GRASP modelling of grazing systems in Great Barrier Reef catchments

Technical Report to Paddock to Reef Integrated Monitoring, Modelling and Reporting program funded through the Australian Government's Caring for Our Country Reef Rescue

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1.0 Introduction

Extensive modification of the Great Barrier Reef (GBR) catchments for agricultural production and urban settlement over the last 150 years has resulted in sediment and nutrient loads in rivers increasing 6-9-fold (Brodie *et al.* 2012, Kroon 2012, Kroon *et al.* 2012) and led to a decline in the water quality entering the GBR lagoon (Furnas 2003, De'ath and Fabricius *et al.* 2010).

In response to the decline in reef water quality, and to ensure the GBR is resilient to the stresses of a changing climate, a joint Queensland and Australian government initiative introduced the Reef Water Quality Protection Plan (2003, 2009) (Department of the Premier and Cabinet 2009). The Reef Water Quality Protection Plan (Reef Plan) was built on existing programs and initiatives. The aim of the Reef Plan was to develop a coordinated and collaborative approach to improving water quality in the GBR through improved land management in catchments adjacent to the reef. The two primary goals of the the Reef Plan were to halt and reverse the decline in water quality entering the reef by 2013; and to ensure that by 2020 the quality of water entering the reef from adjacent catchments has no detrimental impact on health and resilience of the Great Barrier Reef (Department of the Premier and Cabinet 2009).

A key action of Reef Plan 2009 was the development and implementation of the Paddock to Reef Integrated Monitoring, Modelling and Reporting (PRIMMR) program. The objective of the PRIMMR, or Paddock to Reef Program, was to both influence and change on-farm management practices through incentives and policy (Carroll *et al.* 2012), and to measure and report on the progress towards the Reef Plan goals. A suite of management practice, catchment condition and water quality targets were identified to achieve the Reef Plan goals (Department of the Premier and Cabinet 2009).

The Paddock to Reef Program is monitoring and modelling non-point source pollution from broad-scale land uses (grazing, grain, sugar cane, horticulture) in 35 basins of the GBR catchment. These basins drain an area of 423,000km^2 from Cape York in the north to the Burnett Mary region in the south (Carroll *et al.* 2012). Grazing is the predominant land use (77%) in the GBR catchments (DSITIA 2012) and has explicit Reef Plan water quality and management practice targets (see Queensland Government 2011, Carroll *et al.* 2012). Monitoring and modelling of grazing systems at the paddock and catchment scales informs four lines of evidence that support annual reporting and which provide links between management practices, water quality and reef health (Carroll *et al.* 2012). Improvements in water quality through the adoption of improved grazing management practices (as defined under the ABCD framework) is determined by linking 'paddock' model time-series outputs to 'catchment' models (Carroll *et al.* 2012). The paddock models provide a level of processing detail compatible with the management practice investments and on-ground implementations.

Describing grazing management principles and systems within an ABCD framework relevant to soil, nutrient and herbicide management is critical to reporting on progress towards water quality and management practice targets (Carroll *et al.* 2012). Management of grazing systems, through a wide spectrum of practices, is directed at the optimal production and use of forage to ensure goals for livestock production and health of the land are met (Quirk and McIvor 2003). Managing utilisation of pasture (timing, amount and evenness of pasture use) is an important determinant of the amount and quality of forage consumed by livestock, the severity of defoliation of pasture plants and the effects of livestock on the soil (Quirk and McIvor 2003, McIvor 2010). As such, matching stocking rates to feed supply is the fundamental management issue for any grazing enterprise, and one that affects livestock productivity and future condition and productivity of the land (Heitschmidt and Taylor 1991; Ash and Stafford Smith 1996), and ultimately the sustainability and profitability of the enterprise.

Increases in grazing pressure have been associated with a decline in land condition (Tothill and Gillies 1992, McKeon *et al.* 2004) and loss of desirable perennial grasses (Winter *et al.* 1989, Hacker and Tunbridge 1991, Mott *et al.* 1992, Day *et al.* 1997a, Ash et 2001), a decrease in forage production (McIvor *et al.* 1995a, Ash *et al.* 1997), lower ground cover (Scanlan and McIvor 1993), soil surface sealing (Mott *et al.* 1979) and increased runoff and soil loss (McIvor *et al.* 1995b, Scanlan *et al.* 1996). Perennial grasses not only provide the bulk of herbage but they are also important for providing ground cover (Ash *et al.* 1997). Ground cover is a dominating factor in determining the amount of surface run-off and hillslope soil loss from grazing lands (Gardener *et al.* 1990, McIvor *et al.* 1995b, Scanlan *et al.* 1996, Silburn *et al.* 2011), with cover having a strong curvilinear effect on total soil loss (Silburn *et al.* 2011). In the Paddock to Reef Program framework ground cover is an important variable that is used both to report on the specific ground cover target of 'minimum of 50% late dry season groundcover on dry tropical grazing land 2013' (Department of the Premier and Cabinet 2009), and as a data layer to derive the C-Factor in the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.* 1977) for the catchment modelling (Carroll *et al.* 2012).

The GRASP pasture growth model (McKeon *et al.* 2000, Rickert *et al.* 2000) has been applied at the point, paddock, property and regional scales (e.g. Day *et al.* 1997a, Carter *et al.* 2000, Stokes *et al.* 2012) and has been used to evaluate a wide range of grazing management issues from assessing safe carrying capacities (Scanlan *et al.* 1994, Johnson *et al.* 1996) and land degradation (Owens *et al.* 2003, Chilcott *et al.* 2004), to evaluating the impacts of climate variability and climate change and management practices (e.g. Hall *et al.* 1998, McKeon *et al.* 1988, McKeon *et al.* 2008, Scanlan and McIvor 2010, Pahl *et al.* 2011, Whish *et al.* 2012) on extensive grazing lands. The GRASP model was recently modified to enable simulation of key grazing management practices (stocking rate strategies, spelling and use of fire) that were examined in the Northern Grazing Systems Project (see Scanlan and McIvor 2010).

Limitations of the model are well documented (Day *et al.* 1997a, Littleboy and McKeon 1997) although the model deficiencies are not regarded as a major limitation to accurate simulation of degradation risks (Day *et al.* 1997a). The model allows for the simulation of the risks of production losses but, as there are no feedbacks of soil loss on nutrient availability or infiltration, not the long-term consequences of taking those risks (McKeon *et al.* 2000).

The primary purpose of this report is to describe the GRASP paddock modelling that was undertaken to provide time-series ground cover data for use in the Paddock to Reef Program grazing industry 'catchment' models. A brief examination of the influence of climate, grazing pressure and land type on pasture growth, surface cover, runoff and soil loss is also provided.

2.0 Methods

2.1 Study Area

The Great Barrier Reef is listed as a World Heritage Area and covers two-thirds of the east coast of Queensland (Great Barrier Reef Marine Park Authority 2009). Grazing is the predominant land use (77%, DSITIA 2012) across the six Natural Resource Management (NRM) regions in the GBR catchment considered in the Paddock to Reef Program (see Figure 1). Grazing land types with characteristic patterns of soil, vegetation and landform have been described (Whish 2011) and spatially represented (DERM 2011) to provide grazing land managers with practical information to help assess land condition and carrying capacities and inform stocking rate and other management decisions.

2.2 GRASP model

2.2.1 Pasture growth and soil water balance

Simulation modelling was used to determine the impacts of grazing pressure, climate, pasture condition and trees on grazing land types within the NRM regions. Biophysical data were derived using the empirical, point-based native pasture model GRASP that was developed for semi-arid and tropical grasslands (Day *et al.* 1997a, Littleboy and McKeon 1997, McKeon *et al.* 2000, Rickert *et al.* 2000). Growth of pasture is a function of soil water, potential growth rate, transpiration, nitrogen availability, temperature and tree competition (Day *et al.* 1997a, Littleboy and McKeon 1997). Pasture growth in summer rainfall environments is either limited by moisture or soil fertility, primarily nitrogen (McKeon *et al.* 2000). Standing pasture yield is the net result of the processes of pasture growth, death, detachment, consumption and trampling (McKeon *et al.* 2000). The model simulates soil water balance through separate processes of soil evaporation, pasture transpiration (Rickert and McKeon 1982), tree transpiration (Scanlan and McKeon 1993) and runoff (Scanlan *et al.* 1996). Rainfall is partitioned into infiltration and runoff using functions that relate runoff to surface cover, soil moisture and rainfall intensity. Runoff is calculated and then any rainfall that exceeds predicted runoff is infiltrated into the soil profile.

2.2.2 Heavy utilisation

High grazing pressure reduces grass basal area, photosynthetic area, potential pasture growth and surface cover; with subsequent increases in runoff and soil loss, and reductions of available nutrients for plant growth. Other effects of high grazing pressure include reduced fuel loads, fewer fires and increases in survival of woody weeds and tree seedlings (McKeon *et al.* 2000). The majority of these feedback effects are captured in the GRASP model.

The GRASP model was recently adapted to enable the processes of pasture degradation and certain aspects of grazing management to be simulated in a more realistic manner (Scanlan and McIvor 2010, Scanlan *et al.* 2011a, b). Major modifications to the model allow simulated changes in grass basal area, and a weighted utilisation, to be applied on a monthly basis (Scanlan and McIvor 2010, Scanlan *et al.* 2011b) to account for the known biological response to grazing during the growing season (Mott *et al.* 1985).

The original 'heavy utilisation' sub-model was developed to specifically capture the changes in pasture composition (perennial to annuals) (McKeon *et al.* 2000). In GRASP percent perennial grass is used as an indicator of condition along an integer scale originally derived by Ash *et al.* (1996) from observed data (McKeon *et al.* 2000). The condition of the resource (percent perennials) can now be indicated by any real number (Scanlan and McIvor 2010, Scanlan *et al.*

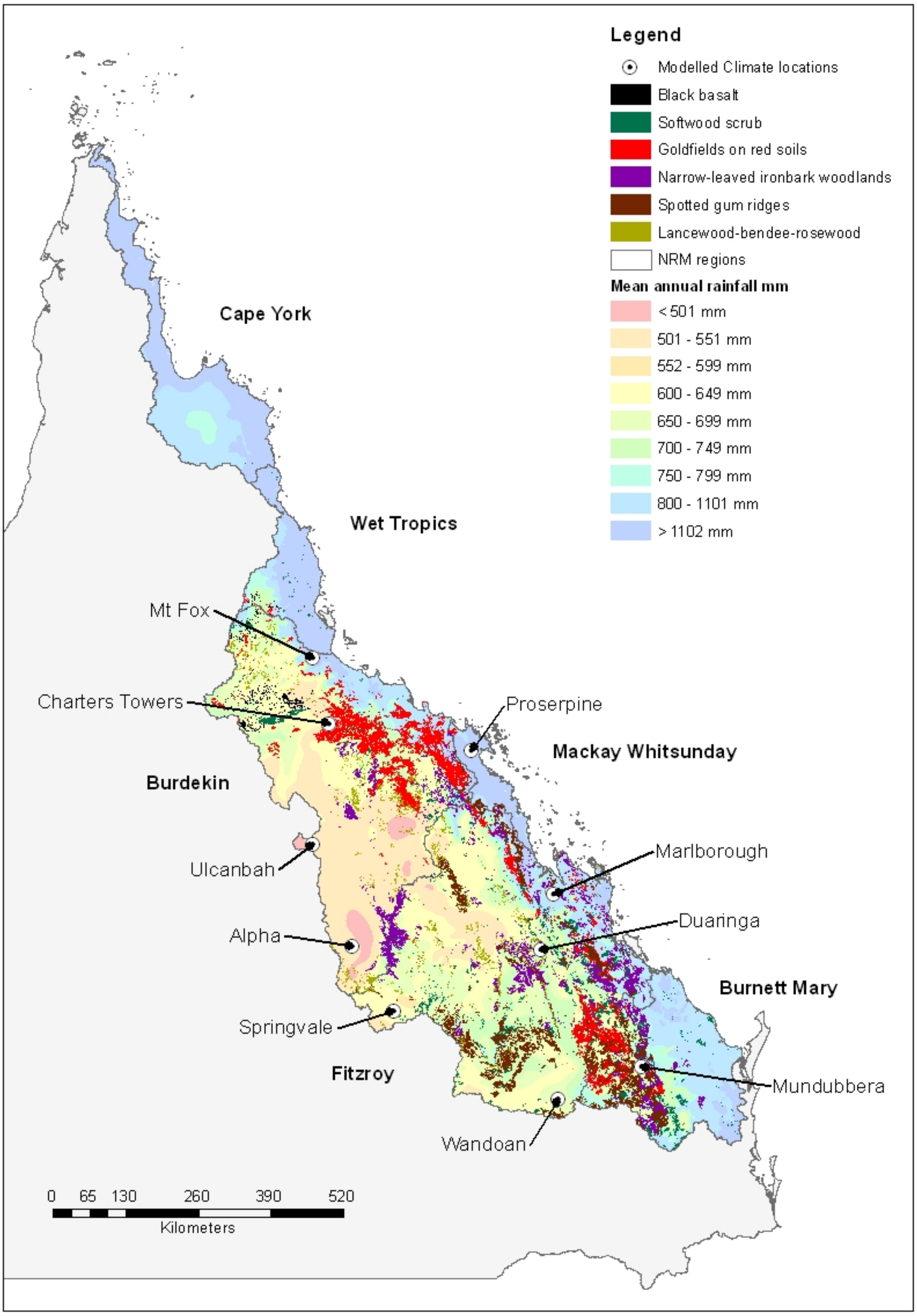


Figure 1. Ten climate locations and six land types modelled in the Paddock to Reef program within the six Natural Resource Management regions of the Great Barrier Reef catchment. Mean annual rainfall (mm) is also shown.

2011b) between 0 and 11. Using this representation, the extreme pasture conditions are a lightly grazed land type in excellent condition that is represented by State 0 (90% perennial grass) and a heavily grazed land type with degraded pastures that is represented by State 11 (1% perennial grass). The State of a land type can change up and down between these extremes in response to different utilisation rates. Recent refinement (Scanlan and McIvor 2010, Scanlan *et al.* 2011b) to the relationship between utilisation and the dynamically linked parameters (Table 1) that represent a pasture in excellent and poorest condition allows the potential rate of change between states for degradation or recovery to be defined (Scanlan and McIvor 2010, Scanlan *et al.* 2011b).

Table 1. GRASP model parameters that represent the best (State 0) and worst (State 11) pasture conditions, and the relationships between these States, used to simulate heavy utilisation and loss of desirable perennial grasses.

Parameter name	Parameter value	Relationship between values in State 0 and State 11
Initial pasture condition	0 to 11	na
Recovery rate – maximum increase in condition during one year under 0% utilisation	1 to 3	na
Degradation rate – maximum decrease in condition in one year under 100% utilisation	1 to 3	na
Can condition recover from state 11	0 or 1	na
% utilisation of growth for an increase in condition by one state	typical values 10-25%	na
% utilisation of growth for a decrease in condition by one state	typical values 25-45%	na
% utilisation of growth when condition does not change	"safe" utilisation	na
Maximum nitrogen uptake (N/ha/yr)		Declines to 70%
Green cover when transpiration is 50%		Declines to 75%
Height (cm) of 1000 kg/ha		Declines to 75%
% N at zero growth		Increases by +0.2
% N at maximum growth		Increases by +0.2
Prop of dead leaf detached per day from 1 Dec to 30 April		Increases by +0.002
Prop of dead stem detached per day from 1 Dec to 30 April		Increases by +0.002
Prop of Dead leaf detached per day from 1 May to 30 November		Increases by +0.002
Prop of Dead stem detached per day from 1 May to 30 November		Increases by +0.002
Soil water index at which above-ground growth stops.	Typical values 0.1-0.4	Increases to 0.9
Soil water index for maximum green cover	Typical values 0.1-0.4	Increases to 0.9
Growth index for green day/frost	0.05	Increases to 0.2

2.2.3 Runoff and soil loss

The impacts of pasture utilisation and ground cover will vary amongst rangeland types depending on pasture species, soil type, rainfall and other environmental factors (Scanlan and McIvor 2010). High stocking rates and tree cover reduce ground cover (Scanlan and McIvor 1993, McIvor 2002, O'Reagain *et al.* 2005) increasing runoff and soil loss (Scanlan and McIvor 2010). In grazed eucalypt woodlands runoff and erosion were small when ground cover exceeded 50% (Scanlan and McIvor 1993). Runoff was 6-10 times greater from hillslope plots with low cover (30-50% of rainfall) compared to plots with high >50% cover (5.9% of rainfall) (Silburn *et al.* 2011). In the same study all soils fitted the same runoff-cover relationship (Silburn *et al.* 2011).

The non-linear empirical relationships between runoff and cover found in analyses by Scanlan *et al.* (1996) are used in GRASP to predict runoff. Surface (ground) cover, daily rainfall, rainfall intensity and soil water deficit are used to derive the relationships. The cover term in the runoff algorithm is a function of total standing dry matter and includes grass litter but not tree litter. However, the contribution that trees continually make to surface litter and the impact on runoff predictions is captured in GRASP by an additional relationship between minimum percent bare soil and tree basal area (Littleboy and McKeon 1997). This relationship produces a minimum surface cover in treed landscapes.

A parameter within GRASP defines the 'effectiveness' of the tree litter component that contributes to the minimum surface cover in runoff predictions using a scale 0 (no effect) to 1 (total effect). Utilisation of tree litter, as may occur in preferentially grazed treed areas, is not currently modelled in GRASP. Soil loss is calculated as a function of runoff and cover (see Scanlan and McIvor 1993) with a constant applied for all land types. The soil erodibility (K) and length-slope (LS) measured values in the USLE are fixed; however, GRASP derived soil loss results can be easily adjusted to include K and LS estimates.

The parameters used to simulate runoff in the grazing Paddock to Reef modelling are shown in Table 2.

Table 2. GRASP model parameters used to simulate runoff as a function of yield for the six Paddock to Reef grazing land types at 10 climate locations.

Parameter name	Parameter value
Maximum runoff of rainfall at zero surface cover wet soil profile	**0.3 (Black basalt) or 1 (all other land types)**
Rainfall intensity as a function of latitude and season	**0.9 and 0.7 for Mt Fox, Charters Towers**
Rainfall intensity as a function of latitude and season	**0.867 and 0.582 for Alpha, Springvale, Wandoan, Ulcanbah, Duaringa, Mundubbera, Marlborough, Proserpine**
Scale for effectiveness of tree litter in runoff	**0.4**

2.3 Land types parameters

Initially, the pasture growth parameters used in the GRASP model were derived for specific pasture communities from datasets collected at 47 localities throughout Queensland (Day *et al.* 1997a). More recently, pasture growth parameters were developed (AGSIP 2006, MLA 2008) for approximately 230 grazing land types (Whish 2011) in Queensland. Simulation modelling undertaken for the Northern Grazing Systems (NGS) Initiative (Scanlan *et al.* 2011c, Whish *et al.* 2012) required adjustment of a subset of the grazing land type parameter datasets. These NGS datasets and their simulated outputs were evaluated with an "average native pasture" model (Day *et al.* 1997a), past grazing studies, expert advice, and available data which was independent of GRASP, to ensure consistency within and across the land type parameters. Evaluation of the land type parameters required consideration of land type characteristics, particularly in relation to other land types, such as landform, vegetation community, soil attributes, and pasture species. Land type parameters used for simulation modelling for the Paddock to Reef Program included the recent modifications to the GRASP model (Scanlan and McIvor 2010) to more realistically represent the processes of pasture degradation and recovery.

2.4 Simulation structure

The fundamental objective of the Paddock to Reef paddock modelling approach for the grazing sector was the provision of time-series ground cover for various levels of pasture management. This cover was used to derive the C-factor in the RUSLE (Renard *et al.* 1977) for use in the 'Source Catchments' model (eWater CRC 2010). The Catchment model derives end-of-catchment pollutant loads for each catchment in the GBR for baseline 2009 and for changes relative to the baseline for each subsequent year 2010-2013 (Carroll *et al.* 2012).

The grazing paddock modelling approach simulated the impact of grazing on a range of land types from various locations within the GBR catchment to obtain ground cover outputs. A 31-year simulation period 1980-2010, in line with other Paddock to Reef modelling, was used to normalise for climate variability (Carroll *et al.* 2012). Daily, monthly and annually derived outputs on cover, runoff and soil loss were provided to the catchment modelling group. Simulated surface cover is reported here as an index with values between 0 and 1 rather than as a percentage.

2.4.1 GRASP model

Simulations were undertaken using the GRASP model (version g21_j7j6_for_test dated October 2010) and the following options:

- Spinup which enables the system to obtain some form of equilibrium and allows the model to adjust soil water, cover and litter pools to more closely align with user defined parameters. In this study a three-year spinup was used.
- Runoff (model 1) (Scanlan *et al.* 1996) and soil loss (model 3) (Scanlan and McIvor 1993) which are functions of surface cover, rainfall intensity and soil-water deficit.
- Monthly grass basal area model (Scanlan and McIvor 2010) modified to capture dynamic monthly changes in grass basal area from the impact of utilisation and growth during the growing season.
- Pasture burning was set as one tenth of land burnt if pasture yield exceeds 800kg/ha. An additional 11kg/hd/yr to liveweight gain occurs in years pasture is burnt (Ash *et al.* 1982).
- Pastures were stocked with 2-year old steers (400kg LW)

- Grazing strategies that dictated stocking rates were:
    - Option 2 responsive stocking rate calculated to eat a proportion of the TSDM on 1st June during the following year
    - Option 13 user defined fixed stocking rate
    - Date for resetting stocking rate was 1st June

- Annual liveweight gain was calculated from % utilisation and percentage of days during the year where pasture growth index was above 0.05 threshold (model 9). The growth index is a product of soil water, solar radiation and temperature indices.

2.4.2 Model variables

Land types, climate locations, utilisation rates, tree cover and pasture condition variables were selected to ensure, as much as possible, that the entire spectrum of the grazing and environmental systems were modelled. As a result of the modelling design there will be land type/climate combinations (e.g. high rainfall with low productivity, high productivity with low rainfall) that are unlikely to occur in the catchments (e.g. Lancewood at Mt Fox, Softwood at Ulcanbah). However, as biophysical data was derived for all potential grazing system environments, the impacts of the more unlikely situations (e.g. high rainfall on heavily grazed low productivity) on surface cover, runoff and soil loss can be examined.

2.4.2.1 Land types

The Paddock to Reef Grazing Steering Committee, comprising of DERM, DAFF, CSIRO Scientists and Extension Officers, and representatives from AgForward, NQ Dry Tropics and FBA Regional Bodies, met to discuss the approach for monitoring and modelling the grazing industry in GBR catchments. After considering a number of criteria (area of catchment, area grazed, productivity/fertility, land condition, total sediment production, previous on-ground investment) the Steering Committee selected six land types (see Figure 1) for the GRASP modelling. A productivity ranking of high, medium or low was determined by expert opinion of DAFF scientists and extension officers and assigned to each modelled land type:

- Black basalt – high productivity
- Softwood scrub – high productivity
- Goldfields on red soils – medium productivity
- Narrow-leaved ironbark woodlands – medium productivity
- Spotted gum on ridges – low productivity
- Lancewood - low productivity

The grazing lands of the six Natural Resource Management regions within the Great Barrier Reef catchment cover approximately 314 000 km^2. The selected six modelled land types (Figure 1) covered approximately 25% of these grazing lands with Black basalt (~ 1 800 km^2), Lancewood (~ 7 400 km^2) and Softwood scrub (~ 9 000 km^2) the smallest grazed areas. Goldfields on red soils (~ 23 000 km^2), Spotted gum ridges and Narrow-leaved ironbark woodlands (~ 18 000 km^2) were the largest grazed areas.

Grazing land types can be assigned a productivity ranking (see Appendix 1, Figure 2) to enable complete spatial coverage of the grazing lands in GBR and to assist in linking paddock GRASP model outputs with catchment models. Approximately 41% (128 300 km^2) of the grazing lands in the GBR catchment were of high productivity (27% of land types), with 57% (179 200 km^2) of medium productivity (42% of land types), and 24% (74 400 km^2) of low productivity (31% of land types).

2.4.2.2 Climate data

Climate locations (Figure 1) were selected to capture the climatic variability (rainfall, humidity, temperature) in the GBR catchments. Long-term climate records for GRASP simulations were obtained from SILO Data Drill (Bureau of Meteorology 2011) for 10 locations (Table 3). Mean annual rainfall for 1980-2010 simulation period ranged from minimum of 512 mm at Ulcanbah to a maximum of almost 1400 mm at Proserpine (Table 3, Figure 1).

Table 3. Mean annual rainfall (mm) for 1980-2010 and locations of climate stations used in paddock modelling of the grazing lands for the Paddock to Reef Program.

Climate station	Latitude Decimal Degrees	Longitude Decimal Degrees	Mean annual rainfall mm
Ulcanbah	-22.00	146.00	512
Alpha	-23.65	146.64	546
Springvale	-24.70	147.30	584
Wandoan	-26.12	149.96	611
Charters Towers	-20.05	146.25	634
Duaringa	-23.71	149.67	641
Mundubbera	-25.59	151.30	654
Marlborough	-22.81	149.89	684
Mt Fox	-19.00	146.00	850
Proserpine	-20.49	148.55	1387

2.4.2.3 Utilisation rates

Utilisation rates and the amount of the total standing dry matter (TSDM kg/ha) present at the end of the growing season (1st June) was used to calculate the stocking rate for the following year. Fourteen utilisation rates that ranged from no grazing (0%) to heavy grazing (95%) were modelled. An additional fixed stocking rate option (1000 head km^{-2}) was used to simulate 'total utilisation' of pasture. This extreme grazing pressure is represented in results as 120% pasture utilisation of TSDM. The following utilisation rates (%) and fixed stocking rate were modelled:

- 0, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 75, 95
- 1000 head km^{-2} (Adult equivalent)

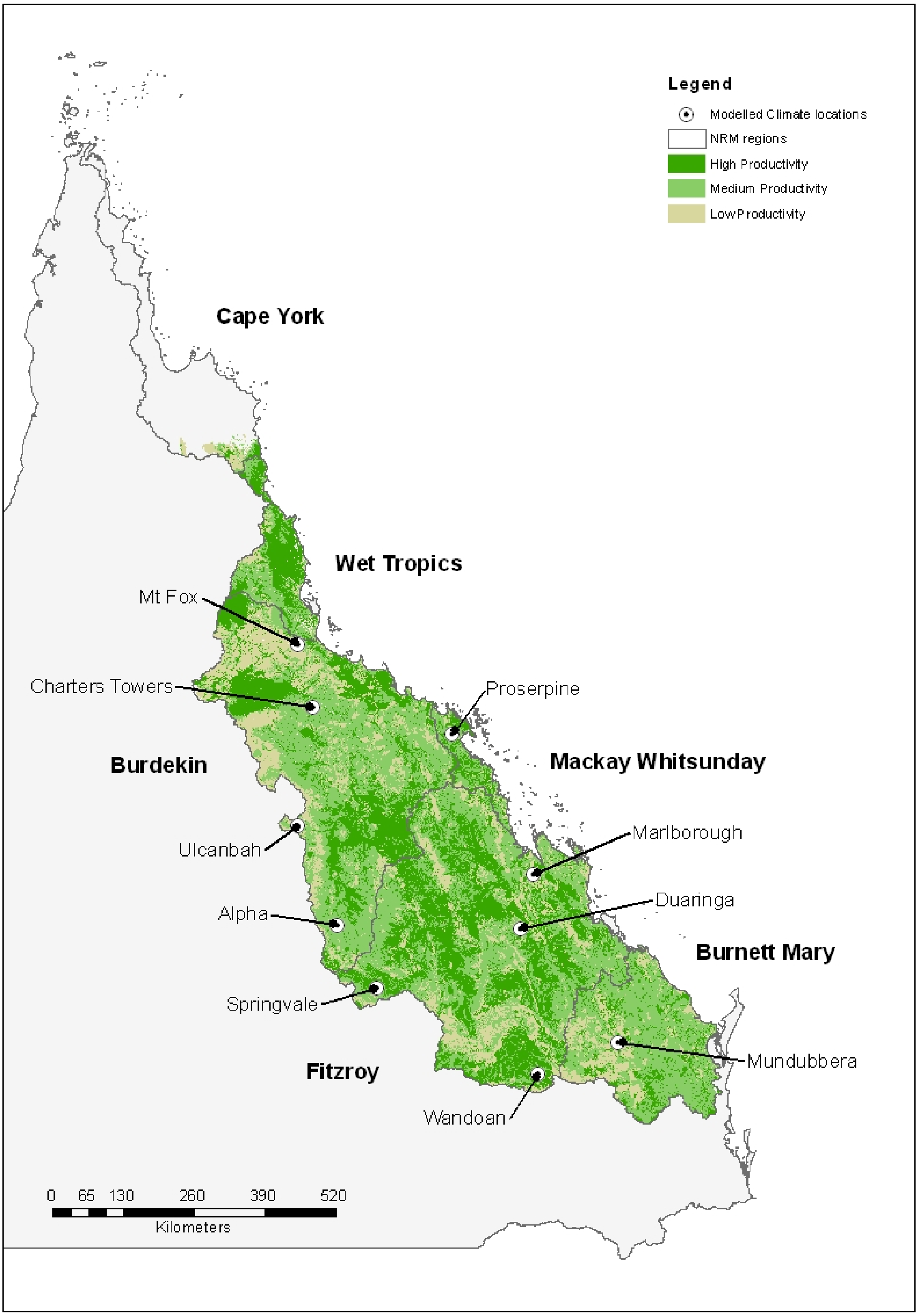


Figure 2. High, medium and low productivity grazing land types of the Great Barrier Reef catchment. Ten modelled climate locations and six Natural Resource Management regions are also shown.

2.4.2.4 Pasture resource conditions

To simulate the interactions of the pasture resource condition (percent perennials), land types, grazing and climate on surface cover, a number of 'starting' pasture resource conditions (determined to occur after the spinup period) were modelled. GRASP percent perennials and State (McKeon *et al.* 2000, Scanlan and McIvor 2010) and estimated ABCD land condition (Quirk and McIvor 2003) of modelled pasture resource condition are as follows:

- A condition, State 2, 84% perennials
- B condition, State 3.5, 60% perennials
- C condition, State 6, 20% perennials

Initially, the three starting pasture conditions were modelled. Evaluation of the simulated annual data at Charters Towers revealed that for each land type, the surface cover after 7 -14 years was virtually the same, regardless of the starting pasture condition. Hence, after approximately 10 years the dominant influence on pasture productivity and surface cover was pasture utilisation, far outweighing any benefit or disadvantage of initial pasture condition. To simplify manipulations and analyses of large datasets all subsequent simulations, and those evaluated and reported on, were only for 'starting' pasture condition B, State 3.5, 60% perennials.

2.4.2.5 Tree cover

Trees impact pasture production through competition for water and nutrients. Trees compete for water most strongly in shallow soils, when tree roots are shallow and during dry periods when the amount of water available for transpiration is reduced (Scanlan and McKeon 1993). The competitive effects of trees on grasses generally result in reductions in pasture production (Scanlan 2002). Scanlan (2002) also highlights the effect variability in tree basal area has on grass production, and the importance of considering this variability in tree basal area when calculating 'safe' stocking rates. Simulations showed pasture production was up to 50% higher in paddocks with a high variability in the distribution of trees compared with areas where trees were uniformly distributed (Scanlan 2002). At the property/landscape level, patches of low tree density or open areas are very important in determining pasture production, particularly in areas of higher tree density. In GRASP, the effects of uniformly distributed trees on pasture production are simulated. Modelled outputs were derived for two constant tree basal areas (tba); cleared and "average," the latter cover being a tree basal area considered to be representative of the land type in the Burdekin and Fitzroy regions. Tree basal area for Softwood scrub represents cleared country with some regrowth. Constant tree basal areas used in simulation modelling ranged from sparsely treed softwood scrub (1 m^2/ha tba) to heavily timbered spotted gum on ridges (10 m^2/ha tba) (Table 4):

Table 4. Cleared and regional average constant tree basal areas (m^2 /ha) for the six land types of high, medium and low productivity used in GRASP paddock modelling of grazing sector.

Land type	Productivity	Tree basal area (m^2/ha)	
		Cleared	Regional average
Softwood scrub	High	0	1
Black basalt	High	0	3
Goldfields on red soils	Medium	0	3
Narrow-leaved ironbark woodlands	Medium	0	8
Lancewood	Low	0	4
Spotted gum on ridges	Low	0	10

3.0 Results and Discussion

Only a subset of the vast amount of data produced from the GRASP modelling is presented in this report. All presented results are means of the 31-year simulation period (1980-2010). An overview of the amount and distribution of rainfall at each climate location is provided. The influences of land type (averages across all pasture utilisations, tree cover and climate locations), climate (averages across all pasture utilisations), and grazing pressure (averages across all climates) pressure on pasture productivity, surface cover, runoff and soil loss are separately examined. Simulated outputs from a more specific “safe” pasture utilisation for each land type are also provided.

3.1 Climate variability

Year-to-year variation in rainfall is a major source of climatic variability affecting plant growth (Day *et al.* 1997a), and in Queensland this variability is high at both a location and regional scale (Johnston *et al.* 2000). Managing the variability in rainfall is a key challenge to sustainable and profitable beef production in northern Australia (Scanlan *et al.* 1994, O’Reagain and Bushell 2011).

Modelled climate stations ranged in mean annual and monthly rainfall from the driest at Ulcanbah (512 and 43 mm respectively) to wettest at Proserpine (1387 and 116 mm respectively) (Table 5). Half of the locations average 600 -700 mm a year and 50-60 mm a month (Table 5). Only at Springvale was the mean annual rainfall (585 mm) less than the median (593 mm). High variations (co-efficient of variation of approximately 30% or more) in year-to-year rainfall were recorded at seven climate locations. Generally, rainfall variability was positively related to latitude, with highest variation in rainfall occurring at the more northerly climate locations (CV 37-38%) and the least variation in rainfall (CV 20%) occurring at Mundubbera in the south of GBR catchment (Table 5, Figure 1).

Table 5. Summary statistics for annual (May to June) and monthly rainfall mm for 10 modelled climate locations from 1980-2010. SD=standard deviation, CV%= coefficient of variation%.

	Annual (May to June) Rainfall mm				Monthly Rainfall mm			
Climate Location	Mean	Median	SD	CV%	Mean	Median	SD	CV%
Ulcanbah	512	493	158.4	30.9	43	17	57.9	135.7
Alpha	546	503	184.7	33.8	46	29	52.7	115.8
Springvale	585	593	158.9	27.2	49	33	52.8	108.3
Wandoan	612	595	169.0	27.6	51	37	48.3	94.7
Charters Towers	634	547	244.3	38.5	53	23	76.1	144.1
Duaringa	641	609	216.5	33.8	53	36	58.0	108.6
Mundubbera	654	656	132.3	20.2	55	42	48.0	88.0
Marlborough	684	633	215.0	31.4	57	34	67.2	118.0
Mt Fox	849	780	316.3	37.2	71	29	106.3	150.1
Proserpine	1387	1290	519.0	37.0	116	56	161.5	139.7

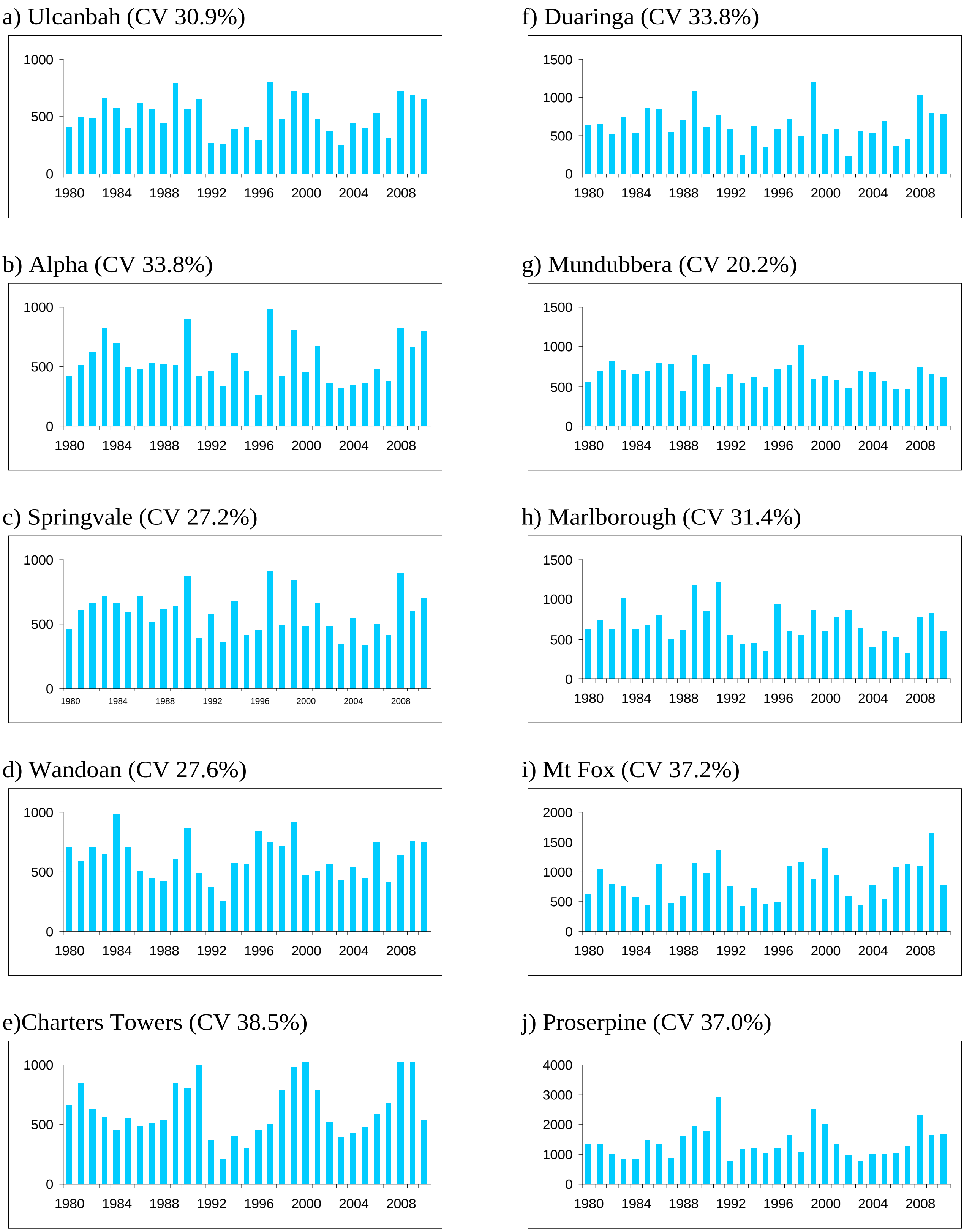


Figure 3. Mean annual rainfall mm (x axis) and coefficient of variation % (CV%) for 10 climate stations (a-j) for 1980-2010.

Figure 4. Mean monthly rainfall mm (x axis) for 1980-2010 and 10 climate stations.

The pattern of inter-annual variability in rainfall from 1980-2010 differs between climate locations (Figure 3). At Charters Towers, Proserpine and Mt Fox annual rainfall variability was characterised by three distinct troughs in rainfall received during 1984, 1992 and 2003. The high year-to-year variability at Alpha (CV 34%) was characterised by five sporadic years with high rainfall which contrasted to the more fluctuating rainfall received between sequential years at Duaringa (CV 34%). Both Wandoan and Mundubbera have the least variation in year to year rainfall, and the most even distribution of rainfall throughout the year (Table 5, Figure 4). Both Springvale and Duaringa have similar distribution of rainfall within the year (CV 108%) but the inter-annual variability in rainfall is higher at Duaringa (CV 34% cf. 27%). Rainfall was strongly seasonal with dry winters and variable but potentially high and intense summer rainfall at the more northerly locations (e.g. Proserpine, Mt Fox, Charters Towers). Wet seasons became less distinct in more southerly (Duaringa, Mundubbera, Wandoan) locations.

3.2 Land types

Climate, land type and land condition all influence pasture productivity and the capacity of the land to support livestock (McIvor *et al.* 2010). Mean annual pasture growth from 1980-2010 for land types across all climate stations, pasture utilisation levels and tree basal areas correlated with the estimated productivity ranking (Table 6). Pasture growth was a magnitude higher (approximately 4000 kg/ha) on Softwood scrub than that of the lowest growth (approximately 400 kg/ha) on Lancewood. Increased grazing pressure affects pasture production through reduced grass basal area, reduced photosynthetic area, loss of perennial species, and increased runoff and soil loss that results from reduced surface cover (McKeon *et al.* 2000). Percent perennials are indicative of the relative robustness of land types to the impacts of heavy grazing. Softwood scrub is the most resilient land type (average 55% perennials) to grazing pressure, whilst Lancewood is the most fragile grazing system (average 28% perennials). The high productivity land types (Softwood scrub, Black basalt) had greater surface cover (0.60, 0.48 respectively) than the low productivity land types (Lancewood, Spotted gum ridges). Runoff and soil loss was lowest on Black basalt and Softwood scrub and greatest on the least productive land types (Lancewood, Spotted gum ridges) (Table 6).

Table 6. Average GRASP outputs for six land types of varied productivity (high, medium, low) from 10 climate stations for 15 utilisation and two tree basal area levels from 1980-2010. tba = simulated tree basal areas

GRASP outputs	Land types and productivity ranking					
	Softwood scrub (tba 0,1)	Black basalt (tba 0,3)	Goldfields on red soils (tba 0,3)	Narrow-leaved ironbark woodlands (tba 0,8)	Spotted gum ridges (tba 0,10)	Lancewood (tba 0,4)
	High	High	Medium	Medium	Low	Low
Pasture growth kg/ha/year	4041	2522	1733	1001	683	391
Green Index days	264	194	234	213	188	205
% Perennials	55	43	39	41	36	28
Surface cover (0-1)	0.60	0.48	0.42	0.33	0.29	0.20
Runoff mm/year	72	31	132	147	198	238
Soil loss kg/ha/year	1199	573	2531	3130	4483	5679

3.3 Land type and climate

3.3.1 Pasture growth

Pasture growth (green biomass) in a summer rainfall environment is either limited by moisture or soil fertility, and when green cover or light interception is low potential perennial pasture growth is proportional to grass basal (McKeon *et al.* 2000). GRASP calculates green biomass under both limiting conditions with the most limiting factor determining growth (Littleboy and McKeon 1997).

Land type fertility is simulated in GRASP through a number of soil and plant parameters (maximum N uptake and plant ability to dilute N) that allow for both the limitations of climate and soil fertility to be represented in simulated pasture growths. Soil characteristics (plant available soil water) and resilience to heavy grazing (e.g. degradation and recovery of % perennials, potential perennial pasture regrowth) are also important land type attributes that effect pasture productivity.

Pasture species vary in their tolerance to water stress and ability to maintain green cover at low soil water. Green Index days are where the soil water is sufficient to support full green cover and the pasture growth index is above 0.05 threshold (Littleboy and McKeon 1997). Soil characteristics of Black basalt (high evaporation from cracking clays) and Spotted gum ridges (low plant available water of skeletal soils) contributed to the relatively low Green Index days of these land types (Table 6). Trees also have a large effect on soil water, pasture growth and Green Index days.

The effects of climate locations, trees and land types on pasture growth are shown in Figure 5. Average pasture growth increases as mean annual rainfall increases, with pasture growth on cleared land types greater than that under trees. Pasture growth was less on the more heavily treed and less productive land types (Narrow-leaved ironbark woodlands, Spotted gum ridges, Lancewood), being least on Lancewood. Pasture growth on the high productivity Softwood scrub is more than double that of the other land types across all locations.

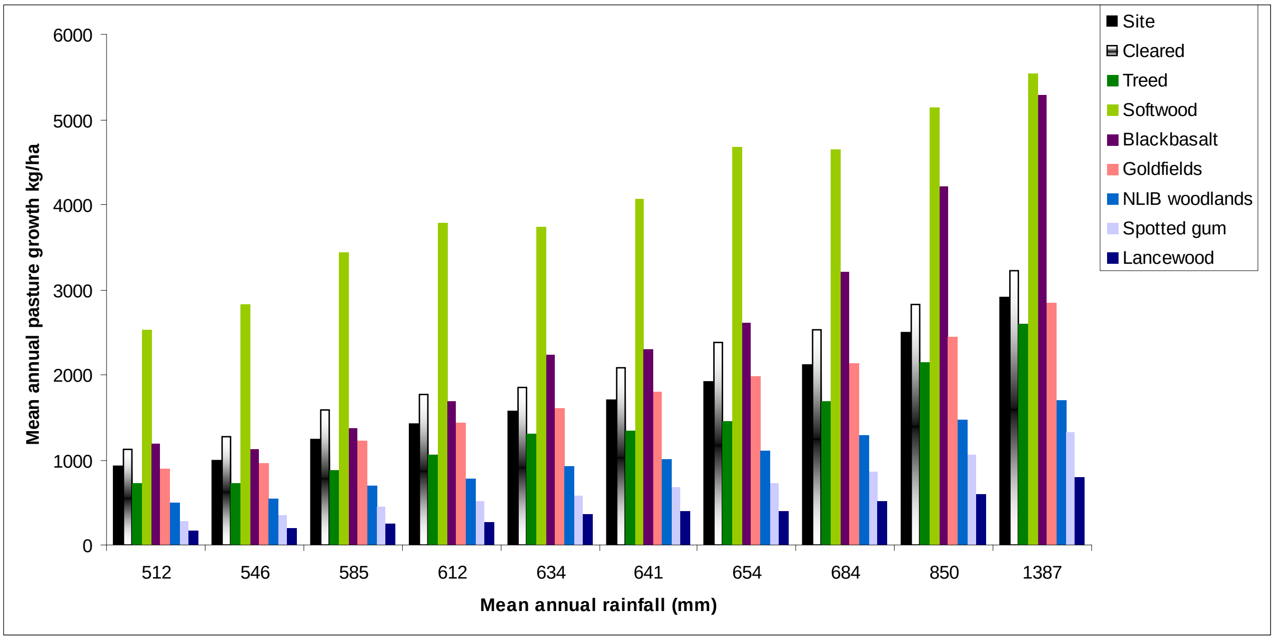
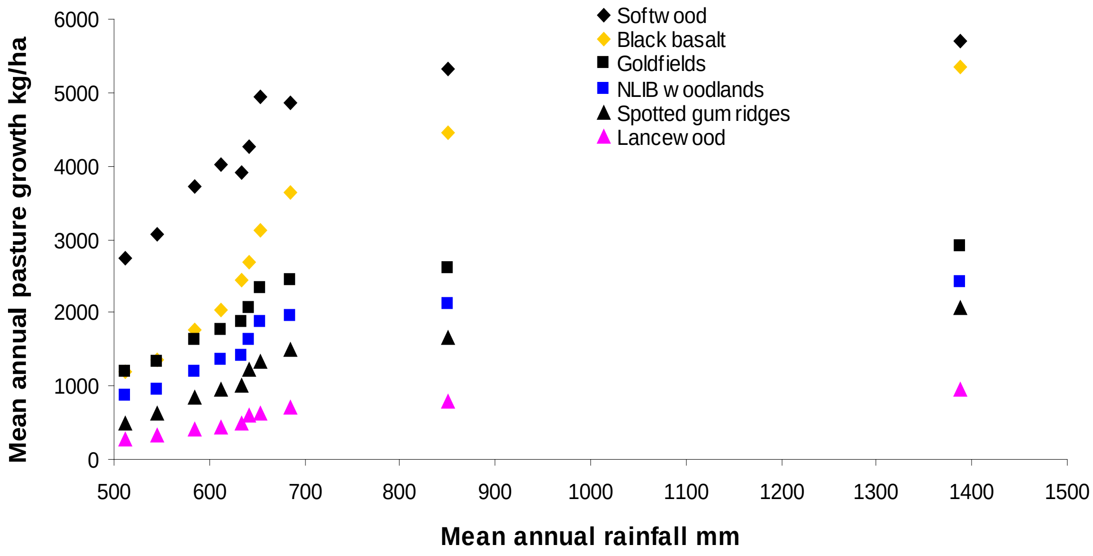


Figure 5. The effects of site, trees and land type on mean annual pasture growth (kg/ha) at each climate station (mean annual rainfall mm).



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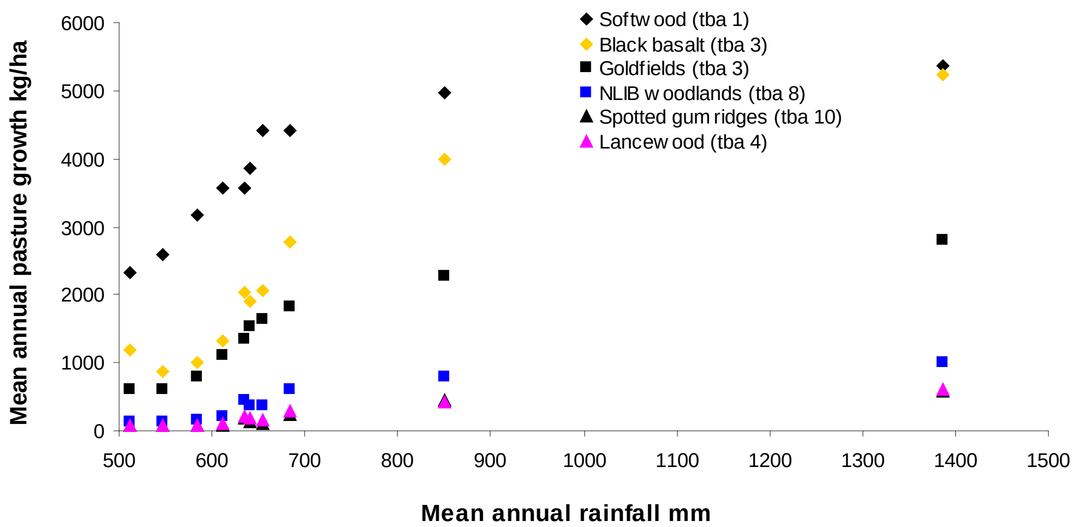

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Figure 6. Mean annual pasture growth kg/ha for 15 utilisation levels over simulation period (1980-2010) for six a) cleared and b) treed land types at 10 climate stations. tba=tree basal area m^2/ha.

Across the climate stations pasture growth on both cleared and treed land types correlated with productivity rankings (Figure 6). For all land types, pasture growth at Proserpine (1387 mm annual rainfall) was more than double (Goldfields, Softwood scrub, Narrow-leaved ironbark woodlands) or triple (Black basalt, Lancewood, Spotted gum ridges) that achieved at the driest location (Ulcanbah 512mm annual rainfall). The relatively high evaporation from cracking clays of Black basalt is limiting pasture growth to be similar to that of a medium productivity land type (Goldfields) when mean annual rainfall is less than 585mm (Figure 6 a). Where mean annual rainfall was above 684 mm, and moisture was no longer limiting pasture growth, improvements in pasture productivity with increasing rainfall were greatest on Black basalt.

The competitive effects of trees on grasses resulted in reductions in pasture production and an increase in the variability of pasture growth (Figures 6). For the same rainfall, the presence of trees reduced land type productivity by 10-90% compared with cleared land type productivity. The greatest reductions (cf. cleared) in pasture productivity occurred under the more heavily timbered land types. For the three least productive, more heavily treed land types, pasture growths were similar when mean annual rainfall is less than 634mm. As rainfall increased from low (512mm) to high (1387mm) the greatest increases in pasture growth were on the low productive, more heavily treed land types (Lancewood, Narrow-leaved ironbark woodlands, Spotted gum).

3.3.2 Surface cover

Surface cover, as a function of the standing dry matter, is correlated to productivity ranking and pasture growths (see Table 6). The effects of climate locations, trees and land types on surface cover are shown in Figure 7. Average surface cover at the sites increases as mean annual rainfall increases from 0.3 to 0.5. Surface cover on cleared land types was greater than that under trees, with the biggest differences (approximately 0.1) occurring between 585 and 684 mm. Surface cover was less on the more heavily treed and less productive land types (Narrow-leaved ironbark woodlands, Spotted gum ridges, Lancewood), being least on Lancewood. Surface cover on the high productivity Softwood scrub is 0.5 or more at all locations.

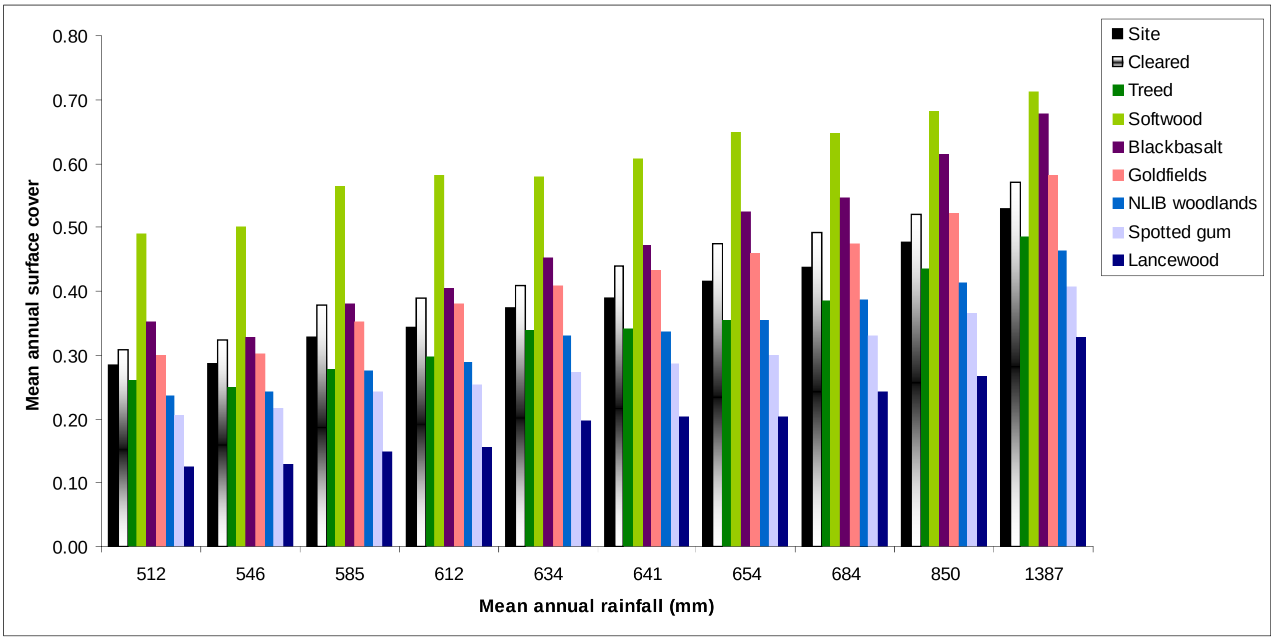
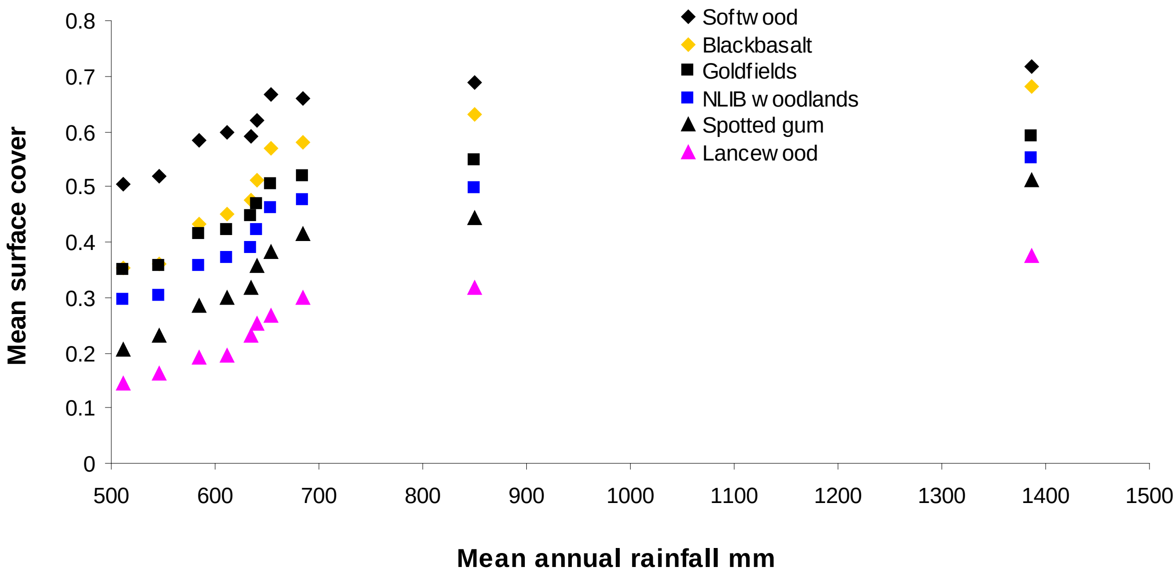


Figure 7. The effects of site, trees and land type on mean annual surface cover (index) at each climate station (mean annual rainfall mm).

Surface cover was correlated to land type productivity with the highest cover achieved on Softwood scrub and lowest cover on Lancewood (Figure 8). On the cleared low productivity land types (Lancewood and Spotted gum ridges) surface cover increased by approximately 60% with the threefold increase in mean annual rainfall from 512 (Ulcanbah) to 1387mm (Proserpine). In comparison, mean surface cover on cleared, high productivity Softwood scrub only had a 29% increase for the same increase in annual rainfall (512 to 1387mm).

Compared to the respective cleared land types, surface cover was reduced by 10% on lightly treed Softwood scrub (tba 1m^2/ha) and by more than 65% in the heavily timbered Spotted gum ridges (tba 10m^2/ha) (Figure 8). Surface cover of each treed land type increased as mean annual rainfall increased. In the high rainfall environment of Proserpine, surface covers of treed land types were similar to that of the respective cleared land type, except for Spotted gum ridges where surface cover was lower under the trees. Surface cover of Spotted gum ridges was close to this land type's tree litter minimum (0.2) when mean annual rainfall was less than 634 mm.



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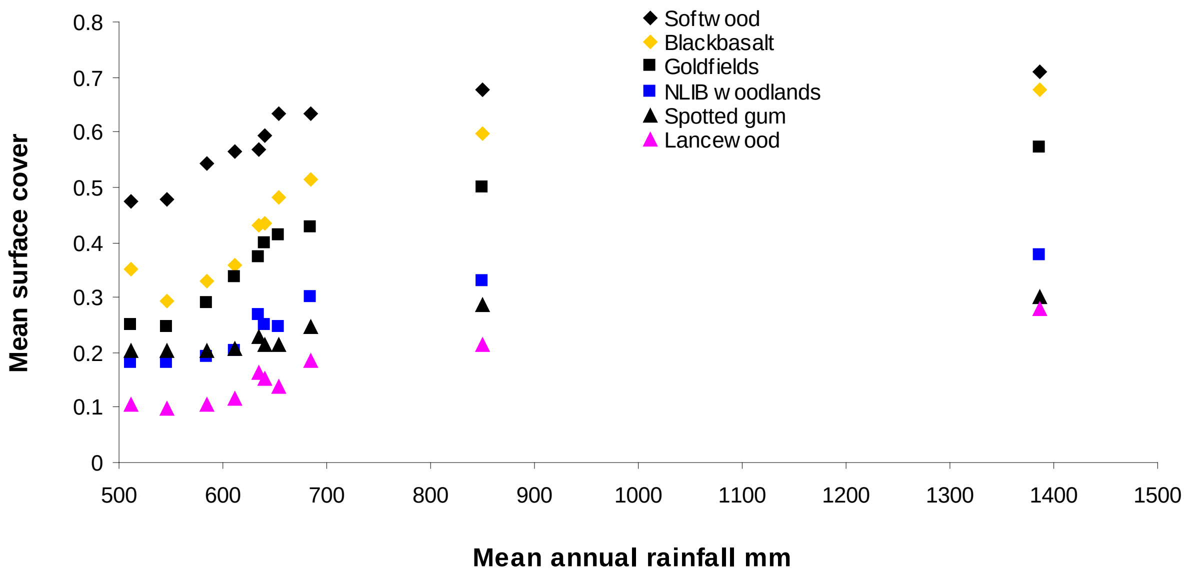
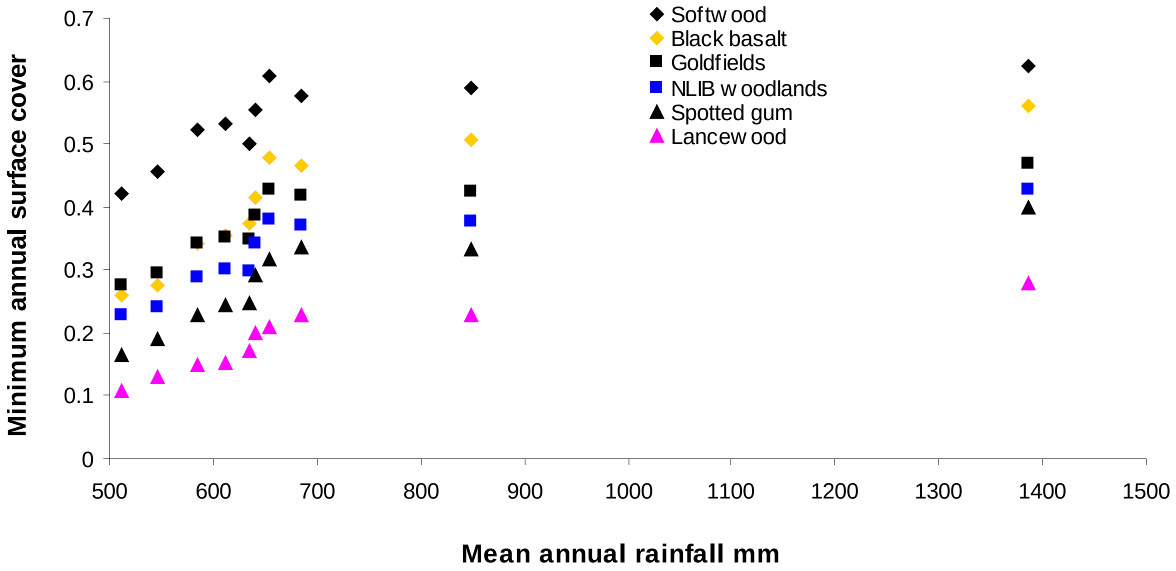


b)
Figure 8. Mean surface cover (index) for 15 utilisation levels over simulation period (1980-2010) for six a) cleared and b) treed land types at 10 climate stations. tba=tree basal area m^2/ha.

3.3.2.1 Minimum annual surface cover

Some beef producers use dry season forage budgets to ensure their stock have enough feed and there is enough stubble on the ground to maintain pasture condition. Surface cover is not only important for the vigour and health of pastures but it is also critical to the magnitude of runoff and soil loss. For both cleared and treed land types the mean (1980-2010, all utilisations of TSDM) minimum annual surface cover was correlated with estimated land type productivities, being highest on Softwood scrub and lowest on Lancewood (Figure 9).



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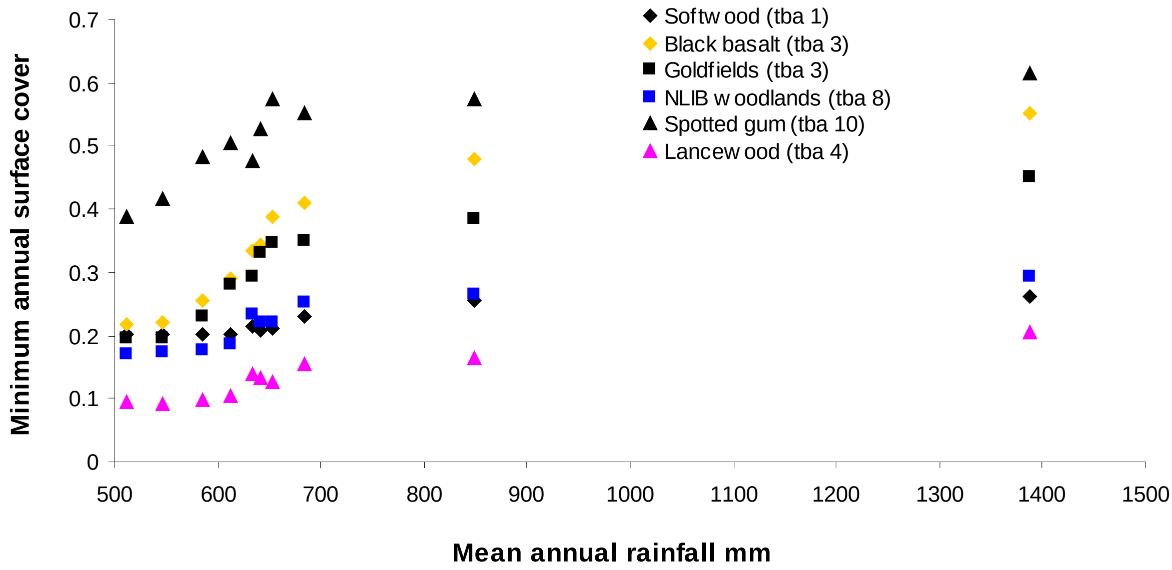

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Figure 9. Mean minimum annual surface cover for 15 utilisations over simulation period (1980-2010) for six a) cleared and b) treed land types at 10 climate stations. tba=tree basal area m^2/ha.

Minimum surface cover generally increased as annual rainfall increased, although the rainfall variability (year to year and seasonal) at 634mm annual rainfall (Charters Towers, see Table 3) limited minimum surface cover. Between the annual rainfall extremes (512mm and 1387mm), minimum annual surface cover ranged from 0.1-0.2 for Lancewood and 0.4-0.6 for Softwood scrub. Greater than 50% mean minimum surface cover was only achieved at 7 cleared and 6 treed Softwood scrub locations, and at the wetter (>850 mm, Proserpine and Mt Fox) black basalt sites. The minimum surface covers of more heavily treed land types were close to each land type's respective tree litter minimum (Spotted gum ridges 0.2, NLIB woodlands 0.16, Lancewood 0.08) when mean annual rainfall was less than 634 mm.

3.3.3 Runoff and soil loss

Climate, stocking rate, tree cover and species composition all impact on runoff and soil loss via effects on surface cover. The effects of climate locations, trees and land types on annual runoff are shown in Figure 10. Average annual runoff is approximately 100 mm at sites that receive an average annual rainfall of between 512 and 684 mm, but increasing to >300 mm where annual rainfall is 1387 mm. Runoff from treed land types is only marginally (10 mm) more than from cleared pastures; although this difference increases to approximately 40 mm the highest rainfall location. Runoff was more on the more heavily treed and less productive land types (Narrow-leaved ironbark woodlands, Spotted gum ridges, Lancewood), being most on Lancewood. Annual runoff was less than 100 mm on the high productivity Softwood scrub and Black basalt at all locations, except with the highest rainfall runoff from Softwood scrub peaked at 170 mm.

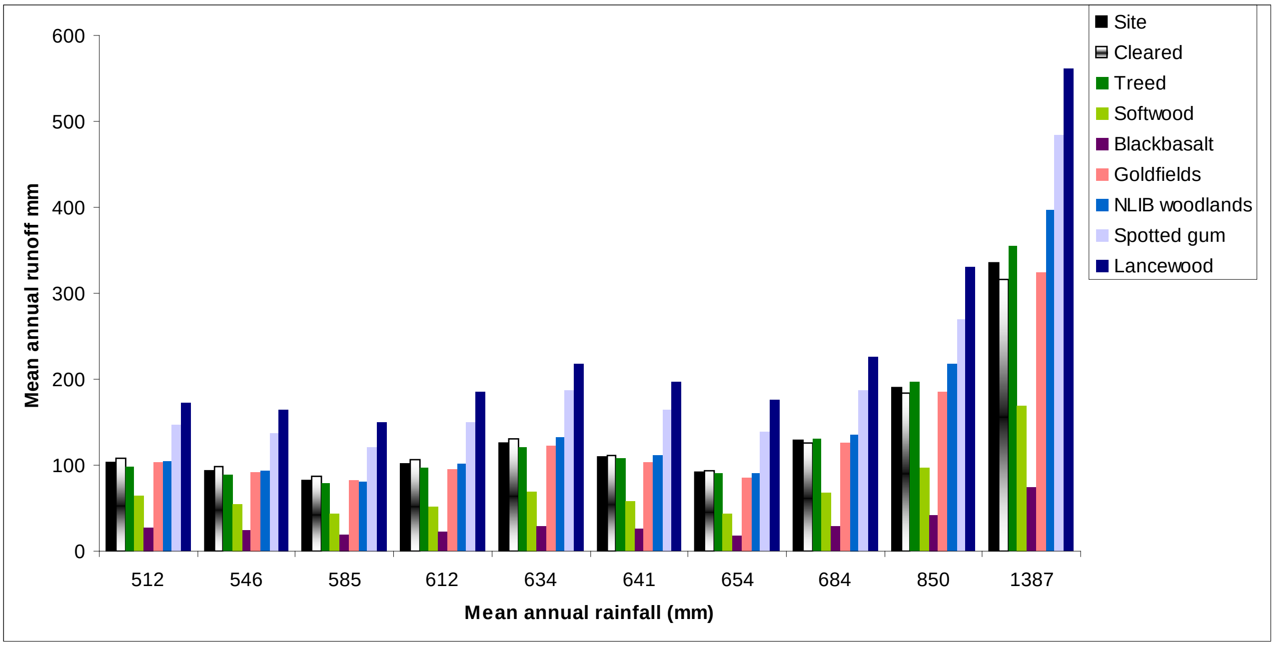
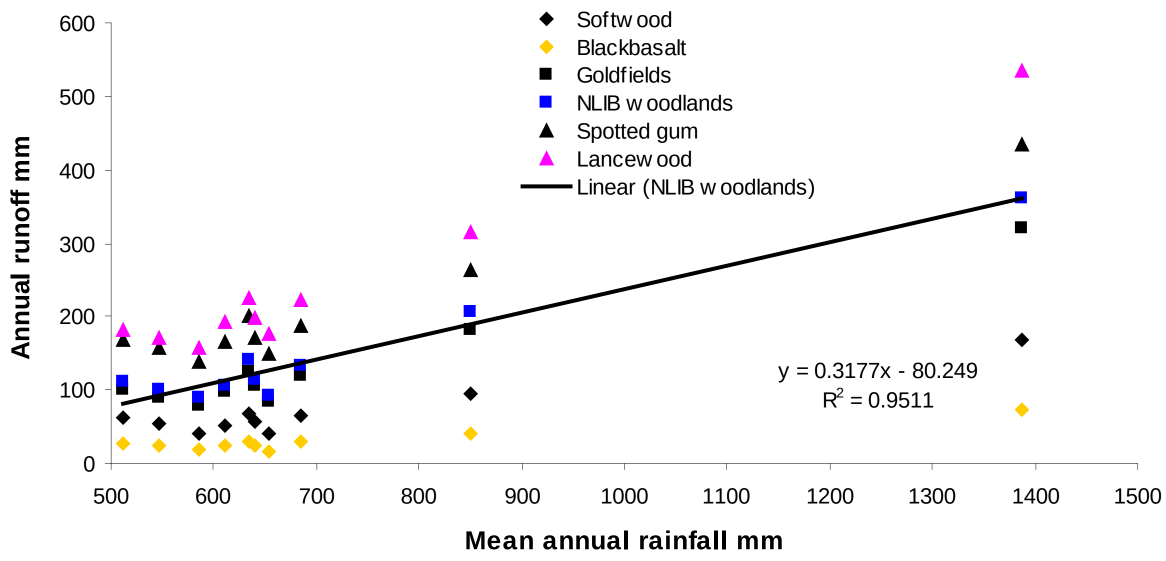


Figure 10. The effects of site, trees and land type on mean annual runoff (mm) at each climate station (mean annual rainfall mm).

Runoff from Black basalt was set to be a third of that for all other land types (Tables 2 & 6). Mean (1980-2010, all utilisations of TSDM) annual runoff for cleared and tree land types was lowest on Black basalt (28, 74 mm respectively) and highest on Lancewood (164, 588 mm respectively) across the range of annual rainfall (Figure 11). Runoff was linearly related to mean annual rainfall with highest runoff occurring at ≥850 mm rainfall (e.g. fitted trendline for Narrow-leaved ironbark woodlands R^2 = 0.95, Figure 11). When pasture growth was limited either by moisture or nutrients (low productivity land types, high tba, low mean annual rainfall) the tree litter surface cover was greater than surface cover (function of pasture yield) on cleared land types. Hence, compared to treed land types, runoff was higher from cleared medium and low productivity land types when mean annual rainfall was < 654mm.



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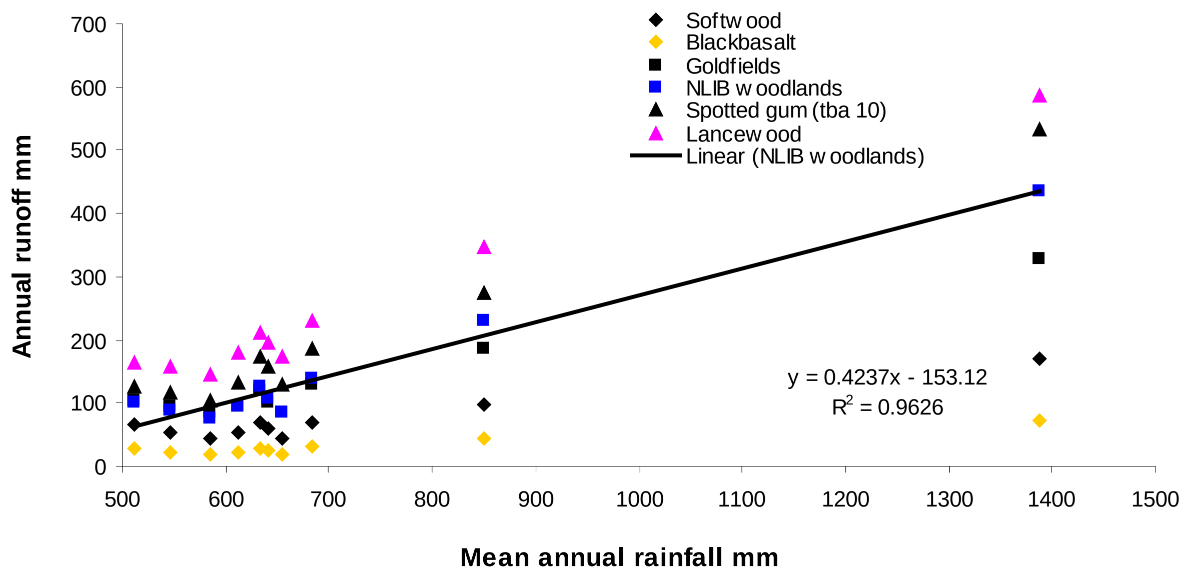

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Figure 11. Mean annual runoff mm for 15 utilisations over simulation period (1980-2010) for six a) cleared and b) treed land types at 10 climate stations. tba=tree basal area m^2/ha. Fitted linear line for Narrow-leaved ironbark woodlands with equation and R^2 displayed.

The effects of climate locations, trees and land types on annual soil loss are shown in Figure 12. Average annual soil loss is approximately 2-3 tonne/ha at sites that receive an average annual rainfall of between 512 and 684 mm, but increasing to 6 tonne/ha where annual rainfall is 1387 mm. Soil loss from treed land types is similar to that from cleared pastures except at the three highest rainfall locations where the difference becomes more pronounced (0.6-2.4 tonne/ha). Soil loss was greatest from the more heavily treed and less productive land types (Spotted gum ridges, Lancewood). Annual soil loss was less than a 1.4 tonne/ha from the high productivity Softwood scrub and Black basalt at all locations, except with the highest rainfall where soil loss from Softwood scrub peaked at 2 tonne/ha.

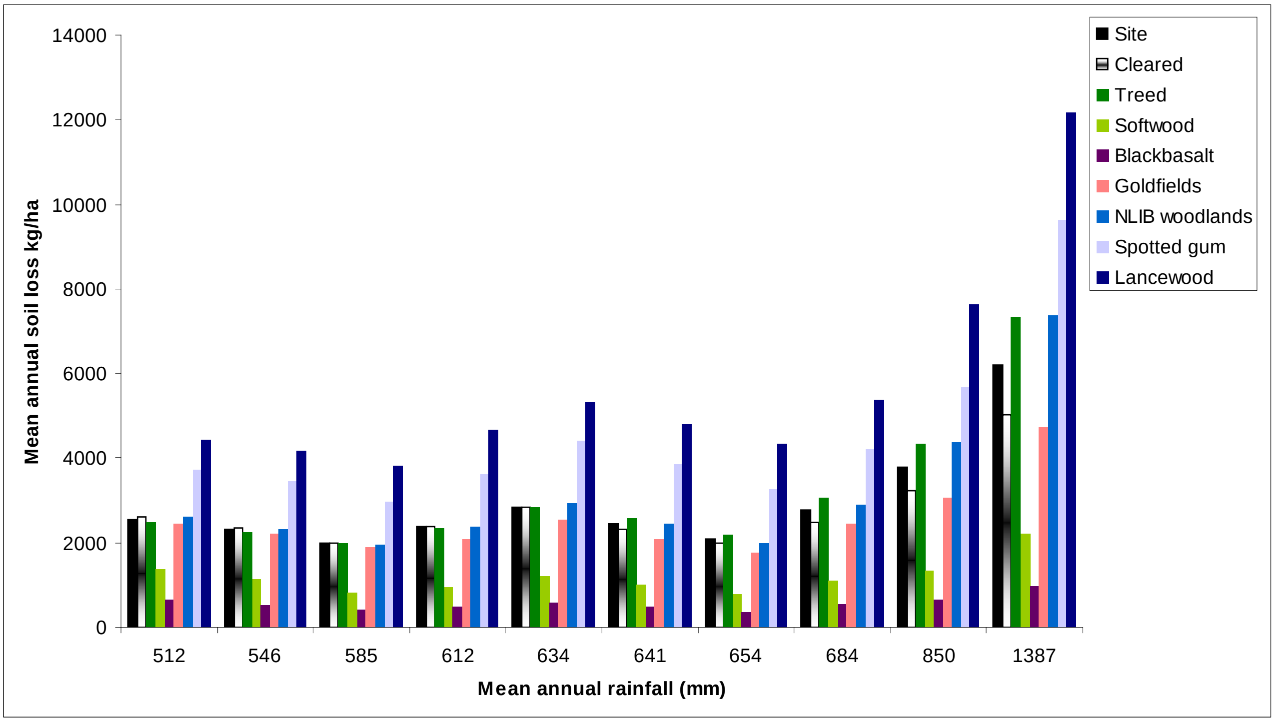
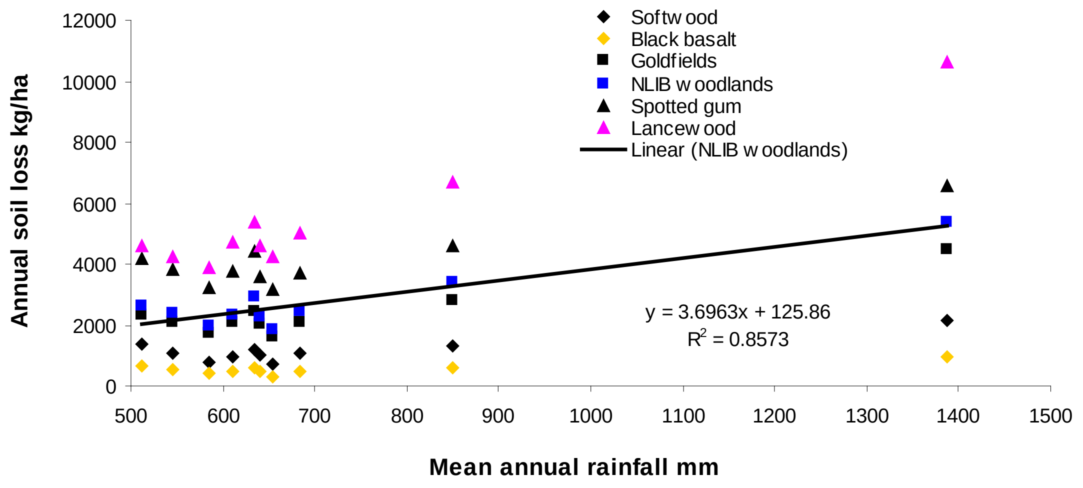


Figure 12. The effects of site, trees and land type on mean annual soil loss (kg/ha) at each climate station (mean annual rainfall mm).

Mean annual soil losses (Figure 13) generally increased as land type productivity decreased, as rainfall increased, with tree cover having less impact on soil loss. Averaged across rainfall, soil losses were a magnitude lower from high productivity Black basalt (~ 0.6 tonne/ha) than from low productivity Lancewood (~6.0 tonne/ha). As rainfall increased sediment losses increased (e.g. fitted trendlines for Narrow-leaved ironbark woodlands R^2 = 0.86, R^2 = 0.95, Figure 8), with the highest losses occurring on the low productivity, heavily treed sites at 1387 mm (Spotted gum ~ 13 tonne/ha, Narrow-leaved ironbark woodlands ~ 13 tonne/ha, Lancewood 14 tonne/ha). Averaged across rainfall, soil losses were between 6-27% greater on treed land types compared to the respective cleared land types. However, with low mean annual rainfall (≤ 640mm) and a minimum tree litter surface cover, soil losses were up to 20% lower from heavily treed low and medium land types (Narrow-leaved ironbark 2.6 tonne/ha, Spotted gum 3.3 tonne/ha, Lancewood 4.3 tonne/ha) compared to respective cleared land types (2.6 tonne/ha, 4.2 tonne/ha, 4.6 tonne/ha). With higher rainfall (>660 mm), soil losses were 20-30% higher from treed than cleared land types.



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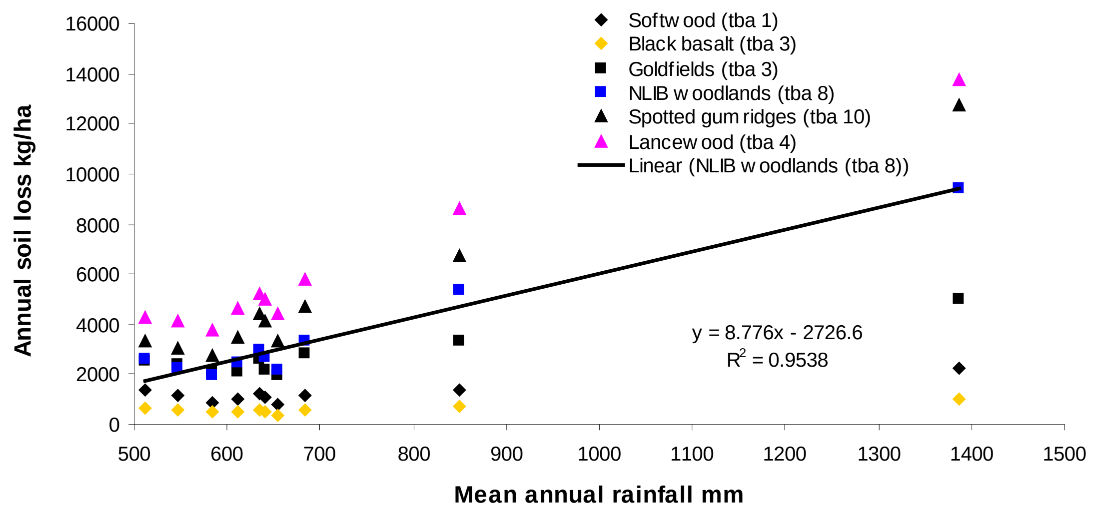


b)

Figure 13. Mean annual soil loss kg/ha for 15 utilisations over simulation period (1980-2010) for six a) cleared and b) treed land types at 10 climate stations. tba=tree basal area m^2/ha. Fitted linear line for Narrow-leaved ironbark woodlands with equation and R^2 displayed.

3.4 Land type and grazing pressure

Management of stocking rate is the fundamental strategy to cope with a variable climate and may include using ‘safe’ carrying capacity, flexible grazing management (changing stock numbers each year), tactical grazing management and tactical rest (Johnston *et al.* 2000). Safe long-term carrying capacity refers to the average stocking rate that a paddock can be expected to support over a period of years without causing land or pasture degradation (McIvor 2010). Safe carrying capacities have been estimated for pasture communities, land types or whole properties in northern, central, south-east and south-west Queensland (McKeon *et al.* 1994, Scanlan *et al.* 1994, Johnson *et al.* 1996, Day *et al.* 1997b). Across a range of pasture productivities (500-5000kg/ha/year) the safe stocking rates represent approximately 15-25% utilisation of average pasture growth during the growing period (Day *et al.* 1997a). Safe utilisations may be lower in regions prone to severe droughts (north-western Queensland) or where the growing season is short and nutrients may be limiting animal production (tropical tall grass communities) (Day *et al.* 1997a).

Stocking at a constant ‘safe’ rate is fundamentally different to a flexible grazing management that involves varying stocking rates in response to variation in standing pasture yield. A flexible responsive grazing strategy was simulated with stock numbers set each year at the end of the May to eat a proportion of total standing dry matter (TSDM). Pasture production over the following growing season ultimately determines the actual utilisation of pasture growth. When the impacts of grazing on pasture (e.g. reduced grass basal area, increased runoff, loss of perennial species) are included in simulations, pasture growth will decline with increasing stocking rate. Utilisation of pasture growth determines the change in pasture condition state (percent perennials). Where utilisation rate is lower then the ‘safe’ rate, pasture condition will improve, and when utilisation rate is higher, pasture will degrade. All land types were parameterised so there was no change to pasture condition when annual utilisation of pasture growth equalled the recommended ‘safe’ utilisations in Land types of Queensland (Whish 2011).

The simulated mean utilisation of pasture growth that approximates the long-term ‘safe’ recommended levels and the corresponding utilisation of TSDM for six land types are shown in Table 7. Simulated annual pasture growth utilisations are the mean of cleared and treed land types across 10 climate locations. Annual utilisation of TSDM correlated well with mean annual utilisation of pasture growth and long-term ‘safe’ utilisation for low and medium productivity land types (Goldfield on red soils, Narrow-leaved ironbark woodlands, Spotted gum ridges). On average, utilisation of TSDM was higher than utilisation of pasture growth on the high productivity land types (Softwood scrub and Black basalt), and lower than pasture growth on the low productivity Lancewood.

Table 7. Long-term ‘safe’ annual utilisations of pasture growth, simulated mean annual utilisation of pasture growth and the corresponding annual utilisation of total standing dry matter (TSDM) for six cleared and treed land types from 10 climate stations from 1980-2010.

Land types	Long-term ‘safe’ annual utilisation of pasture growth	Simulated mean annual utilisation of pasture growth (%)	Corresponding annual utilisation of TSDM (%)
Black basalt	30	30	40
Goldfields on red soils	25	25	25
Lancewood	15	14	10
Narrow-leaved ironbark woodlands	20	21	20
Softwood scrub	40	39	55
Spotted gum ridges	15	17	15

3.4.1 Pasture growth

The effects of grazing pressure (utilisation of TSDM), trees and land types on pasture growth are shown in Figure 14. Average annual pasture growth declines as grazing pressure increases, with pasture growth on cleared land types greater than that under trees. Pasture growth was less on the more heavily treed and less productive land types (Narrow-leaved ironbark woodlands, Spotted gum ridges, Lancewood), being least on Lancewood. Pasture growth on the high productivity Softwood scrub is more than double that of the other land types across all utilisations.

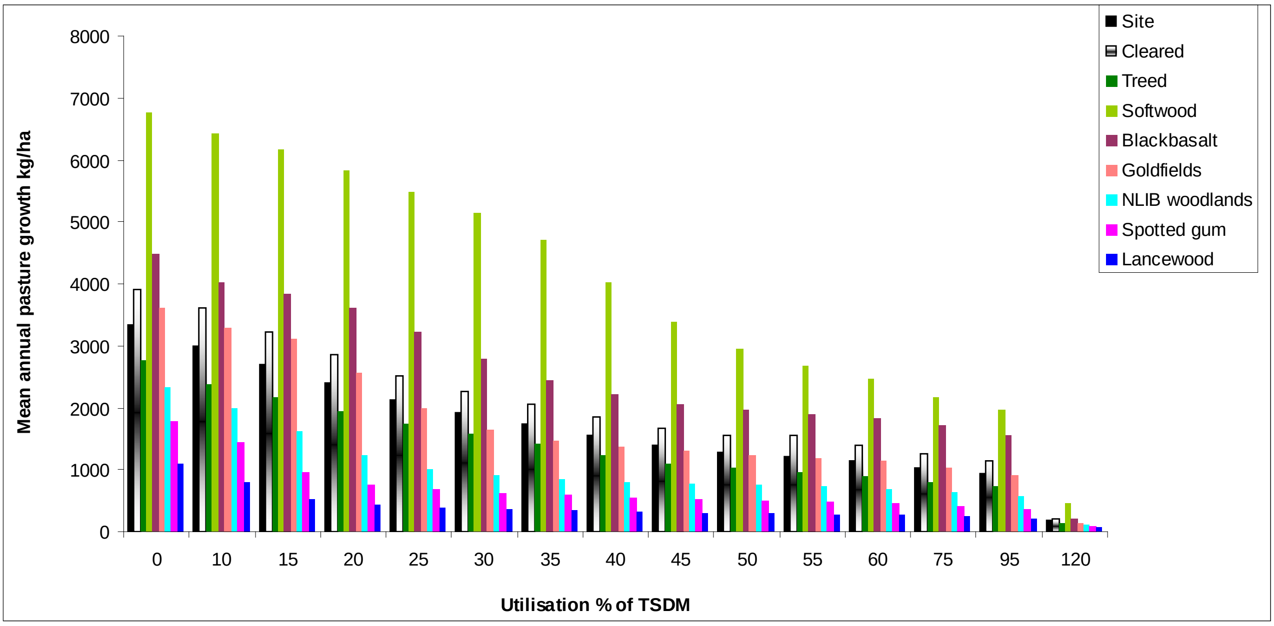
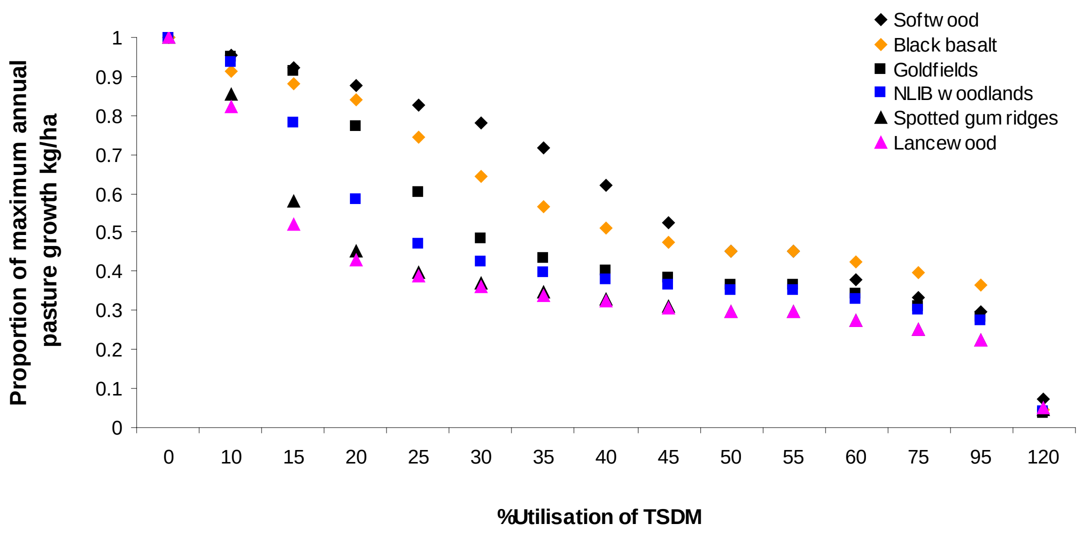


Figure 14. The effects of site, trees and land type on mean annual pasture growth (kg/ha) for 15 levels of utilisation (%) of total standing dry matter (TSDM) across 10 climate locations for simulation period 1980-2010.

Reductions in mean annual pasture growth as grazing pressure increased were correlated with land type productivity (Figure 15). Trees reduced pasture production with the land type productivity and tree basal area cover determining the magnitude of these reductions. Pasture productivity of heavily grazed (95% UR TSDM) cleared land types was 22-35% of maximum pasture growth. Equivalent high grazing pressures on treed land types reduced maximum pasture production by 70-85%. Softwood scrub and Black basalt land types were more robust to grazing, with low productivity and heavily treed land types (Spotted gum and Lancewood) less resilient to grazing.



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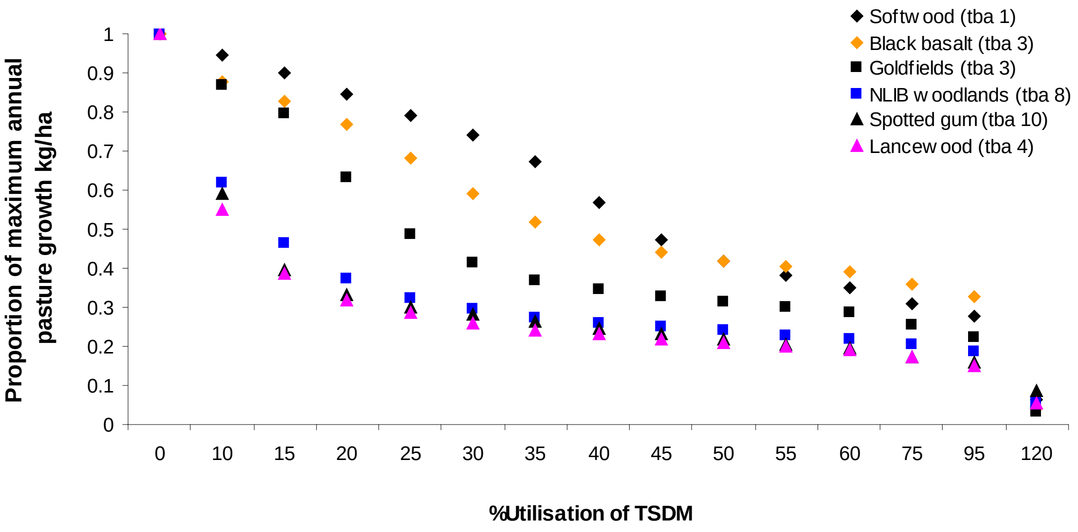


b)

Figure 15. Proportion of maximum mean annual pasture growth kg/ha for six a) cleared and b) treed land types at 15 levels of utilisation (%) of total standing dry matter (TSDM) across 10 climate locations for simulation period 1980-2010.

3.4.2 Surface cover

Maintenance of ground cover will vary between rangeland types and is dependent on factors such as soil type, slope, infiltration rates and pasture vegetation types (Scanlan and McIvor 2010). Minimum ground cover levels of 60% are recommended for Indian couch grass (*Bothriochloa pertusa*) dominated pastures in north-east Queensland (Post *et al.* 2006), while the recommended minimum level of ground cover in Mitchell grasslands is 50% (Scanlan and McIvor 2010). Reef Plan Water Quality targets stipulate “a minimum of 50% late dry season groundcover on dry tropical grazing land” by 2013. Increased grazing pressure (heavy stocking ~4-6ha/AE compared to moderate stocking ~8-10ha/AE) led to lower ground cover and reduced rainfall infiltration, and to an increase in the frequency and magnitude of runoff events at Wambiana (O’Reagain and Bushell 2011).

Simulated mean annual surface cover generally correlated with land type productivity, and was less under trees and declined with increasing grazing pressure (Figure 16). Average surface cover at the sites decreases from 0.75 to 0.25 as grazing pressure increases to very high utilisations. Surface cover on cleared land types was greater than that under trees, with a reduction in the magnitude of this difference at heavier grazing pressures (eg. difference between pasture growth from cleared and treed >0.15 with no grazing and 0.02 at 95% utilisation TSDM). Surface cover was less on the more heavily treed and less productive land types (Narrow-leaved ironbark woodlands, Spotted gum ridges, Lancewood), being least on Lancewood. Surface cover on the high productivity Softwood scrub is 0.5 or more when utilisations levels are less than 55%.

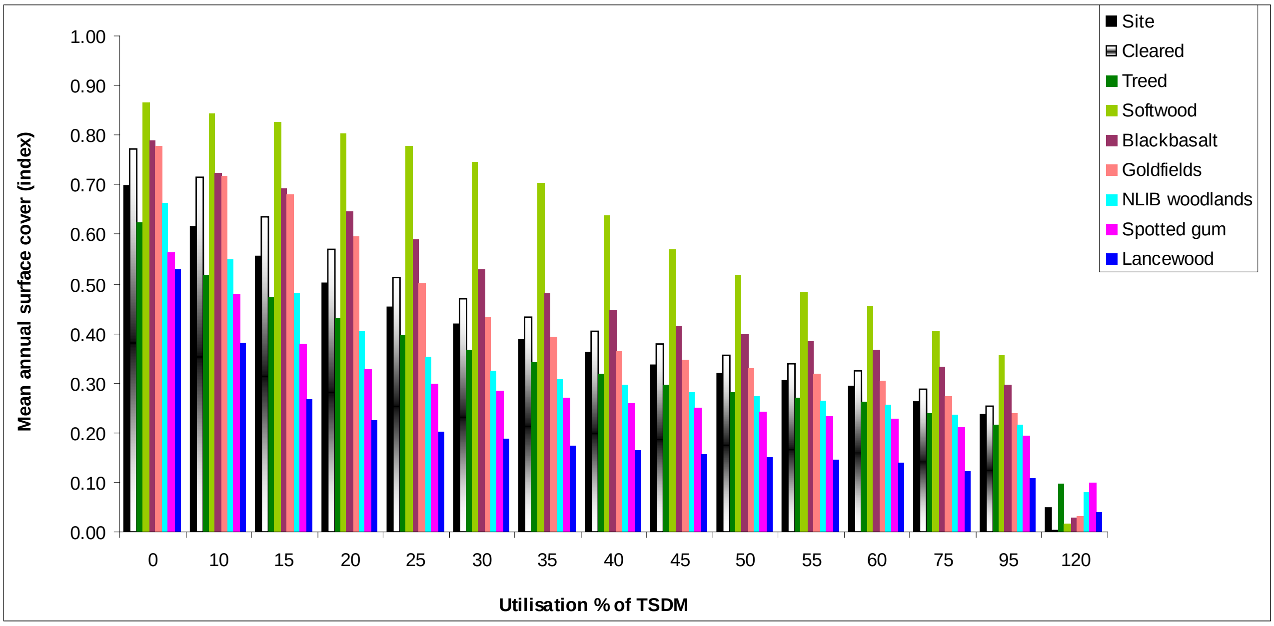
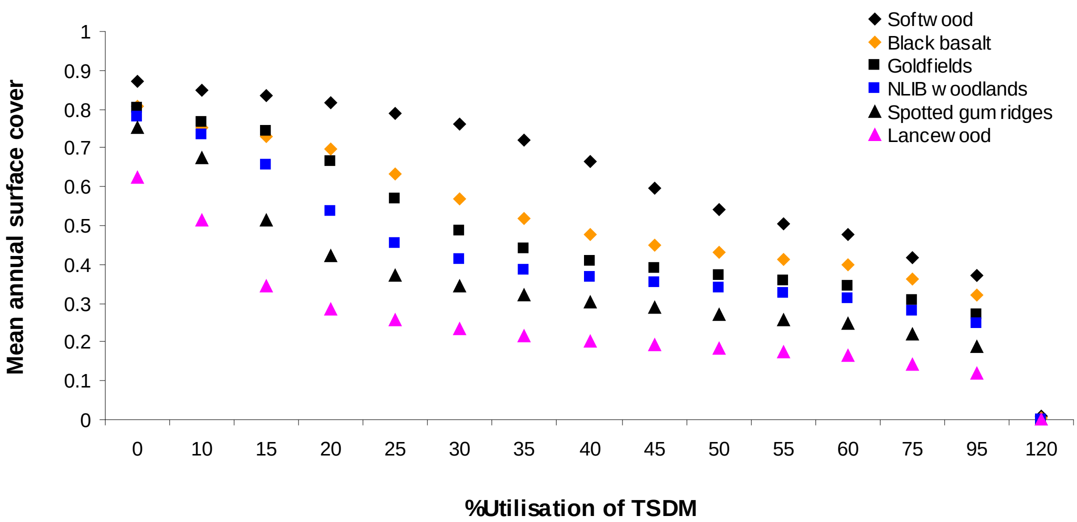


Figure 16. The effects of site, trees and land type on mean annual surface cover (index) for 15 levels of utilisation (%) of total standing dry matter (TSDM) across 10 climate locations for simulation period 1980-2010.

Surface cover of ungrazed or lightly grazed cleared Black basalt and Goldfields was similar (Figure 17). Across the range of grazing pressures, surface cover for cleared land types was highest on Softwood (~0.9 to ~0.4) and least on Lancewood (~0.6 to ~0.1). The interaction of climate variability (spatially and year to year) and grazing pressure reduced cleared land type surface cover by between 2-32%.



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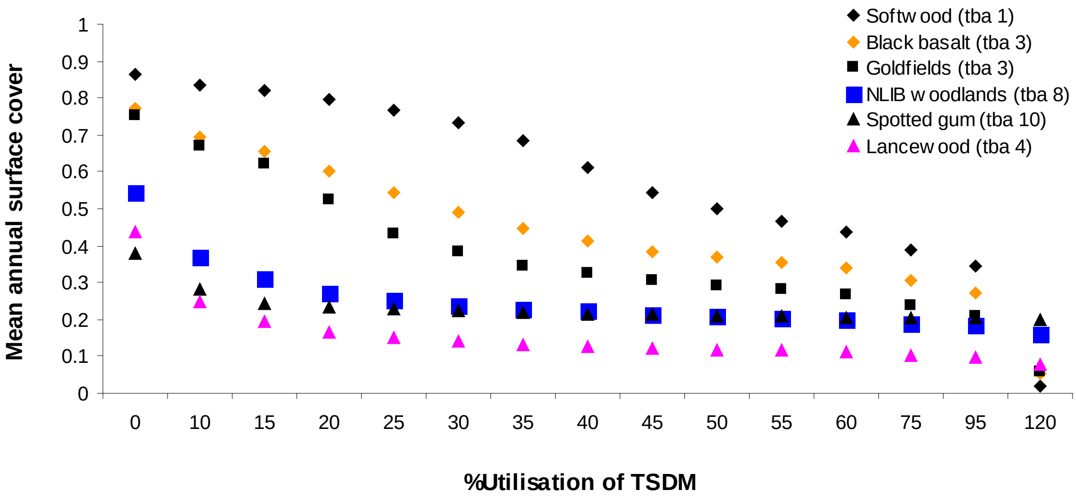


b)

Figure 17. Mean annual surface cover for six a) cleared and b) treed land types at 15 levels of utilisation (%) of total standing dry matter (TSDM) across 10 climate locations for simulation period 1980-2010.

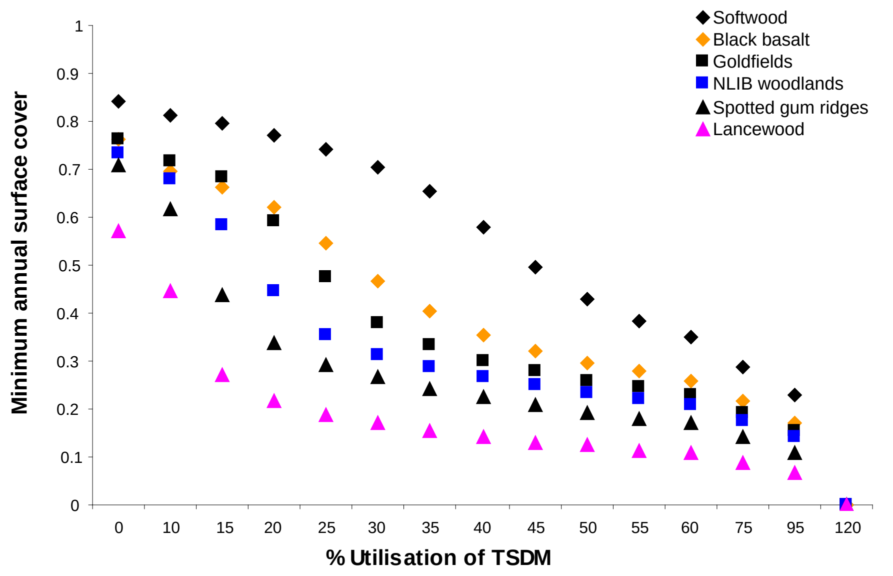
Pasture production, and hence surface cover, was reduced, and the variability in pasture production increased, with trees. Averaged across all grazing utilisations, surface covers on treed land types were between 5-68% lower than those of respective cleared land types. These reductions in surface cover were highest on the lower productive and more heavily treed land types (Narrow-leaved ironbark 68%, Spotted gum ridges 53%, Lancewood 59%). Trees had the greatest impact in reducing surface cover, compared to cleared land types, on the lightly grazed, low productivity land types with high tree basal area. Surface covers on the more heavily grazed (>35% TSDM) treed Narrow-leaved ironbark and Spotted gum ridges land types were similar (~0.2) with tree litter contributing to the surface covers. At the extreme of grazing pressure (120% TSDM =1000 head km^{-2}) when all pasture is eaten leaving only bare ground (cleared land types Figure 17a), the contribution of tree litter to surface cover results in surface covers on tree land types that are greater than cleared land types, and that increase with tree basal area (e.g. Narrow-leaved ironbark 0.16, Spotted gum ridges 0.2, Lancewood 0.08 Figure 17b).

3.4.2.1 Minimum annual surface cover

For both cleared and treed land types, the mean (1980-2010, 10 climate stations) minimum annual surface cover was correlated with estimated land type productivities, and was highest on Softwood scrub and lowest on Lancewood (Figure 18). Minimum covers on cleared Softwood scrub ranged from 0.84 on ungrazed land to no cover on the heavily grazed Softwood scrub. On the cleared low productivity Lancewood, minimum annual surface covers ranged from 0.5 with no grazing to 0.0 with heaviest grazing pressure. Minimum surface covers on the lightly grazed (< 25% TSDM) treed land types were approximately 10% lower than respective cleared land types. The contribution of tree litter to surface cover was the main determinant of minimum surface cover on the more heavily treed land types (Spotted gum ridges, Narrow-leaved ironbark, Lancewood) when utilisation of TSDM was above 25%, and resulted in higher cover than cleared on the more productive land types (Goldfields, Black basalt, Softwood scrub) when grazing pressure was very high (>60% TSDM).

Minimum surface cover above 50% occurred on cleared land types when ungrazed (Lancewood), very lightly grazed (Spotted gum), and lightly grazed (15-20% UR TSDM) medium productivity

(Goldfields, Narrow-leaved ironbark). When utilisation of TSDM was ≤ 25% for cleared Black basalt or ≤ 45% for cleared Softwood scrub minimum surface cover was above 50%. On treed Lancewood, Narrow-leaved ironbark and Spotted gum minimum surface cover of 50% was not achieved. Minimum annual surface cover above 50% was reached with utilisations of 15% for Goldfields, 20% for Black basalt and 40% for Softwood scrub treed land types.



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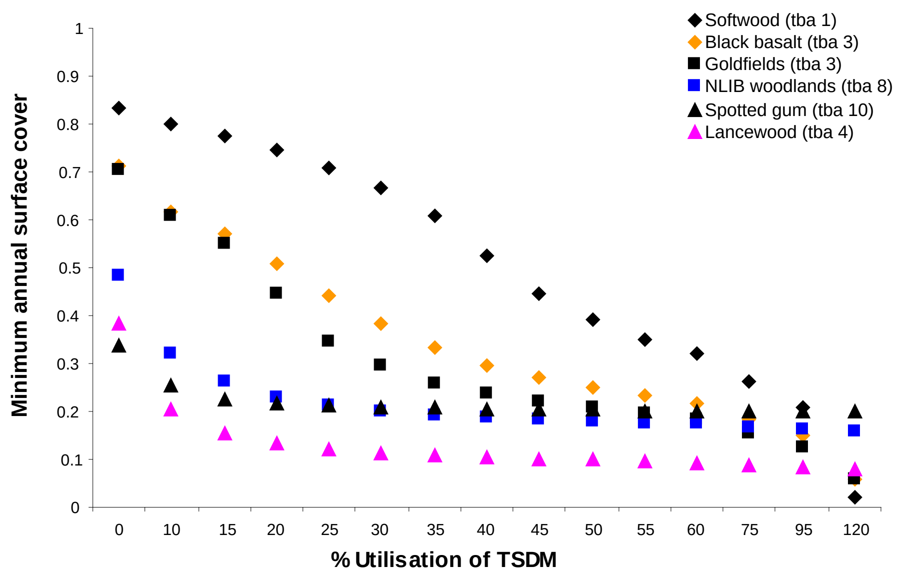


b)

Figure 18. Mean annual minimum surface cover for % utilisation of TSDM of six a) cleared and b) treed land types across 10 climate locations from 1980-2010.

3.4.3 Runoff and soil loss

Simulated mean annual runoff generally correlated with land type productivity, was greater under trees at low pasture utilisation (≤ 40% TSDM) but less under trees at high grazing pressures (≥45% TSDM), and increased with increasing grazing pressure (Figure 19). Average annual runoff at the sites increased from < 50 mm with no grazing to nearly 250 mm with very high utilisations. Runoff was more on the more heavily treed and less productive land types (Narrow-leaved ironbark woodlands, Spotted gum ridges, Lancewood), being most on Lancewood.

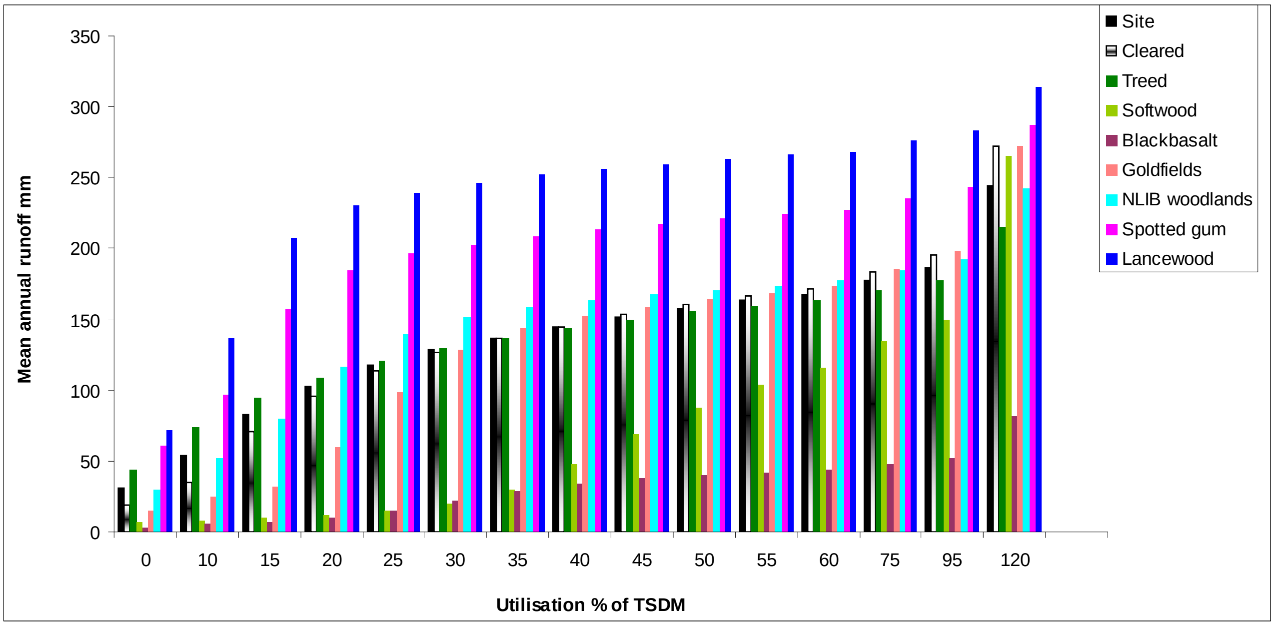
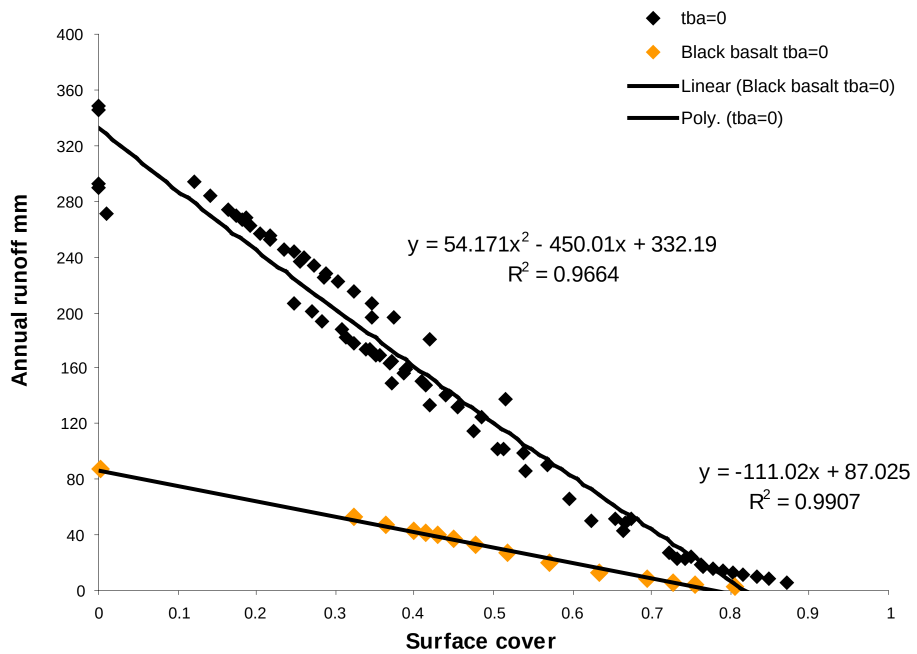


Figure 19. The effects of site, trees and land type on mean annual runoff for 15 levels of utilisation (%) of total standing dry matter (TSDM) across 10 climate locations for simulation period 1980-2010.

The effect of surface cover on mean annual runoff across pasture utilisations was similar for all land types, except Black basalt where runoff was set to be third of that from all other land types (Figure 20). Averaged across all climates locations, mean annual runoff from Black basalt was 88 mm (cleared) and 76 mm (treed) with bare ground, and 27 (cleared) mm and 17 mm (treed) when surface cover was > 50%. For all other land types, surface cover-runoff response curves were similar for cleared and treed land types (see fitted 2nd order polynomial equations R^2 = 0.95, 0.94). Across the range of grazing pressures, for 0%, 50%, 80% surface cover annual runoff was 332mm, 121mm, 7mm respectively from cleared land types, and 315mm, 77mm, 13mm respectively from treed land types. Runoff was less under trees when tree litter provided more surface cover than that of cleared land types (eg. high tba, low productivity, high grazing pressures).



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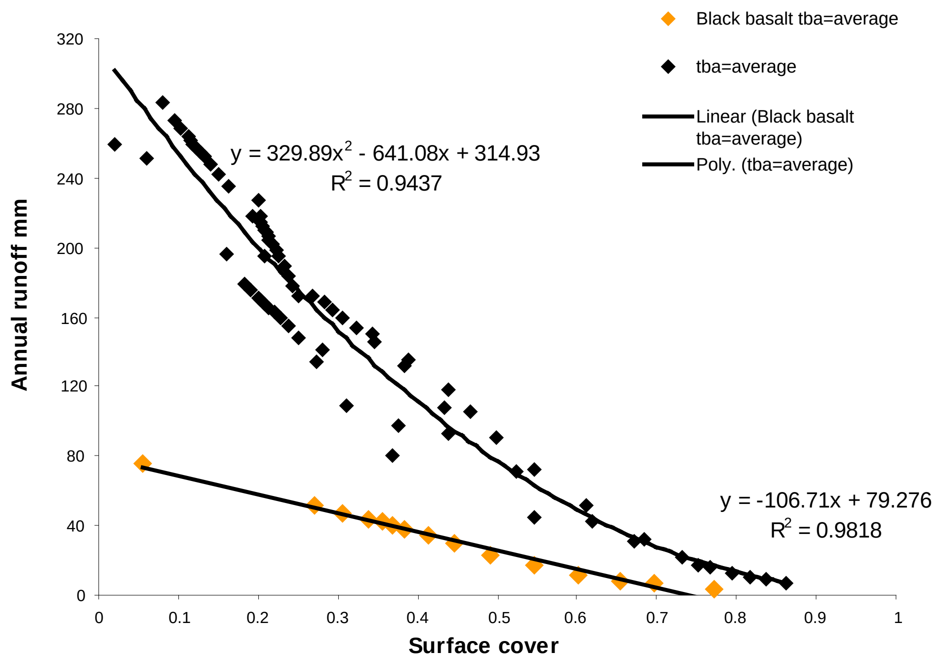


b)

Figure 20. Mean annual runoff and mean surface cover for six a) cleared and b) treed land types for 15 utilisation levels across 10 climate locations from 1980-2010. Fitted curvilinear and linear trendlines, equations and R^2 are shown.

Simulated mean annual soil loss generally correlated with land type productivity, was greater under trees except at very high pasture utilisation (≥ 95% TSDM), and increased with increasing grazing pressure (Figure 21). Average annual soil loss at the sites increased from < 0.5 tonne/ha with no grazing to 6 tonne/ha with very high utilisations. Soil loss was more on the more heavily treed and less productive land types (Narrow-leaved ironbark woodlands, Spotted gum ridges, Lancewood), being most on Lancewood.

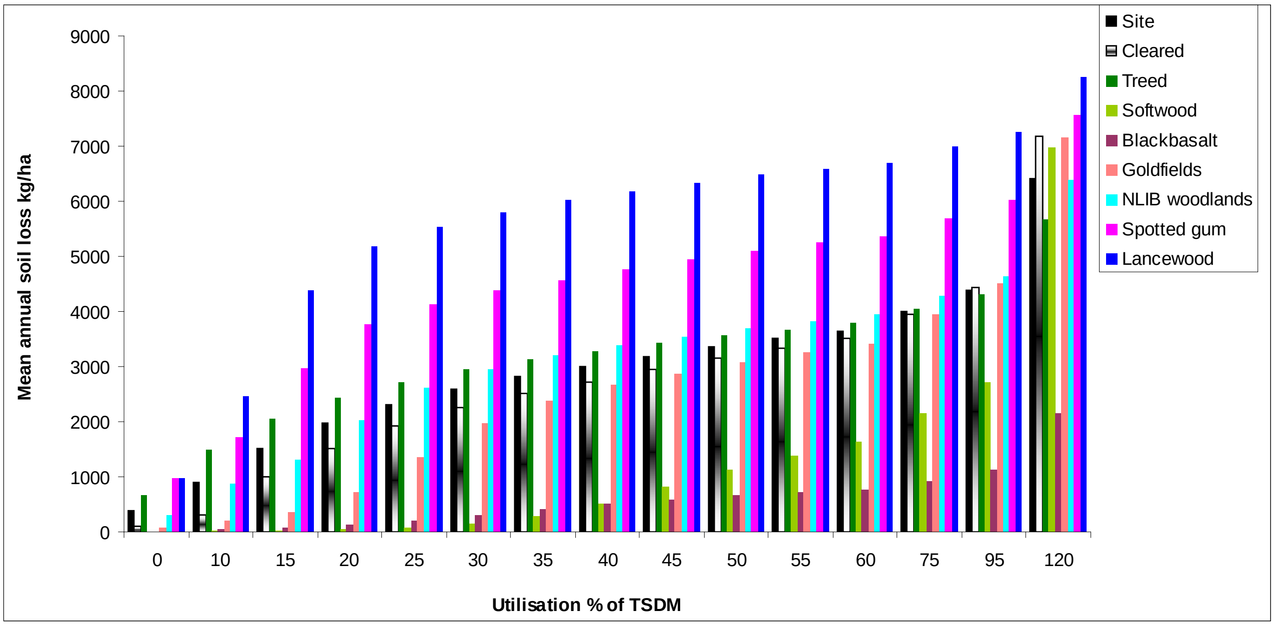
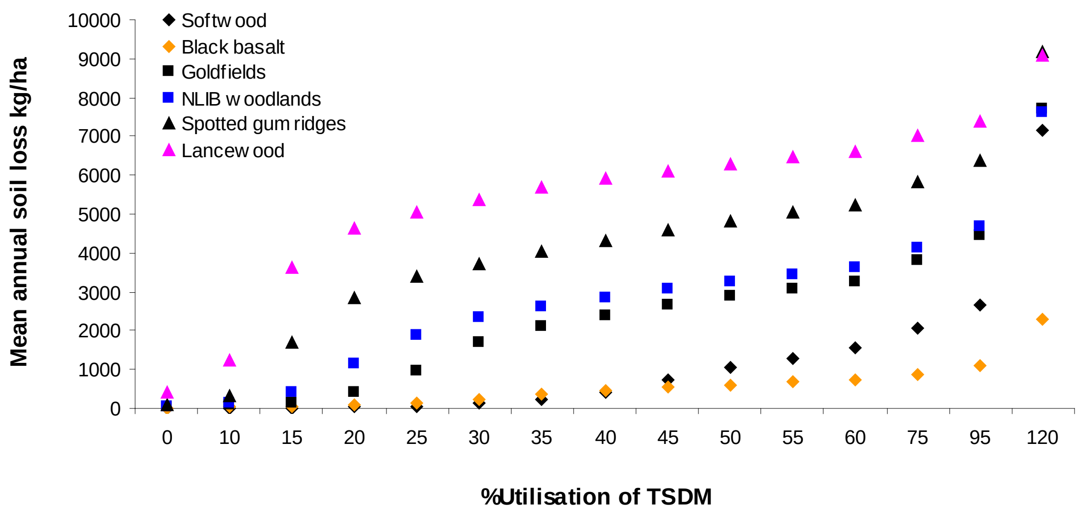


Figure 21. The effects of site, trees and land type on mean annual soil loss for 15 levels of utilisation (%) of total standing dry matter (TSDM) across 10 climate locations for simulation period 1980-2010.

Across the range of grazing pressures, the greatest sediment losses occurred on low productivity Lancewood and Spotted gum ridges land types (Figure 22). Sediment losses on cleared land types ranged from a minimum with no grazing (~ 10-395 kg/ha) to maximum on heavily grazed pastures (~ 2300-9150 kg/ha). The increased variability in pasture production under trees resulted in generally higher sediment losses from treed land types compared to cleared land types with pasture utilisations up to 60% TSDM. However, the contribution of tree litter to surface cover on the heavily grazed pastures (>75% TSDM) resulted in sediment losses less than cleared land types.



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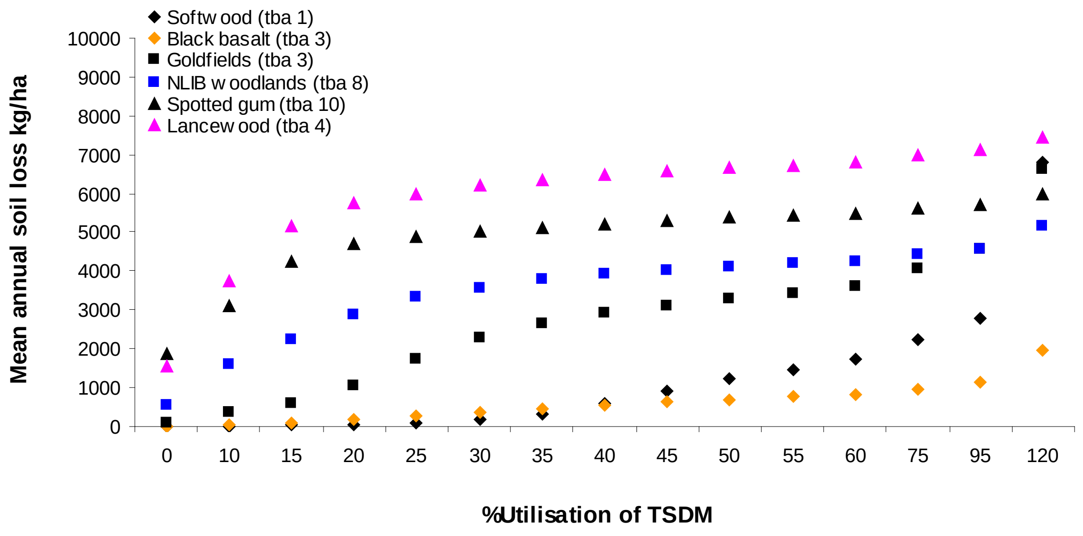

b)

Figure 22. Mean annual soil loss (kg/ha) for six a) cleared and b) treed land types for 15 utilisation levels across 10 climate locations from 1980-2010.

Surface cover 50%

On cleared land types, a range of pasture utilisations achieved mean annual surface cover greater than 50% (Table 8). Softwood scrub pastures were more resilient to grazing achieving 50% surface cover at much higher utilisations of pasture (55%) than either Lancewood (10%) or Narrow- leaved ironbark woodlands (20%). All minimum annual surface covers (38-47%) were up to 10% less than the mean covers on cleared land types (Table 8). Runoff from Black basalt, where it was set to be a third of other land types, was 28 mm with corresponding soil loss of 356 kg/ha at 50% surface cover. At 50% cover, mean annual runoff for other land types ranged between 91 mm (Goldfields) and 137 mm (Spotted gum) with corresponding soil losses of 964 kg/ha to 1684 kg/ha.

On treed land types, pasture utilisations to achieve 50% surface cover were lower than the corresponding cleared land type utilisations. Runoff on Narrow-leaved ironbark woodlands was relatively low (~45mm) with 50% surface cover but this was only achieved when there was no grazing. The low productivity treed Lancewood and Spotted gum land types did not achieve 50% surface cover (Table 8). Minimum annual surface cover (44-48%) were again up to 10% less than the mean covers on treed land types.

Averaged across all climates and 31 years, surface covers greater than 50% were achieved on cleared land types with utilisation of TSDM that corresponded to the “safe” long-term average utilisation of pasture growth (see Table 7 & Table 8). With the impact of trees, greater than 50% surface covers were achieved with utilisation of TSDM that were lower than “safe” utilisations (see Table 7 & Table 8). Minimum surface covers were below 50% on all cleared and treed land types at the same utilisations (Table 8).

Table 8. Percent utilisation of total standing dry matter (TSDM), mean and minimum annual runoff, mean annual soil loss across 10 climate stations from 1980-2010 when mean surface cover is greater than 50% for six land types. na = 0.5 mean surface cover was not achieved

		Softwood scrub	Black basalt	Goldfields on red soils	Narrow-leaved ironbark woodlands	Spotted gum ridges	Lancewood
Cleared	Utilisation of TSDM (%)	55	35	25	20	15	10
	Mean & (min) surface cover %	50 (38)	52 (40)	57 (47)	54 (44)	51 (43)	51 (44)
	Mean annual runoff mm/yr	102	28	91	100	137	102
	Mean annual soil loss kg/ha/yr	1304	356	964	1146	1684	1217
Treed	Utilisation of TSDM (%)	45	25	20	0		
	Mean & (min) surface cover %	55 (44)	55 (44)	53 (45)	55 (48)	na	na
	Mean annual runoff mm/yr	72.8	16.8	71.2	44.6	>97	>93
	Mean annual soil loss kg/ha/yr	928	257	1058	550	>1857	>1535

3.5 "Safe" long-term average utilisation

Simulated GRASP outputs for the 'safe' long-term average utilisation of TSDM (see Table 7) for six cleared and treed land types for each of the 10 climate stations are shown in Table 9 and Table 10.

Safe utilisation rates are, for the most part, determined by factors (climate, land type, land condition) that affect pasture growth at a particular location and, as such, are generally not transferable across regions, climates, land types and vegetation types (McIvor *et al.* 2010). Differences in safe utilisations between regions may be expected from differences in average rainfall, rainfall variability, fertility and grazing tolerance (Day *et al.* 1997b). Safe utilisation rates tend to be higher in areas of higher fertility, more resilient pastures, longer growing seasons (McKeon *et al.* 2009). Lower safe utilisations rates are associated with areas that have shorter growing seasons and more variable climate (inter-annual and seasonality) (Hall *et al.* 1988). Safe utilisations of 27% of annual growth have been estimated for central Burnett land types (Day *et al.* 1997b), of 30% for northern speargrass communities (Scanlan *et al.* 1994), and 21% for forage for south-west Queensland (Johnson *et al.* 1996). Safe utilisation for each region approximated 20% over the growing season (Day *et al.* 1997b). The safe long-term pasture utilisations (Whish 2011) used for land type simulations correlated to estimated land type productivity rankings with sustainable use of pasture highest on Softwood scrub (40% pasture growth, 55% TSDM) and Black basalt (30% pasture growth, 40% TSDM), and lowest on Spotted gum (15% pasture growth, 15% TSDM) and Lancewood (15% pasture growth, 10% TSDM).

3.5.1 Pasture growth

Modelling captured the dominant influences of climate and land type on pasture productivity with a similar and wide range of pasture growths simulated across climates for a land type and across land types for a particular climate. The following extremes of land type productivity (high and low) and climate (highest and lowest annual rainfall) illustrate the variability of pasture growth captured within modelling:

- Softwood scrub cleared (1418-4765 kg/ha/yr), treed (1221-4506 kg/ha/yr)
- Proserpine cleared land types (1419-4848 kg/ha/yr), treed (1113-4756 kg/ha/yr)
- Lancewood cleared (595-1419 kg/ha/yr), treed (113-1113 kg/ha/yr)
- Alpha cleared land types (727-1418 kg/ha/yr), treed (576-1221 kg/ha/yr)

Simulated responses of pasture productivity to grazing, climate and land type influences are in broad agreement with reported data. Rainfall was a major driver of the year to year variation in pasture productivity and ground cover, although management also played a significant role in a long-term grazing trial at Wambiana near Charter Towers (O'Reagain and Bushell 2011). Average annual pasture production (yield) measured from exclosures (no grazing) at Wambiana from 1999-2005 varied from approximately 2000 kg/ha for more productive land types (Box and Brigalow) to 1350 kg/ha for less productive land types (Blackbutt and Ironbark). These pasture yields compare favourably with simulated average (1980-2010) pasture growth on grazed (safe utilisation) Goldfields with Charters Towers climate - 2198 kg/ha for cleared pasture and 1477 kg/ha for treed pastures (see Table 9 & Table 10).

3.5.2 Carrying capacity

Long-term carrying capacity of land types varies in relation to the fertility and productivity of the land type and its resilience to grazing, and is reflected in different safe pasture utilisations (McIvor *et al.* 2010). Simulated carrying capacities were correlated with climate, productivity and tree basal area, with the more productive land types in wetter environments simulated to carry more stock over the long term (see Table 9 & Table 10). Safe long-term stocking rates on cleared land varied by 2-4 times with climate (e.g. Black basalt 2ha/AE Proserpine cf. 8 ha/AE Ulcanbah), and 4-8 times with land type (e.g. Black basalt 2ha/AE cf. Lancewood 15 ha/AE at Proserpine). Trees, through competition for water and nutrients, amplify the impacts of climate and land type variability on pasture production. Treed land type carrying capacities varied between 3-17 times with climate (e.g. Narrow-leaved ironbark woodlands 11ha/AE Proserpine cf. 100 ha/AE

Table 9. Mean GRASP outputs for "safe" long-term average percent utilisation of total standing dry matter (UR%TSDM) for six cleared land types at 10 climate stations from 1980-2010.

Land type	Productivity	UR% TSDM	GRASP outputs	Alpha	CT	Duar	Marlb	MtFox	Mund	Prosp	Spring	Ulcan	Wand
Softwood scrub	High	55	Pasture growth kg/ha/yr	1418	2765	2938	3371	4091	3397	4765	1874	1669	2194
			Stocking rate ha/AE	5.2	2.5	3.8	2.2	1.8	2.3	1.5	3.9	4.0	3.4
			Surface cover	0.33	0.49	0.51	0.56	0.63	0.58	0.69	0.42	0.39	0.44
			Runoff mm//yr	83	95	81	100	142	59	226	67	86	79
			Soil loss kg/ha/yr	1771	1439	1165	1182	1055	779	1270	1206	1837	1335
Black basalt	High	40	Pasture growth kg/ha/yr	1122	2260	2441	3172	3983	2857	4848	1338	996	1637
			Stocking rate ha/AE	8.5	3.7	2.6	3.0	2.3	3.0	1.9	6.4	8.2	5.7
			Surface cover	0.3	0.45	0.5	0.56	0.63	0.57	0.7	0.37	0.31	0.39
			Runoff mm//yr	27	31	26	31	44	18	76	22	31	27
			Soil loss kg/ha/yr	593	531	378	378	369	245	454	449	716	479
Goldfields	Medium	25	Pasture growth kg/ha/yr	727	2198	2370	2902	2938	3171	3110	2289	1365	2206
			Stocking rate ha/AE	9.3	5.3	5.1	4.2	4.0	4.0	3.8	5.3	8.3	5.9
			Surface cover	0.23	0.54	0.57	0.64	0.65	0.67	0.67	0.57	0.41	0.56
			Runoff mm//yr	116	87	77	74	123	42	223	45	89	67
			Soil loss kg/ha/yr	2814	1121	957	558	843	253	1295	511	1768	816
Narrow-leaved ironbark woodlands	Medium	20	Pasture growth kg/ha/yr	1181	1798	1999	2329	2517	2634	2715	1832	1121	1732
			Stocking rate ha/AE	12.7	7.8	7.2	6.3	5.6	5.7	5.2	8.0	11.8	9.0
			Surface cover	0.39	0.51	0.54	0.59	0.62	0.64	0.66	0.53	0.39	0.51
			Runoff mm//yr	79	99	83	91	137	49	238	53	89	77
			Soil loss kg/ha/yr	1564	1450	1072	877	1072	354	1530	672	1809	1056
Spotted gum ridges	Low	15	Pasture growth kg/ha/yr	1100	1379	1750	2078	2074	2121	2343	1484	890	1630
			Stocking rate ha/AE	17.5	13.2	10.9	9.3	9.1	9.3	7.98	13.2	19.2	12.3
			Surface cover	0.41	0.45	0.53	0.59	0.59	0.59	0.62	0.49	0.36	0.51
			Runoff mm//yr	111	154	111	115	182	85	307	83	121	101
			Soil loss kg/ha/yr	2007	2723	1473	1063	1605	799	2273	1120	2468	1308
Lancewood	Low	10	Pasture growth kg/ha/yr	990	1109	1296	1351	1311	1331	1419	1097	595	1188
			Stocking rate ha/AE	23.3	20.4	17.9	17.2	17.2	17.5	15.6	21.3	38.5	20
			Surface cover	0.47	0.5	0.55	0.56	0.55	0.56	0.58	0.5	0.33	0.52
			Runoff mm//yr	74	105	73	83	132	65	222	62	125	76
			Soil loss kg/ha/yr	1051	1385	740	775	1300	618	1938	761	2746	857

Table 10. Mean GRASP outputs for "safe" long-term average percent utilisation of total standing dry matter (UR%TSDM) for six treed land types at 10 climate stations from 1980-2010. tba=tree basal area.

Land type	Productivity	UR% TSDM	GRASP outputs	Alpha	CT	Duar	Marlb	MtFox	Mund	Prosp	Spring	Ulcan	Wand
Softwood scrub (1 tba)	High	55	Pasture growth kg/ha/yr	1221	2578	2682	2881	3658	2681	4506	1500	1386	1961
			Stocking rate ha/AE	6.1	2.6	2.8	2.6	2.0	2.8	1.6	4.7	4.6	3.8
			Surface cover	0.3	0.46	0.49	0.51	0.6	0.5	0.68	0.37	0.35	0.41
			Runoff mm//yr	82	92	81	110	154	70	232	70	87	78
			Soil loss kg/ha/yr	1849	1494	1242	1508	1360	1180	1426	1418	1957	1397
Black basalt (3 tba)	High	40	Pasture growth kg/ha/yr	730	1992	1697	2394	3324	1689	4756	811	996	1096
			Stocking rate ha/AE	11.9	3.9	5.3	4.0	2.7	4.8	1.9	9.8	8.2	8.5
			Surface cover	0.25	0.41	0.41	0.48	0.57	0.43	0.69	0.28	0.31	0.31
			Runoff mm//yr	26	29	29	33	53	22	78	23	31	26
			Soil loss kg/ha/yr	623	558	525	531	617	424	512	551	716	540
Goldfields (3 tba)	Medium	25	Pasture growth kg/ha/yr	576	1477	1787	1956	2676	1950	3093	730	611	1086
			Stocking rate ha/AE	20.8	7.4	6.9	6.2	4.4	6.1	3.8	15.4	15.9	10.9
			Surface cover	0.25	0.42	0.46	0.49	0.61	0.52	0.66	0.3	0.27	0.36
			Runoff mm//yr	94	103	81	109	126	64	229	85	101	87
			Soil loss kg/ha/yr	2281	1996	1408	1776	1165	1017	1504	2033	2448	1831
Narrow-leaved ironbark woodlands (8 tba)	Medium	20	Pasture growth kg/ha/yr	70	495	405	711	963	397	1202	148	107	193
			Stocking rate ha/AE	100	23.8	31.3	16.9	13.5	28.6	11.1	76.9	100	59
			Surface cover	0.09	0.29	0.26	0.33	0.39	0.26	0.46	0.19	0.17	0.2
			Runoff mm//yr	158	117	103	126	193	83	367	75	100	95
			Soil loss kg/ha/yr	4141	2694	2488	2871	3744	1993	5708	1964	2631	2431
Spotted gum ridges (10 tba)	Low	15	Pasture growth kg/ha/yr	79	206	161	283	717	127	694	74	69	94
			Stocking rate ha/AE	200	62.5	100	55.6	23.3	125	25.6	200	200	167
			Surface cover	0.2	0.24	0.22	0.26	0.36	0.21	0.34	0.2	0.2	0.21
			Runoff mm//yr	113	163	153	172	207	123	495	101	123	128
			Soil loss kg/ha/yr	2968	4079	3960	4224	4368	3163	10512	2646	3224	3355
Lancewood (4 tba)	Low	10	Pasture growth kg/ha/yr	144	315	415	644	913	301	1113	117	113	140
			Stocking rate ha/AE	250	62.5	55.6	35.7	25.6	71.4	20.4	200	167	143
			Surface cover	0.19	0.22	0.27	0.35	0.44	0.22	0.51	0.12	0.12	0.14
			Runoff mm//yr	84	182	150	150	194	150	278	139	156	170
			Soil loss kg/ha/yr	2211	4336	3400	3048	3268	3678	3401	3640	4035	4429

Alpha), and 10-50 times with land type (e.g. Softwood 5ha/AE cf. Spotted gum ridges 200 ha/AE at Ulcanbah).

Grazier estimated stocking rates for 20 pasture communities in central Queensland ranged between approximately 2 -7 ha/AE (Day *et al.* 1997b), and for 45 properties in Dalrymple shire from 4-33 ha/AE (Scanlan *et al.* 1994). Across all land types simulated 'safe' stocking rates at Mundubbera ranged from 3-18 ha/AE on cleared and 3-125 ha/AE on treed land types, and at Charters Towers from 3-18 ha/AE on cleared land and 3-118 ha/AE with tree cover. Simulated safe stocking rates differ substantially from grazier estimated stocking rates with low productivity land types and high tree cover. Any direct comparisons between simulated and grazier estimated stocking rates need to consider the scale (e.g. land type, pasture community, property), wide range of modelled land types and heterogeneity of tree cover. In reality a paddock may consist of several land types with each land type varying in soils, 'patchiness' of pasture sward and tree cover. A mix of cleared and treed areas is common within one land type, with variation of cover extending within the treed areas from singular to scattered to dense. The pasture production from paddocks where the trees are uniformly distributed (as simulated in GRASP) may be half that where the distribution of trees is highly variable (Scanlan 2002). Additionally, lower tree basal areas occur in monsoonal areas of the north than the moderate to high tree basal areas that occur in southern Queensland (Scanlan 2002).

3.5.3 Surface cover

Simulated safe utilisation of pasture on all cleared land types resulted in an average (1980-2010) surface cover of 50% or more at most locations bar the two driest at Alpha and Ulcanbah (see Table 9 & Table 10). Additionally, mean surface covers of slightly less than 50% occurred on the heavier clay soils of Softwood scrub and Basalt land types where soil water supply and, hence transpiration, was limited by low rainfall at Springvale and Wandoan. The same 'safe' pasture utilisations (as for cleared land types) caused some degradation of treed pastures. Average surface cover of 50% was achieved only on the more productive, lightly treed land types (Softwood scrub, Black basalt, Goldfields) at the wettest locations (Marlborough, Mt Fox, Mundubbera, Proserpine).

3.5.3.1 Time series data

The effects of climate and trees on surface cover of Goldfields on red soils grazed at 'safe' utilisation (25% UR TSDM) over the 31 year simulation period (1980-2010) are shown in Figure 23. The high rainfall at Proserpine limits the impact of trees on pasture growth and surface cover, and enables close to maximum pasture production and surface cover to be achieved for the majority of years. In contrast, at the lower rainfall locations (Ulcanbah and Charters Towers) pasture production and surface cover fluctuates greatly in response to wet and dry periods, with the impact of trees exacerbating these fluctuations.

The impacts of grazing and trees on surface cover of Goldfields on red soils grazed at three levels of utilisation (0%, 25%, 95% UR TSDM) over the 31 year simulation period (1980-2010) are shown in Figure 24. The maximum surface cover achievable for this moderate productivity land type at Charters Towers (average annual rainfall of 634 mm) is 80% for cleared pastures and 76% for treed pastures. Even without the impact of grazing pasture growth and surface cover are reduced during the driest years of below average rainfall (1983-1988; 1992-1997; 2002-2006). The interaction of climate and grazing amplify the adverse impacts on pasture growth and cover during poor growing seasons. During these dry periods, particularly when trees were competing with grasses for moisture, minimum surface covers (10%) occurred whether pastures were grazed at 'safe' or very heavy utilisation levels.

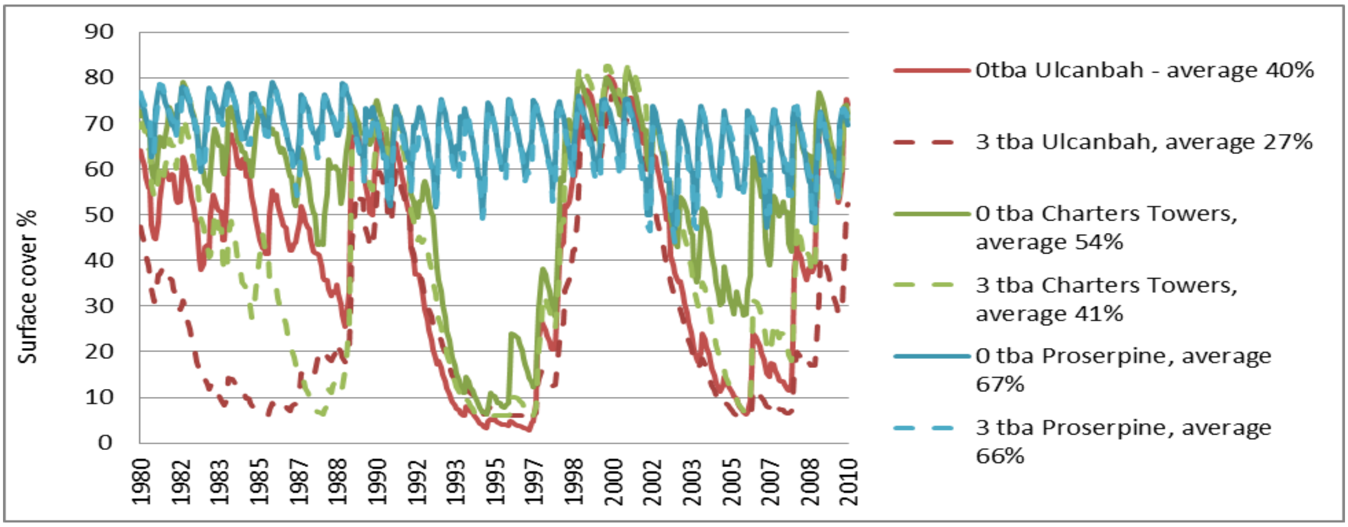

Figure 23. Time series (1980-2010) monthly surface cover (%) for cleared (0 tba) and treed (3 tba) grazed (25% utilisation TSDM) Goldfields on red soils pastures at Ulcanbah, Charters Towers and Proserpine. Average surface cover for 1980-2010 is shown in legend.

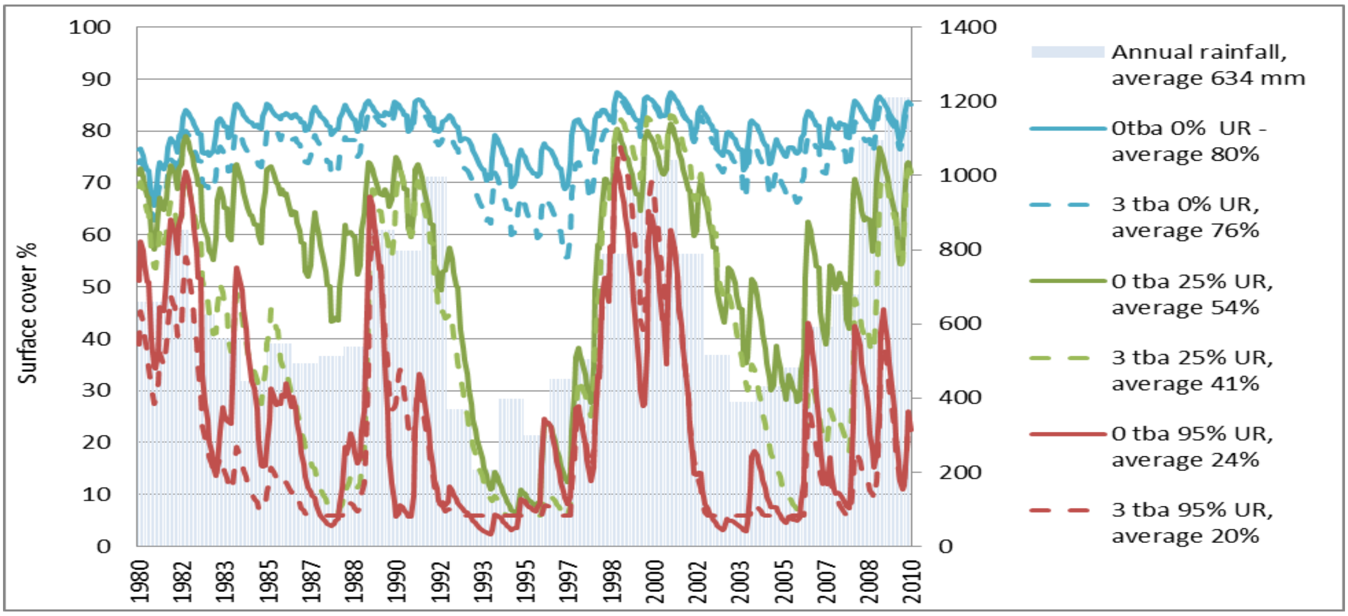

Figure 24. Time series (1980-2010) monthly surface cover (%) for cleared (0 tba) and treed (3 tba) Goldfields on red soils pastures at Charters Towers for three grazing utilisations (0%, 25% and 95% utilisation TSDM). Secondary y axis is annual rainfall mm for Charter Towers. Average annual rainfall and surface cover for 1980-2010 is shown in legend.

A Reef Plan and Reef Rescue target for grazing lands is to achieve a minimum of 50% late dry season groundcover. The maximum surface cover (with no grazing) that can be achieved on moderately productive Goldfields land type at Charters Towers ranges between 55-85%. However, the year-to-year variability in surface cover increases when pastures are grazed and achieving > 50% cover occurs less frequently. When stocked at long term safe levels (25% UR TSDM) an average of 54% cover was achieved on cleared pastures; however, surface cover was less than

50% for a third of the years. Under trees the variability in surface cover increased with an average 41% surface cover achieved with almost two-thirds of the years achieving >50%.

Modelling suggests that achieving a minimum of 50% late dry season groundcover is not practical for grazed pastures, and that runoff and soil loss could be significant during the drier years where surface covers are below 30%. End of dry season cover of 40% may be sufficient to significantly reduce soil and nutrients loss from hillslopes (Roth *et al.* 2004), and is likely to be achieved on conservatively managed grazing lands. Adopting management practices that reduce pasture utilisation whist maintaining animal productivity (strategic burning to reduce patch grazing, inclusion of water points, spelling to improve pasture productivity, control regrowth), particularly of less productive, more heavily treed pastures, will assist in achieving the Reef Plan and Reef Rescue minimum of 50% late dry season groundcover target.

3.5.4 Runoff

Runoff from long-term 'safe' pasture utilisation on cleared land types ranged from 18-307 mm/yr and on treed land types 78-495 mm/yr across all climates (see Table 9 & Table 10). With pasture utilisations equivalent to 'safe' levels runoff at the wettest location (Proserpine) was highest on the low productivity cleared land types (222-307 mm/yr or 16-22% of rainfall) and on the most heavily treed land types (278-495 mm/yr or 20-35% of rainfall). A study at Springvale (Silburn *et al.* 2011) found runoff was high (200-300mm/yr or 30-50% of rainfall) with low cover and low (35mm/yr or 5.9% of rainfall) with high cover (>50% cover). Predicted 31 year average runoff (22-83mm/yr or 3-14% of rainfall) at Springvale from 'safe' pasture utilisation of cleared land types with high surface cover (~0.4-0.6) was slightly higher but within range of the 7 year average measured by Silburn *et al.* (2011). Predicted runoff from treed land types (23-139mm/yr or 3-24% of rainfall) with low to moderate surface covers (0.1-0.3) achieved with 'safe' pasture utilisations were below the high levels (30-50% of rainfall) recorded at Springvale. Runoff from Black basalt at Springvale (3.7% of rainfall) with moderately high cover (0.3-0.4) achieved with safe utilisation of pastures is lower than the average from sandstone-mudstone (Silburn *et al.* 2011), but within range of reported average annual runoff from heavy clays (2-5% of rainfall) (Silburn *et al.* 2007, Thornton *et al.* 2007, Freebairn *et al.* 2009). Use of runoff and soil loss study site data may permit evaluation of Black basalt land type parameters for estimating runoff and possible improvement in the runoff / soil loss parameters used in this modelling.

3.5.5 Soil loss

Soil losses from long-term 'safe' pasture utilisation on cleared land types ranged from 0.2-2.3 t/ha/yr and on treed land types 0.4-10.5 t/ha/yr across all climates (see Table 9 & Table 10). The highest sediment losses (3.5-10.5 t/ha/yr) occurred at Proserpine on the heavily treed low productivity land types despite high mean average cover (0.34-0.51). On the higher productivity treed land types soil losses were greatest at the driest locations (Alpha and Ulcanbah). On cleared land types the highest soil losses occurred when surface covers were lowest. These high sediment losses highlight the importance of minimum surface cover and the timing of high rainfall events.

At Wambiana lower ground cover and reduced rainfall infiltration led to an increase in the frequency and magnitude of runoff events under heavy stocking (~4-6ha/AE) than under moderate stocking (~8-10ha/AE). Loss of nutrients and sediment and bed load increased with declining cover and increasing long-term pasture utilisations rates (O'Reagain and Bushell 2011). On steep slopes associated with coalmine rehabilitation Carroll *et al.* (2000) found average annual soil loss to be <0.1t/ha when pasture had >50% cover and 200t/ha from bare ground. At Springvale, Silburn *et al.* (2011) found average annual soil losses ranged from 1-4 t/ha when cover was >40% and between 10-30 t/ha when cover was <20%.

Predicted annual soil losses at Springvale on cleared land (0.4-1.2 t/ha) with surface cover >40%, for a ~3% slope, are at the lower range of those reported by Silburn *et al.* (2011) for a 6% slope.

Surface cover on treed land types varied between 10-40% and associated annual soil losses varied between 0.5-3.6 t/ha. Predicted soil losses (1.9-3.6 t/ha) from the least productive, heavily timbered land types with low surface cover (<20%) at Springvale are much lower than those measured at Springvale by Silburn *et al.* (2011). Differences in average annual soil losses may be due to the period examined (31 years cf. 7 years), the large events that dominate total soil loss and differences in slope and soils. Further evaluation of site data with simulated outputs for the same years could provide a better comparison of results. Identification of slope at Springvale sites and including the slope factor to simulated soil losses may also provide a better comparison between predicted and observed data.

4.0 Conclusion

4.1 GRASP modelling of grazing lands

This report describes the modelling approach used to provide time-series ground cover data to the ‘Catchment’ model to permit reporting on progress towards achieving the Reef Plan targets and goals for grazing lands. Additionally, the GRASP modelled utilisation levels will link grazing management practices and the Catchment model to allow identification of grazing management practices that lead to an improvement in water quality.

Reporting of GRASP simulated outputs has progressed from very general overview (mean of all climate, utilisations, tree cover, 31 years) to more focussed examination of climate or grazing pressure (mean of climate or utilisation and 31 years) to the investigation of 31 year mean specific surface cover (>50%, minimum) and utilisation outputs (safe long-term). Thus, even the most specific reported data is an average of the 1980-2010 simulation period. However, it is the variability in annual pasture production that poses a major challenge for managers of grazing lands in the GBR catchments. Identifying management practices that cope with the year-to-year variability of pasture production effectively reducing runoff and sediment losses during dry periods when surface covers are low will improve water quality outcomes for grazing lands in GBR catchments.

4.2 Main findings

Generally, soil surface cover was higher on lightly grazed, more productive land types with less tree cover, at more favourable climate locations (higher annual rainfall, less seasonal variation). Overall, pasture production and, hence, soil surface cover was less under trees, with the variability of pasture growth increasing as water and nutrients become scarcer in the drier, more heavily grazed systems. Runoff was greater at the more northerly locations (Charters Towers, Mt Fox, Proserpine), where the amount and intensity of rain was higher, and from the low productivity and more heavily treed land types. Highest soil losses occurred with highest rainfall, heaviest stocking rate and with highest tree cover.

Achieving a minimum of 50% late dry season groundcover is an important Reef Plan and Reef Rescue target to improve water quality in the GBR. An average (1980-2010) annual surface cover of 50% or more was achieved on cleared pastures grazed at ‘safe’ utilisation levels at all locations bar the two driest. However, the adverse impact of trees on the pasture productivity resulted in only the more productive lightly treed land types at the wettest locations achieving an average of 50% annual surface cover when grazed at safe levels. Even with no grazing on the low productivity, more heavily treed pastures average annual surface cover was less than 50%.

Despite achieving an average of > 50% ground cover between 1980-2010, cleared pastures grazed at safe utilisation levels have low surface covers (< 50%) for approximately a third of these years. Climate is a major driver of year-to-year variability in pasture productivity and surface cover, with the impacts of climate exacerbated by land type, land condition and grazing pressure. As tree cover and pasture utilisation levels increase, the frequency of years with low cover and high runoff increase. Modelling suggests that achieving a minimum of 50% late dry season ground cover every year is unlikely for conservatively grazed pastures in the variable climate of the GBR catchments, and that runoff and soil loss could be significant during the drier years when surface covers are below 30%.

Given this, some consideration could be given to setting ground cover targets that more accurately reflect the impact of climate variability on pasture productivity and surface cover (e.g. targets for low rainfall areas would be lower than targets for high rainfall areas) to provide managers with realistic goals to achieve desired water quality outcomes. There may be some merit in determining cover thresholds and setting ground cover targets that more accurately reflect the inherent capabilities of grazing lands, particularly on the low productivity treed grazing lands where sediment loads are predicted to be high.

Some consideration should also be given to the impact of tree litter on runoff. Predicted surface covers in treed land types included an estimate of tree litter which was considered to be effective in reducing runoff when cover would otherwise be zero. The contribution of tree litter to surface cover of the heavily treed, degraded land types resulted in more cover than the equivalent cleared land types. Although the impact of tree litter only appears significant on low productivity land types at very dry locations, further evaluation of the effectiveness of tree litter in reducing runoff, and the removal of litter by runoff or stock, is required to gauge the sensitivity of this parameter and its importance in predicting sediment loads. Additionally, the inclusion of slope and soil erodibility factors in the Catchment model may adjust runoff and sediment loads to more accurately reflect the on-ground soil water conditions.

4.3 Implications for managers of grazing lands

Managing grazing pressure in the variable climate of the GBR remains an effective practice in controlling water quality in the GBR catchments, and is particularly important in the higher rainfall areas where sediment losses can be high if ground cover is low. Identification of grazing lands that are at risk of high runoff and sediment loads could highlight where changes to management practices could be most effective in achieving desired water quality outcomes. Adoption of management practices that improve or maintain land condition, such as varying stocking rates in response variability in rainfall, should reduce the risk of pasture degradation during drier periods, maintain surface cover at sufficient levels to minimise runoff and soil loss for most years, and improve enterprise profitability. Actually achieving effective changes in management practices to improve water quality outcomes will require identification of the financial costs and benefits associated with practice change. Extension of grazing land management information would be suited to situations where there is an economic benefit to producers to change management practice (e.g. improving land condition of productive grazing areas). In situations where the is little or no economic gain for producers to change their management practice (e.g. rehabilitation of low productivity grazing land), then the use of financial incentives to encourage an alternative land use (timber for fencing, conservation area) with limited or sporadic grazing may be an efficient approach to improving water quality in the GBR catchments.

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Appendix 1.0

Productivity classes (high, medium, low) of the mapped grazing land types of the Great Barrier Reef catchments.

Modelled land types are indicated by italic font and with *.

High Productivity – 37 land types	Medium Productivity – 58 land types	Low Productivity – 42 land types
Alluvial	Bastard scrub	Bendee ridges
Alluvial brigalow	Blackwood scrubs on structured clays	Blackwood scrubs on massive soils
Alluvial flats and plains	Bloodwood and stringybark (coastal plains)	Bloodwood-ironbark woodland on steep rocky hills
Belah and brigalow plains on texture contrast soils	Blue gum, ironbark and bloodwood slopes and hollows	Box and napunyah
Black basalt *	Bluegrass browntop plains	Bulloak country (BR)
Blue gum / river red gum flats (FT)	Box country (BD)	Bulloak country (FT)
Blue gum flats (CB)	Box country (DU)	Coastal sand dunes
Blue gum on alluvial plains	Box flats	Coastal teatree plains (FT)
Brigalow and brigalow belah	Box on clay	Coastal teatree plains (MW)
Brigalow blackbutt	Coastal eucalypt forests and woodlands	Cypress pine and carbeen forest on undulating sandy plains
Brigalow gidgee scrubs	Coastal flats with mixed eucalypts on grey clays	Cypress pine country
Brigalow softwood scrub	Coastal wetlands	Cypress pine on deep sands
Brigalow with melonholes (FT)	Coolibah country (NG)	Cypress pine on duplex soil
Brigalow with melonholes (MB)	Eucalypt hills and ranges	Frontal dunes
Brigalow with softwood scrub species	Eucalypts and bloodwood on clays	Hard ironbark country
Brown basalt	Eucalypts and bloodwood on loamy red tablelands	Ironbark, stringybark and supplejack on ridges
Channels and swamps associated with major streams	Eucalypts and bloodwood on sandy tableland	Ironbarks and spotted gum ridges
Clayey alluvials	Georgetown granites	Jump-ups (BR)
Coastal rainforests	Goldfields country - black soils	Jump-ups (DU)
Coolibah floodplains (FT)	***Goldfields country - red soils ****	Lancewood - bendee - rosewood (BD)
Downs (BD)	Gum-topped box (CB)	Lancewood (NG)

High Productivity – 37 land types	Medium Productivity – 58 land types	Low Productivity – 42 land types
Downs country (DU)	Gum-topped box (IB)	Lancewood (SG)
Frontage (DU)	Gum-topped box flats	**_Lancewood, bendee, rosewood (FT) *_**
Frontage (NG)	Hoop pine scrub	Narrow-leaved ironbark and wattles
Loamy alluvials	Ironbark (SG)	Narrow-leaved ironbark on ranges
Mitchell grasslands (MB)	Ironbark country (DU)	Narrow-leaved ironbark on shallower soils
Open downs (FT)	Ironbarks and bloodwoods on non-cracking clays (IB)	Narrow-leaved ironbark with rosewood
Rainforests (closed forests) on basalts	Ironbarks and bloodwoods on non-cracking clays (MO)	Range soil (NG)
Red basalt (BD)	Ironbarks and blue gum on clays	Range soils (WT)
Scrubs on deep clays	Ironbarks and spotted gums on duplexes and loams (CB)	Ranges
Softwood scrub (BD)	Ironbarks and spotted gums on duplexes and loams (IB)	Sand
Softwood scrub (CB)	Ironbarks on granite	Sand ridge
Softwood scrub (FT) *	Marine plains (FT)	Sandy forest (NG)
Softwood scrub (IB)	Marine plains and tidal flats	Sandy forest country (SG)
Softwood vine scrub	Mixed eucalypts on coastal plains	Serpentine ironbark
Wet highland rainforests	Mixed open forests on duplex and loams (MO)	**_Spotted gum ridges (FT) *_**
Wooded downs (MGD)	Mountain coolibah woodlands	Spotted gum ridges (IB)
	Narrow-leaved ironbark	Tea-tree flats
	Narrow-leaved ironbark on deeper soils	Yellow earths (NG)
	Narrow-leaved ironbark on granite	Yellowjacket country
	Narrow-leaved ironbark woodland *	Yellowjacket country plus/minus wattles
	Old alluvials	Yellowjacket with other eucalypts
	Open alluvia	
	Poplar box / brigalow / bauhinia	

High Productivity – 37 land types	Medium Productivity – 58 land types	Low Productivity – 42 land types
	Poplar box and brigalow	
	Poplar box and silver-leaved ironbark	
	Poplar box flats	
	Poplar box on red soils	
	Poplar box with shrubby understorey	
	Poplar gum woodlands	
	Red earths (NG)	
	Scrubs on shallow clays	
	Silver-leaved ironbark	
	Silver-leaved ironbark on clay	
	Silver-leaved ironbark on duplex	
	Tall open forest on snuffy soils	
	Tall open forests on basalts	
	Tall open forests on steep hills and mountains	

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