Unravelling the economic and environmental tradeoffs of reducing sediment movement from grazed pastures

Peter Donaghy*, John Rolfe[#], and James Gaffney[#]*

Queensland Department of Primary Industries and Fisheries,
Rockhampton, Queensland, Australia
[#] Central Queensland University,
Rockhampton, Queensland, Australia
[#*] Gaffney Consulting,
Toowoomba, Queensland Australia

An undesirable consequence of grazing activities in eastern Australia is the quantity of sediment emptying into the Great Barrier Reef Lagoon. One of the challenges to reducing sediment loads stems from the lack of private incentives to improve land management practices. There is also a poor understanding of the financial implications resulting from the adoption of sustainable management practices, and, in particular the lack of scientific and economic knowledge linking on-farm management actions to catchment scale impacts. Bio-economic modelling has been used to identify the economic and environmental trade-offs encountered when grazing strategies are altered to reduce off-farm sediment movement from a black spear grass pasture in central Queensland.

Keywords: bioeconomic modelling, grazing, economic and environmental tradeoffs, sediment reduction

1.0 Introduction

Recent research suggests the contribution from agriculture to declining water quality in Queensland is significant. Many streams emptying into the GBR lagoon have poor water quality, which can potentially lead to degradation of estuarine and inshore marine ecosystems. Concerns about the water quality in the GBR lagoon have been expressed in a number of recent studies and reports (see, for instance, Furnas 2003; Productivity Commission 2003; Science Panel 2003; SQCA 2003). These concerns surfaced both from Commonwealth and State Governments through the Memorandum of Understanding signed by the Commonwealth and Queensland Governments in August 2002 and the release of the *Reef Water Quality Protection Plan*.

There is a wide range of industries that contribute pollutants and sediments to streams in the catchment of the GBR (Haynes, 2001, Haynes and Michalek-Wagner 2000, Moss et al. 1993). While these include both point and non-point sources, the Productivity Commission (2003:42) argues that "…dry tropics catchments have the greatest (and most variable) discharges; and the principal sources of the main types of pollutants appear to be diffuse (agriculture)".

The main non-point sources of pollution are agricultural practices and terrestrial runoff. Key agricultural activities include grazing (soil erosion on grazing properties) and cropping (overuse/misuse of fertilizers and chemicals by cropping industries) (Hunter *et al.* 1996). The Productivity Commission concludes that "diffuse sources, particularly cattle grazing and crop production, make the most significant contribution to pollutant discharges into the GBR lagoon (Productivity Commission 2003:XXIX).

Central Queensland's Fitzroy basin is no exception. The quality of water discharging from the Fitzroy basin into the GBR lagoon has deteriorated markedly over the last 150 years (GBRMPA, 2001). Table 1 shows the dominance of grazing in the Fitzroy basin and the change in total sediment exports since pre-European settlement.

Table 1 The dominance of grazing in the Fitzroy basin and the increase in sediment exports since pre-European settlement

Total Area ha	Grazed Area ha	% Grazed	Sediment Exported in 1850	Sediment Exported in 2000	Relative Increase
14.25 m	12.5 m	87.50%	.125 m t	2.64 m t	20 times

Source: GBRMA

For point source pollutants (e.g. urban sewage plants and stormwater, manufacturing and processing industries and aquaculture), where the source's abatement responsibility can be identified, the resulting export of pollutants has traditionally been managed through regulatory policy mechanisms. For the non-point source pollutants, such as sediment from grazing lands, identification of the source and amount of pollutant is very difficult, making targeted controls difficult to administer and expensive (Carsen et al 2003). Also, the linkages between management actions, water quality and any subsequent environmental damage are not always clear and impacts on water quality often occur over time and space, so that it is difficult to identify precise causes or to mitigate any impacts (Rolfe et al 2005).

Problems of water quality loss due to agricultural land use also stem from the lack of incentives to improve land management practices. In many instances there appears to be little private financial incentive on the part of land managers to reduce soil and nutrient loss from grazing and farming lands to socially desirable levels. There is also a poor understanding within government and regional planning groups of the financial implications resulting from the adoption of sustainable management practices, and, in particular how this knowledge could be used to design voluntary extension programs promoting sustainable outcomes. These problems are exacerbated by the multiple parties involved, and the lack of scientific and economic knowledge linking on-farm management actions to catchment scale impacts.

This is particularly the case for Australia's rangelands where a lack of quantitative data makes it difficult to properly consider the economic and environmental trade-offs of alternative grazing strategies for a range of pasture conditions, land types and climate variability. This paper will detail research undertaken in central Queensland to identify the economic consequences of adopting sustainable grazing practices to restore land condition and water quality. Section 2 details the methodology used in undertaking the research and section 3 presents the results of the research. Key issues emerging from the work are discussed in section 4 and the conclusions are presented in section 5.

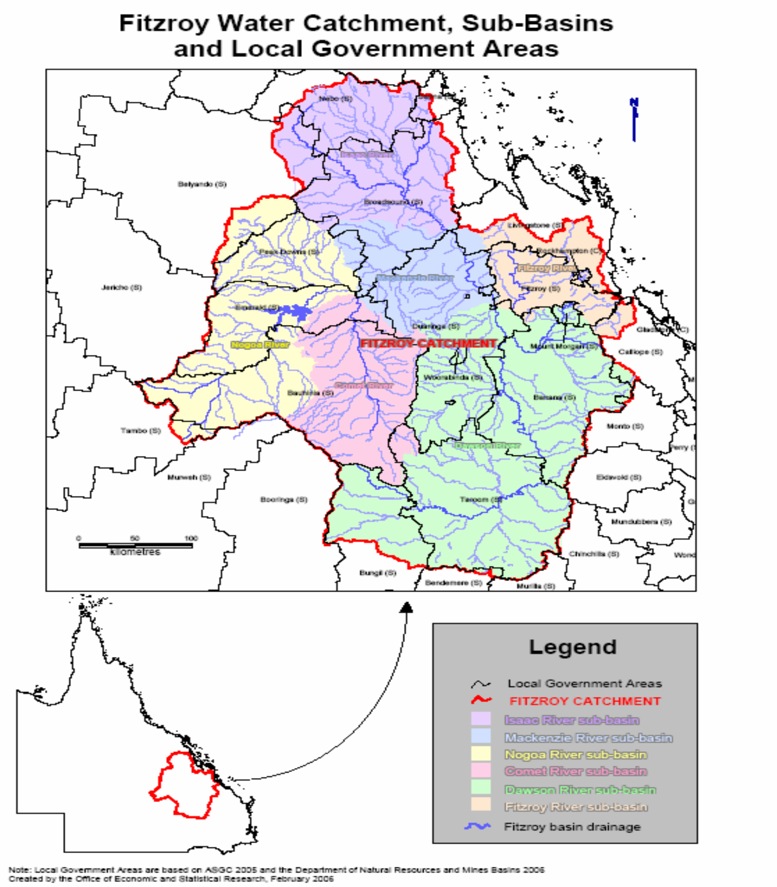
2.0 Methodology

The research presented in this paper is a combination of simulated biophysical data generated using the GRASP[1] simulation model and economic analysis undertaken in Excel. The GRASP data was produced via simulation experiments using the GRASP model (McKeon et al. 2000) parameterised for a case study property (a productive but low fertility black spear grass community) at Raby Creek in central Australia. Clewett[2] (2006a and 2006b) provides a detailed description of the GRASP model and the parameters used in parameterising GRASP for land units that are broadly typical of the low nitrogen Raby Creek case study site.

The case study property comprised 4,000 hectares in the catchments of Raby and Mimosa Creeks, roughly 160 km west of Rockhampton in Queensland. Figure 1 provides a map showing the location of the Fitzroy basin within Queensland and the quantity of the state it occupies. The case study property has an annual rainfall of 714 mm and is predominantly covered by a black spear grass pasture in 'A' condition. That is, it 'can sustain a reliable forage supply and contribute to the long term health of the grazing enterprise' (Silcock et al 2006). It is maintained free of trees and burnt every 2 to 3 years. The property is used exclusively for breeding with weaner cattle being turned off at 6 to 8 months of age.

[1] GRASP version 'GVT89c13.for' dated 30 Jan 2003 was used to perform the simulations with the options enabling dynamic changes in pasture basal area, pasture degradation if high utilization levels persist, runoff and soil loss estimation, and pasture burning all activated.
[2] Copies of these reports are available from the AgSip 13 website www.agsip.cqu.edu.au.

Figure 1



Daily climate data for the case study property was obtained from the Silo data drill (Jeffery et al. 2001) for latitude / longitude -23.95S 149.35E which is within a few kilometres of the Raby Creek site. The Raby Creek land unit is a deep yellow earth with silver leafed ironbark woodland on an alluvial plain on the southern side of the Black Down Tableland[3] and the black spear grass pasture at the site was assessed to be in good condition. Clewett (2006a) describes the soil as a deep yellow massive earth (sandyloam, Gn2.12, 2.22) with light sandy clay at 1.45+ m. Isaac is the closest fitting Agricultural Management Unit in the Central Highlands Field Manual (Bourne and Tuck 1993). Suggested stocking on cleared land is often 12 to 17 AE/km^2 (uncleared 10 to 12 AE/km^2).

Simulations in the GRASP model were initially undertaken over five 20 year simulation periods for three initial pasture start conditions and ten alterative alternative pasture utilisation rates. These are summarised below:

- Six pasture utilisation rates of 20, 30, 40, 50, 60, 70% of total standing dry matter (TSDM);
- Five 20 year simulation time sequences commencing in 1891, 1911, 1931, 1951 and 1971; and

[3] Refer to Land Unit 119, page 188 of Gunn and Nix (1977) for a detailed description of the land type modelled.

- Three levels of initial pasture condition starting at 90, 70 and 31% perennials.

To overcome the rigidity of a constant stocking rate and to explore grazing strategies that more realistically reflect current grazing practices, a flexible grazing strategy was analysed.

Flexible Grazing Strategy

Under the flexible grazing strategy the annual stocking rate is determined by the amount of available pasture at the end of the wet season. Stocking rates were adjusted on the 1st July in each year and calculated as a function of the total standing dry matter. The following stocking rate function describes the calculation of annual stocking rates.

*SR = (TSDM (1st July) * percent utilization of pasture)/ estimated intake/hd/year*

Where:

SR = stocking rate for the next 12 months
TSDM = total standing dry matter

Commercial grazing enterprises often target 30 % utilization of dry matter *growth*, which equates to about 45% of TSDM by winter (1st July). The feature of the flexible grazing model is that while the % utilization of TSDM is held constant for the period of the simulation, the stock numbers per unit area vary from year to year depending on the feed availability. This experiment examines the influence of grazing pressure by testing six levels of utilization of TSDM on 1 July. They were 20, 30, 40, 50, 60 and 70% utilisation of TSDM on the 1 July.

The approach contrasts to a constant stocking rate approach in that it more realistically reflects the sensitivity of graziers to their fluctuating feed supplies over time. Because cattle breeding is essentially a stable enterprise and not readily suited to changes in herd size from year to year, a mixed breeding and steer trading enterprise was used in the economic analysis of the flexible grazing strategy.
In modelling each grazing strategy it was recognised that the i*nitial pasture* condition would effect the biophysical and economic performance of each grazing strategy. The 70% perennial starting pasture condition was viewed as an appropriate representation of a typical regional woodland pasture state. The model results for the 90% and 30% perennial pasture species starting condition was used to indicate the sensitivity of the results to extreme pasture conditions i.e. pristine and degraded.

Finally to help redress the limitation of the single sequence of 20 years of climate data, GRASP simulations were run and economic and environmental trade-offs estimated for 5 sets of 20 year sequences of climate commencing in 1891, 1911, 1931, 1951, 1971.

2.1 Modelling the Economic impacts

To estimate the economic performance of each grazing system under a range of alternative climate and pasture start conditions, an analysis of the GRASP output was undertaken using a comparative partial budgeting technique (Makeham and Malcolm

1993). The annual liveweight gain per steer predicted from the GRASP model was modified into breeding herd performance estimates using a technique similar to MacLeod et al (2004) where the following assumptions and relationships were used:

- 150 kg average live weight of both steer and heifer weaners;
- Mortality (breeders) % = $6 + 94e^{-0.027(LWG + 50)}$;
- Branding % = $0 \leq 15.6 + 0.488*LWG \leq 80$; and
- Drought feeding rules: In each year of the simulation, supplementary feeding was considered necessary if the estimated annual liveweight gain per steer was less than 50 kg. For liveweight gains between 0 and 50kg, a urea-molasses lick supplement (urea 8% - M8U) was fed to maintain a minimum liveweight gain of 50kg. The feeding rule was 2 days of M8U feeding for each kilogram of liveweight gain less than 50kg. A more complex rule was applied for drought years.

MacLeod et al's (2004) approach was adapted for the analysis reported here in the following manner:

- The breeder mortality rate estimated by the morality function was reduced by 1% and a ceiling rate of 15% introduced;
- The branding rate (%) was limited to a maximum of 75% to better reflect regional averages;
- The average weaner steer weight was increased to 180 kg, and three sets of weighting factors were introduced to ensure weaner weights were sensitive to grazing pressure, year to year seasonal differences and the sex of the weaner; and
- A set of 3 cull cow sale weights of 450kg, 400kg and 350kg was used to better reflect year to year variation in seasonal conditions and cull cow weights[4].

The net present value (NPV) of the stream of 20 year-increments in annual cash flows due to changes in herd size was used to measure the economic impact of altering the grazing strategy. Changes in herd size and associated individual animal performance was used to measure the prospective improvement or loss in wealth of the grazier from altering the properties stocking rate.

For the representative Raby Creek beef cattle property breeding and turning off weaners, the annual incremental net cash flow streams are obtained as the difference between the 'with the extra cattle' and 'without the extra cattle' total gross margin in each year plus any additional fixed costs and interest on livestock capital. The capital cost of the extra livestock was borne at the start of the investment period and recouped at the end of each 20 year sequence when all cattle are sold. The opportunity cost of changes to livestock capital was valued at 6%. MacLeod et al (2004) define a gross margin as a simple measure of the gross contribution to enterprise profit of each stocking rate or pasture utilisation level and is defined as follows:

[4] An explanation of the derivation of the weaner weight weaning factors and cull cow factors is provided in Gaffney et al (2006).

Gross margin/100 breeders = gross animal revenue – (livestock purchases + direct husbandry + direct marketing costs + supplementary feed costs).

where, gross revenue = total kilograms (liveweight) of sale animals of all sexes and classes x price per kilogram + sales of surplus and cull animals associated with a breeding herd.

The annual gross margin was adjusted for any difference in supplementary drought feeding costs, purchases to replace severe stock losses and additional 'fixed (mainly labour)' costs due to the increase in herd size in the 'with' situation. A slight adjustment was also made to the fixed costs. These costs are divided into two components. One component equal to half the average fixed cost is held constant; the other half varies depending on the breeder numbers. When breeder numbers are lower than average this component reduces proportionately. When breeder numbers are higher than average it increases proportionately. Because of the marginal nature of the increments, the property infrastructure (the yards, fences, water supplies) was assumed adequate and not affected by the increase in numbers.

With variability in herd performance stemming from several sources in the modelling (eg. annual weaner and cull cow weights, branding, mortality and stocking rates and cattle sale process changing depending on seasonal conditions) it was important to have some idea of the pasture productivity and herd performance figures for an "average season" that were used to underpin the economic modelling. Table 2 provides the indicative average herd performance measures for the weaner-breeding enterprise assuming the standard conditions of 25 AE's per square kilometre grazing pressure, an average season, 70% perennial pasture starting condition, 165 kg base weaner steer weight, and a 0.96 weaner weight factor applying when the grazing pressure is 25 AE's/km^2.

Table 2 Average herd parameter values for the representative grazing model

1901 Liveweight Gain from GRASP for 25 AE's, and 70% perennials	kg/hd	153.2
Branding percentage	%	75
Breeder mortality	%	5.4%
Dry stock mortality	%	1.00
Percentage of Bulls per 100 breeders	%	4.00
Heifer replacement rate	%	18
base weaner weight	kg/hd	165
grazing pressure factor for 25 AE's		0.96
Weaner steer live weight	kg/hd	158
Weaner heifer live weight	kg/hd	145
Cull cow live weight	kg/hd	400
Gross Margin per breeder unit	$/bdr	$210
Capital Value per breeder unit	$/bdr	$818
AE's per breeder unit	AE's/bdr	1.52

Table 3 provides a summary of the key parameters used to estimate the gross margin per breeder unit reported in table 2 above.

Table 3 Gross margin per breeder unit

Proceeds from Sale cattle	Sales/yr no.	Sale Weight kg/hd	Price $/kg	Total Value $/100 bdr	Total Value $/bdr
wnr steers	37	158	$2.20	$12,950	
wnr heifer culls	19	145	$2.00	$5,631	
cull cows	12	400	$1.50	$7,301	
cull bulls	1	600	$1.80	$1,080	
				$26,963	$270
variable costs per 100 cows		no.	$/bdr	$/100 bdr	$/bdr
buy replacement bulls		1	$2,000	$2,000	
veterinary costs		100	$8	$800	
hay cost for wnrs		75	$10	$750	
selling costs - wnrs		57	$33	$1,871	
selling costs - adults		13	$44	$579	
				$6,001	$60
Gross Margin per Breeder Unit					$210

Table 4 describes the adult equivalent weightings used to estimate the grazing pressure per breeder unit.

Table 4 Grazing pressure per breeder unit

	no's	av annual AE/hd	AE/100
bulls	4	1.2	5
cows -wet	75	1.35	101
cows - dry	25	1	25
6 mth repl wnr hfr	18	0.49	9
18 mth repl hfr	18	0.71	13
Total grazing Pressure per 100 Breeders	140	total AE =	152
Grazing pressure per breeder			1.52

Table 5 describes the beef cattle prices used in the analysis to estimate the livestock capital value of each breeder unit.

Table 5 Livestock Capital value per breeder unit

Stock on hand at the start of each year	No.s per 100 cows	Average liveweight kg	Price $/kg	Value $
Repl wnr hfrs	18	145	$2.00	$5,200
Repl ylg hfrs	18	298	$2.00	$10,583
Breeding herd	100	400	$1.50	$60,000
Bulls	4	$1,500		$6,000
Total capital value per 100 breeders				$81,783
Average Capital value per breeder unit				$818

Model adaptations for the flexible grazing model

Measuring the economic impacts of a flexible grazing model required a number of additional assumptions that revolved around the following points:

- operating a mix of breeding and trading steers;
- the introduction of a steer trading enterprise; and

- the reduction and restoration of breeder unit numbers with the onset and recovery from dry season conditions.

Table 6 provides a sample of the GRASP output generated assuming 40% utilization of the TSDM at the end of each year to determine the stocking pressure that will need to be set for the subsequent year.

Table 6 GRASP output for 40% utilization of the 'tsdm' at the end of each year to decide grazing pressure in the following year

			%peren=	70	%U tsdm=	40	start =1889	n=Rab		
Year	rain	runoff	SLkgSc	tsdm	growth	%basal	hd/km2	lwg/hd	lwg/ha	%peren
1891	817	27	190	1573	2856	5.5	37.8	144.4	72.8	84
1892	512	2	19	1526	2634	3.8	22	167.9	36.9	84
1893	899	29	224	2433	3159	3.8	21.3	174.7	37.2	88
1894	1140	67	419	2360	3442	4.4	33.9	163.4	55.4	90
..	..	..	..	..	..	..	..	..	..	..

The following calculation illustrates the process used to calculate the year to year stock adjustments required under the flexible grazing model. For example in 1892 the year ends with 1,526 kg/ha of TSDM in July. The formulae used to calculate the stocking rate for 1893 is as follows:

hd/km^2 in 1893 = 1,526 kg x 40% x 100 ha /(7.85 kg/hd/day x 365 days) = 21.30 hd/km^2

Deciding the mix of breeder and trade steer numbers from year to year

The challenge in modelling the changes in stock numbers under a flexible stocking regime is deciding on the mix of a trade steer and breeder/weaner enterprise. The approach taken was to assume the average carrying capacity for each level of per cent utilization for each set of 20 year climate sequences would be known by the modellers and used as a quasi substitute for long-term local grazier knowledge. This enables the average AE’s available for each 20 year set of GRASP data to be calculated and in turn used to calculate a set of rules to decide the herd composition from year to year.

For the flexible grazing strategy model the rules employed were as follows:

- That 90% of the average feed supplies for a 20 year period would be used to calculate the number of breeder units carried (each breeder unit is equivalent to 1.52 AE’s in grazing pressure);
- In years where feed supplies exceed 90% of the 20 year average, the available feed surplus would be used to determine the number of trade steers purchased and carried for the following 12 months. Each trade steers starting weight was 300 kg and gains the amount of live weight specified in the GRASP output. To determine the number of trade steers purchased, each yearling steer was assumed to be equivalent to 83% of an AE; and
- In years where feed supplies are less than 90% of the 20 year average, breeder unit numbers are reduced to match the level of feed available.

The price, cost, and mortality assumptions used in the gross margin calculations for the trade steer enterprise mix are detailed in table 7.

Table 7 Trade steer gross margin parameters

Steer purchase price	$/kg	2.00	Steer sale price	$/kg	2.00
freight in	$/hd	10	freight out	$/hd	12
health	$/hd	5	selling costs	$/hd	40
			deaths	%	2

The final consideration in the model is the potential of breeder numbers and related stock to be reduced should seasons turn dry, and then restored when favourable conditions return. This necessitates provision of a process for the sale and restoration of whole breeder units. Table 8 details the expected cost in turning over breeder units and briefly illustrates the extent and frequency with which it can happen.

Table 8 Calculating the livestock capital loss of turning over breeder units

	Sale price per unit			$736		
	Buy back price unit			$900		
	Capital loss per breeder unit			$164		
	% Loss			22%		
			Breeder unit transactions			
Year	Breeder units		De-stocking	Proceeds	Re-stocking	Costs
1891	617	0	0	$0	0	$0
1892	579	38	38	$27,987	0	$0
1893	561	18	18	$13,558	0	$0
1894	617	-56	0	$0	56	$50,803
1895	617	0	0	$0	0	$0
..	..		..	..	..	..

With these rules established, it is a simple, albeit tedious matter to systematically evaluate relative to the base rate of 20% utilisation of TSDM each of the 5 higher utilization rates of 30%, 40%, 50%, 60% and 70% for the 5 sequences of 20 years starting in 1891, 1911, 1931, 1951, and 1971 for each of the 3 starting pasture conditions of 90% perennial, 70% perennial, and 32% perennial species in the stand.

2.2 Modelling the environmental impacts

Soil loss and pasture condition impacts revealed by the simulation experiment results are available almost directly from the GRASP output. Table 9 illustrates the soil movement estimates for a stocking rate of 25 AE's/km^2 for the Raby Creek site. The table uses the "between 10% and 15%" rule (Rattray et al. 2005) to convert changes in soil movement estimates into quantities of suspended sediment exported from the site as runoff. It as assumed that 12.5% of soil movement was lost as suspended sediment leaving the property.

Table 9 Estimating suspended sediment exports from GRASP output

Year	rainfall mm	runoff mm	..	hd/km2 AE's	..	Soil Loss kg/ha
1891	817	19		25		94
1892	512	2		25		11
1893	899	26		25		186
..						..
1908	993	57		25		369
1909	536	18		25		165
1910	1019	41		25		227
Total Soil movement (or loss) over 20 yrs per hectare					kg/ha	6084
% of Soil Lost as suspended sediment						12.5%
Total Suspended sediment exported over 20 yrs per hectare					kg/ha	761
Area of property					ha	4000
Total Sediment exported over 20 years from 4000 ha					tonnes	3,042

* Given 90% perennial or 'state 1' initial pasture conditions

The product of the % Basal Area and % Perennials for any given year in the GRASP output provides the second of two criteria used by MacLeod et al (2004) to characterise pasture condition as being in either States 1, 2, or 3. In their study, State 1 pasture condition applies when the per cent of black spear grass and other desirable species in the pasture is in excess of 70% and the per cent basal area occupied by these plants exceeds 1.7%. Table 10 shows the full set of conditions defining the respective pasture states.

Table 10 Pasture state parameters

	%Perennial spp.	%B-P (lowest value)	%B-P (highest value)
State 1	>70	>1.7	
State 2	70	1	1.7
State 3	20	0.5	1

Table 11 illustrates the use of the MacLeod rules to describe the pasture condition (end-of-year State) over time at Raby Creek under 25 AE's/km^2 constant grazing pressure for the 20 years of climate commencing 1891.

Table 11 Estimating land condition using pasture state scores

YEAR	Rainfall mm	..	hd/km2 AE's	..	%basal area	%peren grasses	%B x %P	End of yr state
1891	817		25		5.5	90	3.5	1
1892	512		25		3.9	90	3.51	1
..	..		..		..	..	..	..
1901	381		25		2.8	88	2.464	1
1902	445		25		2.1	88	1.848	1
1903	473		25		1.7	84	1.428	2
1904	915		25		3.1	88	2.728	1
1905	595		25		4.6	90	4.14	1
..	..		..		..	..	..	..
1908	993		25		4.4	90	3.96	1
1909	536		25		4.2	90	3.78	1
1910	1019		25		4.1	90	3.69	1
Summary results :					Terminating pasture state			State 1
					Number of years out of 20 in 'State 2'			1
					Number of years out of 20 in 'State 3'			0

In this instance, the 20-year impact of grazing 25 AE's/km^2 on the condition of the pasture is slight. Only when in drought (1902-1903) does the pasture condition drop into 'State 2' returning to 'State 1' in the following year and remaining in that state for the rest of the time.

3.0 Results

Combining the economic and environmental impacts together yields an integrated profile of the animal performance, soil loss, pasture condition and net incremental cash flow impact of a grazing management change over each 20 year sequence. Condensing the results for each change in % utilization and stocking rate enables sets of impacts to be compiled and the overall pattern of economic and environmental trade offs observed.

A full set of results was generated using climate data from 1891 to 1971 and three pasture start conditions of either 90%, 70% or 32% perennial pasture. Because the 70% perennial pasture condition is the most representative of the current condition of spear grass pastures in the Fitzroy basin, only the results of the flexible models with a 70% perennial pasture start condition are presented in detail.

3.1 Results for the flexible grazing model

An example of the bio-economic data generated for the flexible grazing system is presented in Table 12.

Table 12 Economic and environmental tradeoffs' for the flexible grazing strategy with a 70% perennial pasture start condition

Start year	% perennial Initial pasture condition	Grazing pressure as % Utilization	NPV of change	Total sed exported (t)	marginal increase in sediment exported (t)	opportunity cost per tonne of sediment reduction	terminating pasture condition	years out of 20 in state 2	years out of 20 in state 3
1891	70%	20%		1,754			1	0	0
1891	70%	30%	$264,335	2,284	530	$499	1	0	0
1891	70%	40%	$394,724	3,059	775	$168	1	0	0
1891	70%	50%	$480,227	4,199	1,140	$75	1	2	0
1891	70%	60%	$495,838	7,193	2,995	$5	2	9	1
1891	70%	70%	$198,099	19,157	11,964	-$25	3	5	11
1911	70%	20%		2,250			1	0	0
1911	70%	30%	$254,158	2,966	716	$355	1	0	0
1911	70%	40%	$377,022	3,845	880	$140	1	0	0
1911	70%	50%	$410,021	5,241	1,396	$24	1	2	0
1911	70%	60%	$478,034	6,756	1,515	$45	2	5	0
1911	70%	70%	$338,664	11,777	5,021	-$28	2	16	0
1931	70%	20%		1,994			1	0	0
1931	70%	30%	$249,564	2,636	642	$389	1	0	0
1931	70%	40%	$390,721	3,488	852	$166	1	0	0
1931	70%	50%	$456,800	4,739	1,252	$53	1	0	0
1931	70%	60%	$352,539	9,876	5,137	-$20	2	9	0
1931	70%	70%	$340,104	15,142	5,266	-$2	3	5	4
1951	70%	20%		2,146			1	0	0
1951	70%	30%	$303,831	2,761	615	$494	1	0	0
1951	70%	40%	$480,342	3,559	798	$221	1	0	0
1951	70%	50%	$602,160	4,546	987	$123	1	0	0
1951	70%	60%	$568,449	8,442	3,896	-$9	2	12	0
1951	70%	70%	$103,022	26,242	17,800	-$26	3	6	12
1971	70%	20%		2,489			1	0	0
1971	70%	30%	$277,475	3,021	532	$522	1	0	0
1971	70%	40%	$460,341	3,852	832	$220	1	0	0
1971	70%	50%	$606,560	4,852	1,000	$146	1	0	0
1971	70%	60%	$700,619	6,376	1,524	$62	1	0	0
1971	70%	70%	$542,509	18,807	12,431	-$13	3	5	8

Table 12 provides the first insight into the nature and order of the economic and environmental trade offs that underlie changes in pasture utilisation of grazing lands in the Fitzroy basin. Each row of data represents the environmental impact and economic outcome of grazing over a twenty year period (eg 1891-1910). The model commenced with a pasture in fair condition in 1891 and a stocking rate that utilised only 20% of TSDM. An estimated 1,754 tonne of sediment was exported from the 4,000ha property over a twenty year period. If the pasture utilisation rate was increased to 30% the property owner would be immediately $264,335 better off and generate an additional 530 tonnes of sediment over 20 years. The pasture would have commenced and terminated in state 1 condition after 20 years.

If the pasture utilisation rate was increased from 20% to 60% of TSDM for the twenty year period commencing in 1891 (i.e. row 5 of table 12) the grazier will have reached an economic optimal and generated an additional $495,838 above what would have been achieved if he had chosen to utilise only 20% of TSDM. Total sediment exported would have increased from 1,754 tonnes to 7,193 tonnes over 20 years for the 4,000ha property.

Combining and averaging the sets of tradeoffs displayed in table 14 yields a single set of tradeoffs representative of the likely range of economic and environmental tradeoffs currently confronting graziers in the Fitzroy basin. This summary is presented in table 13.

Table 13 Summarised economic and environmental tradeoffs for the flexible grazing strategy with a 70% perennial pasture start condition

% Peren start cond	% Utilization	Equivalent AE's per sq km	Expected NPV incr rel to 20% utiln	Expected total sediment exported (t)	marginal increase in sediment exported (t)	Expected OPP cost per tonne sed redn	Times out of 5 terminates in State 1	Years out of 100 Pasture Condition is in State 2	Years out of 100 Pasture Condition is in State 3
70%	20%	16.2		2,126			5	0	0
70%	30%	22.2	$269,873	2,733	607	$445	5	0	0
70%	40%	27.3	$420,630	3,560	827	$182	5	0	0
70%	50%	31.5	$511,153	4,715	1,155	$78	5	4	0
70%	60%	33.6	$519,096	7,728	3,013	$3	1	35	1
70%	70%	29.2	$304,479	18,225	10,496	-$20	0	37	35

The following observations are drawn from table 13:

- The economically optimal pasture utilisation rate is 60% of TSDM (or roughly 33 AE's/km^2) for the black spear grass dominant pasture. At this rate it is estimated that 7,728 tonnes of sediment will be exported over 20 years from a typical 4,000 ha paddock; the pasture will terminate at the end of year 20 in state 1 only 20% of the time, however it will be in 'State 2' 35% of the time, and in 'State 3' 1% of the time.
- By lowering the pasture utilization rate from 60% to 50% utilization, the land holder will forego a lumpsum payoff of $8,000 and will achieve a significant reduction in sediment of 3,013 tonnes or 40% over the 20 years. This implies an opportunity cost of only $3 per tonne over twenty years for each of the 3,013 tonnes of sediment that remains on farm. As well the pasture will

always terminate in 'State 1' at the end of 20 years, it will be in 'State 2' for only 4% of the time and never decline into 'State 3'.
- If the grazier decided to increase his utilisation rate from 20% to 70% of TSDM he will have gone past the economic optimal of 60% pasture utilisation and foregone a lump sum payment equivalent to $214,617. The sediment leaving the property would also have increased by 10,496 tonnes over twenty years and the pasture would never end in state 1.

These findings lie at the heart of this research and are its most important results. Figure 2 provides a graphic illustration of these tradeoffs.

Figure 2 Economic and environmental tradeoffs for the flexible grazing strategy with a 70% perennial pasture start condition

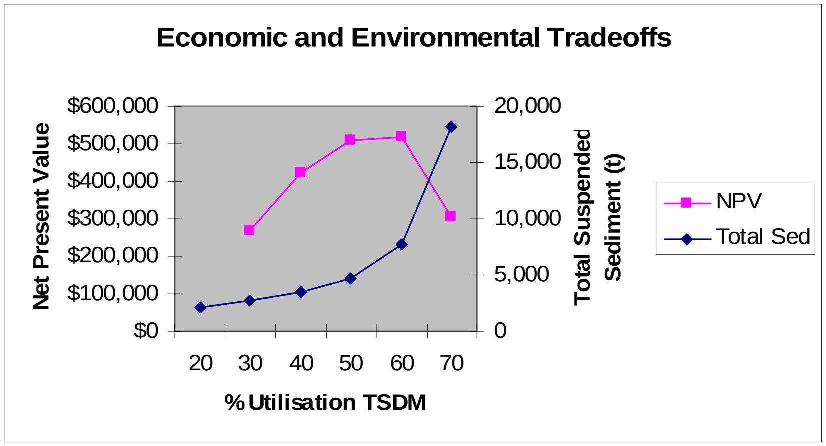


Figure 2 clearly shows how the quantity of sediment leaving the 4,000ha property increase as the % utilisation level increases, and in particular how the quantity exported leaps once the grazier goes beyond the economic optimal of 60% utilisation of TSDM. 60% pasture utilisation then becomes a critical threshold for the grazier beyond which diminishing marginal returns begin.

As discussed earlier if the grazier chose to operate at 50% utilisation rather that 60% there is only a slight opportunity cost incurred equivalent to $8,000. Sediment loads however, are reduced by 3,013 tonnes or 40% over 20 years suggesting an opportunity cost of only $3 per tonne over twenty years for each of the 3,013 tonnes of sediment that remains on farm.

If the grazier was asked to reduce his grazing pressure even further he begins to encounter significantly higher opportunity costs for each tonne of sediment kept on farm. Reducing the pasture utilisation rate from 50% to 40% would result in the grazier immediately foregoing $90,523 and sediment movement falling by an additional 1,155 tonnes or $78/tonne. Table 14 presents similar findings using pasture start conditions of 90% and 32% perennial pastures.

Table 14 Summarised economic and environmental tradeoffs for the flexible grazing strategy with 70% and 32% perennial pasture condition

% Peren start cond	Grazing Pressure as % Utilization	Expected NPV incr rel 20% utiln	expected total sediment exported (t)	marginal increase in sediment exported (t)	Expected OPP cost per tonne sed redn	Times out of 5 terminates in State 1	Years out of 100 Pasture Condition is in State 2	Years out of 100 Pasture Condition is in State 3
90%	20%		2,110			5	0	0
90%	30%	276,060	2,749	639	$432	5	0	0
90%	40%	431,353	3,527	777	$200	5	0	0
90%	50%	539,804	4,542	1,015	$107	5	1	0
90%	60%	565,352	6,821	2,279	$11	3	17	0
90%	70%	401,276	16,287	9,467	-$17	0	39	28
32%	20%		2,388			5	1	0
32%	30%	254,143	3,099	711	$357	5	2	0
32%	40%	370,116	4,173	1,073	$108	5	7	0
32%	50%	313,344	8,189	4,016	-$14	4	24	8
32%	60%	81,343	18,293	10,104	-$23	0	59	33
32%	70%	-212,273	28,540	10,247	-$29	0	37	63

The general findings of the flexible grazing model with a 70% perennial pasture start condition are similar to the 90% perennial pasture start condition. With a 90% perennial pasture start condition, the profit maximising pasture utilization rate is also 60% but the sediment leaving the property falls from 7,728 tonnes to 6,821 tonnes. If the grazier chose to reduce his pasture utilisation rate from 60% to 50% the opportunity cost per tonne of sediment left on farm is $11/tonne.

The 32% perennial pasture condition was included to reflect a degraded pasture. The results in table 14 demonstrate a significantly lower profit maximising pasture utilization rate of 40% when the perennial pasture content is set at 32% initially and significantly lower overall economic returns. Also for the first time the business incurs an immediate loss of $221,273 once the pasture utilisation level reaches 70%, rather than an opportunity cost.

3.2 Sensitivity analysis of the flexible grazing strategy

To test the influence of weaner sale weights on the research findings the economic and environmental tradeoffs for the sequence of years 1891 – 1911 were estimated for the flexible grazing strategy using a 70% perennial pasture start condition and base weaning weights of 155 kg and 175 kg. The impact on the opportunity costs per tonne is shown in Table 15.

Table 15 Sensitivity analysis of base weaning weights in flexible grazing strategy

Start Condition	Grazing pressure as % Utilizn	marginal redn in sed exported (t)	Sensitivity of Opportunity costs ($/ t) of Sed. Redn. to the base weaning weight			Terminating condition	years in state 2	years in state 3
			base wt	alternative wts				
			165 kg	175 kg	155 kg			
70%	20%					1	0	0
70%	30%	530	$499	$526	$477	1	0	0
70%	40%	775	$168	$173	$159	1	0	0
70%	50%	1,140	$75	$79	$74	1	2	0
70%	60%	2,995	$5	$2	$9	2	9	1
70%	70%	11,964	-$25	-$28	-$22	3	5	11

* assuming the 20 years from 1891 is a good approximation of the average for all sequences

The analysis demonstrates that whilst the optimum level of pasture utilization does not change with altered weaning weights, the opportunity cost per tonne of sediment reduced does. If the grazier chose to decrease his pasture utilisation rate from 60% to 50%, 2,995 tonnes of sediment would be reduced at a cost to the grazier of $2 per tonne when a weaning weight of 175kg is achieved and $9/tonne when the weaning weight falls to 155kg.

The results imply the profitability of the breeding herd relative to the steer trading enterprise inversely influences the intensity of the resource use, and hence the opportunity cost per tonne. This result prompted two further tests. Namely, the influence on the opportunity cost per tonne of sediment exported to changes in the steer prices and the magnitude of the breeding herd in comparison to the trade steer herd. The results of these analyses are shown in table 16.

Table 16 Sensitivity analysis of changes in steer prices and enterprise mix

Start Condition	Grazing pressure as % Utilizn	Sensitivity of Opportunity costs ($/ t) of Sed. Redn to herd composition			Sensitivity of Opportunity cost ($/ t) of Sed. Redn to sale cattle prices		
		base	alternatives		base price	alternatives	
		90%	100%	80%	$2.00	$1.80	$2.20
70%	20%						
70%	30%	$499	$466	$552	$499	$428	$570
70%	40%	$168	$148	$180	$168	$135	$202
70%	50%	$75	$66	$87	$75	$57	$93
70%	60%	$5	$1	$6	$5	$1	$10
70%	70%	-$25	-$22	-$28	-$25	-$23	-$27

* assuming the 20 years from 1891 is a good approximation of the average for all sequences

The results again indicate the robustness of the economic optimal pasture utilisation rate of 60% TSDM for the flexible grazing model and suggest some sensitivity of the opportunity cost of sediment reduction to changes in enterprise mix and cattle sale prices. A higher percentage of breeders and lower trade steer buying and selling price leads to a lowering of the opportunity cost of sediment reductions on farm.

4.0 Discussion

Each year 2.64 million tonnes of sediment from the Fitzroy catchment is deposited in the GBRL. The majority of this sediment originates from the grazing lands in this region. The first challenge for policy makers in attempting to redress this trend is to gain an understanding of the economic and environmental trade-offs that underlie the existing pattern of pasture use in the catchment. Due to the spatial and temporal nature of the problem a modelling process was needed to quantify the economic and environmental trade-offs associated with reducing grazing pressure to improve water quality. The results of this research have clearly demonstrated the effectiveness of combining simulated biophysical data generated using the GRASP model with an economic analysis using parameters gained from a representative regional grazing enterprise to unravel these tradeoffs.

The results of this research have also provided useful insights into the economic and environmental tradeoffs associated with a range of alternative grazing strategies in Australia's north that require further discussion. They include:

- The unprofitable and environmentally destructive results of over grazing black spear grass pastures and the apparent conflicting objectives of minimising sediment movement and maximising economic return up to critical threshold points;
- The complexity and variation in opportunity costs resulting from alternative grazing strategies and the effects of economic threshold points;
- The apparent economic and environmental risks associated with stocking rates at profit maximising levels;
- Opportunities to broaden this analysis from an individual property scale to sub catchment and catchment estimates of the economic and environmental tradeoffs associated with improved water quality; and
- Thoughts on how these results might be used to assist policy makers in choosing the most cost effective strategy to improve water quality coming off grazing lands.

For each of the three pasture start conditions analysed, progressively larger opportunity costs were encountered as the stocking rate was increased beyond a threshold point identified by the economic optimum.

The presence of threshold points and the impact of slipping beyond an appropriate stocking strategy highlights how easily a grazier can slide from a desirable position to one with dramatic environmental and economic consequences. To avoid this volatility a less risky strategy would be to graze TSDM at just below the economic optimal where sediment loads are considerably reduced and a buffer introduced that provides flexibility for managers having to operate without the benefit of perfect knowledge. The real surprise is how affordable this less risky strategy is for a grazier operating near the economic optimal.

What remains unclear is whether the profit maximising position of the grazier aligns with the desires of natural resource management groups and government policy makers. For example what would happen if the community desired even lower pasture utilisation rates, of say 30%? Under this scenario sediment loads would again be drastically reduced but at a cost to the grazier of $249, 223 (refer to table 13). Expecting the grazier to voluntarily adopt a decrease in grazing pressure of this magnitude would be unrealistic and naïve given the magnitude of opportunity costs involved. Even with the assistance of incentive programs, achieving significant rates of adoption would be difficult and expensive.

4.1 Future research efforts

The logical progression for this research is to extend the analysis to the sub-catchment and catchment scale using a number of different land types, enterprise options and remote sensing technologies to estimate what it might cost to achieve a reduction in sediment movement off grazing lands across the entire catchment. These additional analyses could explore the impacts of climate change scenarios and the development of climate forecasting tools. The following extrapolation is included only to demonstrate how this work could be applied at the catchment scale, rather than to provide any definitive estimates of what it might cost to reduce sediment loads from the Fitzroy basin.

Brodie et al (2003) estimate that 91% of the sediment delivered to the coast from the Fitzroy River originate from grazing properties. If its assumed the grazing lands of the catchment are comprised entirely of homogenous 4,000 ha properties of predominately black spear grass pasture, we can estimate the quantity of sediment exported per property that would be needed to account for 90% of all sediment delivered to the mouth of the Fitzroy River. This is done in Table 17 below.

Table 17 Estimating the sediment currently exported from an average 4,000 ha property

Total Sediment from Catchment	t / yr	2,640,000
% from Graz land		90%
Current Sediment exports from grazing land per year	t / yr	2,376,000
Fitzroy catchment grazing land area	ha	12,500,000
Example property size	ha	4000
No. properties		3125
Av. sediment exported per year per 4,000 ha property	t / yr	760
Order of sediment exported over 20 yrs per 4,000 ha	t/20 yrs	15,206
Likely range of actual sediment exports per 4,000 ha property	t/20 yrs	4000 - 20000
Sediment exports when perennial pasture start condition is 70%	t/20 yrs	7700

Table 15 shows that on average a 4,000 ha property would export over 20 years 15,206 tonnes of sediment. Bearing in mind the variability in likely contributions from different parts of the region, the range of sediment exported per property could well vary from a low of 4,000 tonnes to a high of 20,000 tonnes, it is apparent that the 7,700 tonne of sediment estimated for the flexible grazing strategy utilizing 60% of TSDM and commencing with 70% perennial pastures, lies well within this range.

The data presented in table 16 draws on the sediment reduction/opportunity cost trade-off encountered when pasture utilisation is reduced from 60% to 50% (refer to table 13 above) to estimate the order and cost of sediment reduction *theoretically* achievable across the catchment. It does so by compensating land holders for their opportunity costs when adopting a reduction in % utilization of pasture from 60% to 50%, assuming the whole region is made up of 3,125 homogenous 4,000 ha case study properties.

Table 18 The potential catchment-wide payoff and cost

		Potential	More Likely
Current Sediment exports from Catchment Graz land per year	t/yr	1,980,000	
The marginal reduction in 20 yr sediment exports	t/20 yrs	3000	3000
The marginal annual reduction in sediment exports	t/yr	150	150
No. properties adopt		3125	1,563
annual reduction in sediment exports by reducing % utilization by 10%	t/yr	468,750	234375
% reduction in sediment exported from grazing lands		24%	12%
Estimated lump sum opportunity cost per tonne over 20 years	$/t/20yrs	$3	$12
Lump sum opportunity cost to landholders if implemented		$28,125,000	$56,250,000

The data in table 18 suggests a possible reduction in total sediment exports of 24% over 20 years at a theoretical cost of $28,125,000 is achievable by targeting pasture utilisation reductions reflected in area B of figure 3. A more realistic scenario might be a 50% adoption of the reduced grazing pressure at a cost of $12/t of sediment kept on farm (i.e. a 4 fold increase in the graziers opportunity cost). Even under these conditions a 12% reduction in total sediment exports at a cost of $56 million would appear plausible. The results reinforce the point that understanding the economic and environmental tradeoffs confronting the Fitzroy basin's graziers, may actually offer an affordable solution to a problem of serious regional and national concern.

4.2 Limitations of the research

There were a number of significant limitations to the research that the reader needs to be aware of. They include the following points which are briefly discussed:

- The use of a bio-economic model to represent a complex management, environmental and economic system;
- The simplistic grazing rules used in each of the grazing strategies;
- The inability of the GRASP model to carry its terminating environmental condition from one 20 year sequence into the start of the following 20 year sequence;
- The assumption of a homogenous land type for the entire Fitzroy catchment;
- The assumption that the current economic prospects will persist;
- The unrealistic timing of stock adjustments in the grazing model;
- The restriction of evaluations to only five historical sequences of climate;
- Landholders attitudes to risk and the confidence intervals surrounding these results. Both of these might help to explain graziers tendency to stock heavily

The research undertaken relies entirely on modelled output from GRASP, the conversion of liveweight gain data from GRASP into breeding herd performance estimates and finally the construction of an economic model to estimate the NPV resulting from changes in herd size and pasture utilisation levels. Whilst every effort has been made to ensure the results generated are broadly indicative of what might happen on a black spear grass pasture in central Queensland, it would be an assumption of heroic proportions to believe that the case study presented provides anything more than a broad approximation of the true nature of the economic and environmental tradeoffs likely to occur.

Nevertheless, both the overall pattern of resource use and profit maximising pasture utilization levels and their underlying economic and environmental trade-offs have a 'look' to them that accords with the diminishing returns concept of economic theory and regional grazing management practices observed by the authors. Further work is needed to understand how the risk attitudes of graziers affect these results and the confidence [placed in their interpretation. The challenge now for economists, policy makers and scientists' lies in discovering what package of incentives are needed to encourage graziers to adjust stock numbers back from their profit maximising levels to less risky positions that are more in tune with community expectations of improved water quality.

5.0 Conclusions

The present study, although based principally on modelling rather than direct experimentation, provides some insights into the complexities surrounding the economic and environmental tradeoffs for a flexible grazing system under a range of initial pasture conditions and climate variability. The research has confirmed that in many instances there appears to be little private financial incentive on the part of land managers to reduce soil and nutrient loss from grazing lands to socially desirable levels. This is particularly the case when graziers are asked to reduce stock numbers well below their profit maximising level.

The one exception to this generalisation was observed with the unprofitable and environmentally destructive results of over-grazing black spear grass pastures. For each of the three pasture start conditions tested a reduction in grazing pressure from unsustainable levels back towards the economic optimum not only improved the economic performance of the business, but dramatically reduced sediment movement and halted resource decline.

Understanding the complexity and variation in opportunity costs resulting from alternative grazing strategies and the effects of economic and environmental threshold points, greatly improves understanding of why graziers are reluctant to adopt socially desirable stocking strategies. The severity of environmental outcomes that occur beyond the economic threshold point highlights the environmental risks associated with over-grazing. What remains unclear is how the graziers attitude to this environmental risk compares to the risk of lower incomes associated with conservative stocking rates that exist below the economic threshold point.

Whilst the results of this analysis have been encouraging, additional work is required to test the methodology and findings on a range of alternative land types across the Fitzroy basin. This information could then be combined with remote sensing data estimates of land condition and groundcover to generate broadly indicative estimates of current pasture utilisation rates and what it might cost the grazing industry to reduce the quantity of sediment leaving properties.

Finally whilst a number of limitations to the research have been identified, there does not appear to be any issues that cannot be progressed with more sophisticated modelling, replication, industry consultation and additional collaboration between biophysical scientists, resource economists, graziers and policy makers. The key to making this happen lies in demonstrating the usefulness of this research to industry, government and natural resource management funding bodies who inturn have an opportunity to invest in an on going research program.

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