of cover (folia, litter), presence of perennial grass, soil surface condition, erosion. Indian couch seems to cause a different functional relationship between landscape leakiness and cover. Therefore, in the context of this project patches will be defined in terms of an interaction between landscape function (soil surface condition) and pasture condition. Specific patch definitional criteria and thresholds are being developed, drawing on input from within the project team and beyond. Such definitions and thresholds will be clear, robust and repeatable (see Proposed Patch Classification System – Jeff Corfield, April 2004)

Three paddocks would be chosen at Virginia Park (linked / flume studies), Fanning River Mt Success paddock (site of existing intermediate scale patch studies) and Wambiana, which contrast in grazing management treatment (i.e. low grazing pressure, high grazing pressure, wet season spelled). The fate of patches will be determined on a within- paddock basis, with repeated survey of specific, individually known patches. 6-10 patches of each main patch type would be located within each paddock. The location of the marked patches would be randomly drawn from a broad level survey of patches located in part 2) of the sampling procedure (see below). If there are no examples of a patch type in the paddock at the start these would be added as they occur. Detailed patch scale data to be collected is found in **Table 53**.

Table 53: Details of whole patch study metrics and methods

VARIABLE	DESCRIPTION	TYPE
A. Whole Patch data		
Paddock ID	Property / paddock code	alpha text
Transect ID	Transect number	alpha-numeric
Patch type	Predetermined patch type or category based on landscape function / pasture condition criteria	categorical
Patch ID	Individual patch ID number for each patch type	numeric
GPS location	Either direct acquisition into palmtop or as waypoint number.	eastings/northings WGS84 datum
Vegetation unit	Broad scale descriptive veg community type	categorical
Soil type unit	Broad scale sol type	categorical
Landscape position	Broad scale location in landscape e.g. ridge/hill top, upper slope, mid-slope, lower slope, riparian	categorical
Slope / aspect	Slope class and aspect descriptor	categorical
Patch size	Perpendicular maximum length and breadth (m)	Direct measure
Burn status	Record whether recently burnt	Binary/categorical
B. Quadrat data	Scored in 1m contiguous quads along max length	
Herbage biomass	Comparative yield estimate (Botanal)	calibrated visual estimate
Mean herbage height	Mean patch pasture height	Direct measure (cm)
Species composition	Dominant 4 species in percent rank order	visual estimate
Defoliation	Visual defoliation rating for dominant species and whole quadrat on 0-5 scale (Andrew, 1986)	visual rating
Basal area	Direct estimate of perennial grass basal area	Calibrated visual estimate
Total projected cover	Direct estimate of total cover	calibrated visual estimate
Litter cover	Direct visual estimate of litter cover	calibrated visual estimate
Soil surface condition key variables	Score key descriptors of LFA soil surface condition (Tongway & Hindley, 1995) including litter source and incorporation, soil surface resistance, erosion & deposition type and extent	Visual rating as per Tongway & Hindley (1995)

These patches are measured in April/May (post-wet season) and in October (pre-wet season).

2. Describe patch structure on the hill-slope.

In order to develop a predictive understanding, it is necessary to be able to determine what biotic and abiotic variables best describe patch structure. At least 6 paddocks for which we have stocking level and fire data, over the past say, 10 years (these may include paddocks from the grazing distribution study, the Wambiana grazing trial or Virginia Park study). These paddocks should cover a range of biotic and abiotic circumstances and it will be necessary to get information on the location of fence lines, watering points, and other features (areas burned recently, roads, etc.), from paddock maps or aerial survey. The paddocks should cover a range of climatic (i.e. rainfall) & soil types.

Sampling will be based upon randomly located belt transects where we determine the size, frequency/cover of the various patch types described above, and determine their relationships to biotic and abiotic factors. Variables to be recorded in transect based patch surveys can be found in **Table 54**.

Table 54: Variable and methods for recording for hillslope patch size/frequency study

VARIABLE	DESCRIPTION	TYPE
A. Whole Patch Data		
Paddock ID	Property / paddock code	alpha text
Transect ID	Transect number	alpha-numeric
Patch start and end location	Either GPS position or direct tape based measurement. (m, cm)	eastings/northings or direct measure
Patch type	Predetermined patch type or category based on landscape function / pasture condition criteria	categorical
Vegetation unit	Broad scale descriptive veg community type	categorical
Soil type unit	Broad scale sol type	categorical
Landscape position	Broad scale location in landscape e.g. ridge/hill top, upper slope, mid-slope, lower slope, riparian	categorical
Slope / aspect	Slope class and aspect descriptor	categorical
Patch width	Maximum patch width (m, cm)	Direct measure
B. Within Patch Data	Recorded every 2m if patch < 5m, every 5m if patch <20m and every 10m if patch >20m	
Burn status	Record whether recently burnt	Binary/categorical
Herbage biomass	Comparative yield estimate (Botanal)	calibrated visual estimate
Mean herbage height	Mean patch pasture height – take at leat one measurement per linear 5m of patch length where patches are >10m or one measure/10m where >10m	Direct measure (cm)
Species composition	Dominant 4 species in percent rank order	visual estimate
Defoliation	Visual defoliation rating for dominant species and whole quadrat on 0-5 scale (Andrew, 1986)	visual rating
Basal area	Direct estimate of perennial grass basal area	Calibrated visual estimate
Total projected cover	Direct estimate of total cover (compliment of bare ground)	calibrated visual estimate
Litter cover	Direct visual estimate of litter cover	calibrated visual estimate
Soil surface condition key variables	Score key descriptors of LFA soil surface condition (Tongway & Hindley, 1995) including litter source and incorporation, soil surface resistance, erosion & deposition type and extent	Visual rating as per Tongway & Hindley (1995)

These measurements will have to be made on a seasonal basis e.g. once in the wet (April/May) & once in the dry (October).

LFA Transects – Main flume (flume 1) Aires Bottom paddock, Virginia Park

Landscape function analysis (LFA) (Tongway and Hindley, 1995) was seen as a key tool to link observed land condition impacts to hydrological function. LFA had already been used to develop linkages between soil surface condition and measured infiltration in NAP 3.224.

LFA transects were established on key patch and transition areas both within flume catchments and on adjacent hillslopes in November/December 2002, to characterise patches in terms of LFA soil surface condition parameters and derived stability, infiltration and nutrient cycling indices. Fifteen LFA transects were established across the range of patch types and transitions stratified across upper, middle and lower slope sections of flume catchments to monitor changes in landscape function over time. Transects varied in length from 10-25m depending on the size of patches and transition zones covered. A further 15 transects were established on key patch types adjacent to flume 3 (scald flume), specifically to characterise patch types in terms of both LFA and other independent measures such as soil respiration and landscape leakiness (described later). They were placed outside the flume sites to avoid undue disturbance to flume catchment areas by regular LFA and other calibration measurement activity.

These patch transects are scored using standard LFA recording techniques (Tongway and Hindley, 1995) at both end of wet / early dry season and end of dry season. Mean LFA stability, infiltration and nutrient cycling indices are subsequently derived for both patch / interpatch “query zones” identified along transects and transects as a whole entity, using standard LFA calculations, as shown in the following example.

These patch and inter-patch “query zones” are then used to categorise flume grid quadrats according to dominant LFA patch type, during contemporaneous grid surveys..

Appendix H: Managing Recovery: Tools for sustainable grazing in the Burdekin catchment

The following series of brochures, *Saving for a Rainy Day, The Patchy Path to Recovery, Wet Season Spelling, and the Upper Burdekin ABCD Land Condition Framework* were distributed to all graziers in the Burdekin catchment in mid-2007 as part of an information pack for graziers titled *Managing Recovery: Tools for sustainable grazing in the Burdekin catchment.*