OVERLAND FLOW TRANSPORT OF SEDIMENT AND NUTRIENTS FROM LANDS UNDER DIFFERENT MANAGEMENT REGIMES IN THE ATHERTON TABLELAND

J.M. Burton[A], *C.A.A. Ciesiolka*[B] *and H.Ghadirit*[A]
[A] Centre for Riverine Landscapes, Faculty of Environmental Science, Griffith University, Brisbane, Australia.
[B] Natural Resources and Mines, 203 Tor Street, Toowoomba, Australia.

Abstract
A series of field rainfall simulations were carried out to study the impact of different land-use and management techniques on sediment and nutrient movement in the southern Atherton Tableland. Both farm management techniques and landscape factors appear to influence sediment and nutrient loss in runoff. The highest sediment concentration was produced on a cattle track and was substantially higher than sediment concentrations produced at all other experimental plots. In general higher sediment concentrations were associated with beef farms where the soil was most heavily impacted by cattle trampling. Loss of dissolved nitrate was at its highest on dairy sites which had greater nutrient inputs through fertilisation and nitrogen fixation by leguminous plants than either beef or rainforest sites. Nitrate concentration in runoff on the organic dairy farm was similar to the concentration at the dairy farm where mineral fertiliser was used. The position in the landscape was found to influence nitrate concentration, with the highest concentrations being measured in the lower toeslopes. Results indicate that farms should be managed and designed according to landscape features. They also demonstrate the importance of undertaking landscape scale rather than point scale studies.

Additional Keywords: Atherton Tableland, soil loss, nitrate movement, Great Barrier Reef, rainfall simulation

Introduction
Intensified land use and subsequent changes in sediment and nutrient levels in terrestrial runoff has been identified as a major environmental threat to the Great Barrier Reef World Heritage Area (Hook, 1997; Zann, 1995). Grazing associated with the beef and dairy industries comprise 77% of land-use within the Great Barrier Reef Catchment (Johnson *et al.* 2001). Increased grazing pressures have coincided with a growing awareness of the impact of sediment and nutrients in terrestrial runoff on water quality and health. Many studies have identified intensive grazing industries in the Great Barrier Reef Catchment as a dominant source of sediment and nutrients in waterways (Moss *et al.* 1992; Johnson *et al.* 2001; Neil *et al.* 2002). However this conclusion has in many cases been drawn by apportioning pollution contribution according to percent area of grazing as a land-use. This methodology leads to grossly inaccurate predictions because in landscapes where the spatial distribution of infiltration rates is highly variable there are localised sources and sinks associated with the hillslope morphology. At the drainage unit scale in tropical North Queensland it has been shown that surface runoff contributes only about 50% of any flood hydrograph; the remainder coming from residual water stored in the landscape from previous rainfall (Bonell, 1997). Thus, nutrient data from stream samples can be strongly influenced by the residual time that it is stored in the landscape before it appears in runoff. This investigation used a large field rainfall simulator to carry out on-farm rainfall-runoff experiments in order to measure and compare hydrological behaviour as well as nutrient and sediment generation and transport from lands under different management regimes in the Atherton Tableland.

The objectives were 1) to examine the impact of intensive grazing practices and farm management regimes on nutrient movement; 2) to identify the factors influencing nutrient movement within the landscape; 3) to provide best management techniques that will reduce the impact of intensive livestock industries on local waterways and the Great Barrier Reef Lagoon.

Materials and Methods
Study Area
The Atherton Tableland is situated in the Wet Tropics of North Queensland (Lat. 16º 50'S to 18º 50' S; Long. 144º 10' E to 145º 30' E), with an altitude between 700 and 900m above sea level. Mean annual rainfall across the Tableland varies from 1250mm to 1680mm (AUSIFD, 2001). The region is drained to the North by the Barron River and to the south by the Johnstone River. Both rivers pass through areas of intensive agriculture such as beef, dairy and croplands, as well as rainforest and urban areas before entering the Great Barrier Reef Lagoon. The catchment drained by the Barron river is one of the most extensively developed and heavily impacted of all wet

tropics catchments (Anderson et al 1993; Cogle et al 2000). This study focused on 2 beef farms, 3 dairy farms and 3 rainforests within the upper reaches of these catchments.

Site Selection and Description

Experimental sites were chosen to cover a range of different land uses and/or management practices. Factors considered when choosing simulation sites within each land use type included: 1) position in the drainage order of the catchment; 2) slope position; 3) slope shape; and 4) capturing any other significant features of the landscape, for example cattle tracks and advancing gully heads. Simulations were carried out on sites which were observed to be part of a drainage network and which were typical of the surrounding hillslopes. Field work was constrained by time and weather and as such priority was placed on obtaining data from a variety of sites rather than replication of sites. Table 1 summarises land-use and management techniques studied.

Runoff generation

A total of 15 simulations were carried out on 12.5 m by 2.0 m plots. At some sites simulations were carried out on more than one position in the drainage network. The rainfall simulator (RFS) used was an upgraded version of that described by Loch et al (2001). It consisted of six 'A' frame modules made of aluminium tubing. Nozzles were set one metre apart and oscillated across the plot. Pressure gauges were attached to the nozzles to monitor water pressure which was maintained at 60kPa for all simulations. Water was supplied to the RFS by a 6000L tank that was connected to an electric 1500W water pump, located at the base of the plot and housed in a steel frame with a 120L reservoir. Rainfall was measured using 7 pluviometers and 26 rain gauges, while runoff was measured by a tipping bucket device placed at the end of the plot. Rainfall was applied to all farm and rainforest sites at an average intensity of 98.2mm/hr (S.E. = 2.15) and 145mm/hr (S.E. = 7.38) respectively, until a constant rate of runoff was achieved.

Table 1. Summary of land-use and farm management at experimental sites

Site	Catchment	Landuse	Grazing Density/Management	Fertiliser Application	Soil Profile Class
1	Barron	Beef (b1)	Stocking rate =1.03AE/ha. Rotation= 7-10days on/off	P fertiliser every 3-4 years (DAP or CK66) Nitrogen on rotational 25 ha each year.	Pin Gin (red ferrosol)
2	Johnstone	Beef (b2)	Stocking rate= 0.81AE/ha Rotation= 2 paddocks rotated	No fertiliser	Pin Gin (red ferrosol)
3	Johnstone	Dairy (d1)	Stocking rate= 1.34AE/ha Rotation= 2 days in 4 days out; daytime only	organic dairy farm – N input from leguminous plants 111 kg/ac CK66, November 1995	Pin Gin (red ferrosol)
4	Johnstone	Dairy (d2)	Stocking Rate= 160AE/haDay Paddock. Rotation= 21 day cycle 1 day/paddock; daytime only. Irrigation: 25-27mm/hot week, or half of this on cool weeks.	Every 3 weeks 100kg/ha urea plus NPK mix 150kg/ha. 14 years. Evrey 4-5 years 1 tonne / ha	Pin Gin (red ferrosol)
5	Barron	Dairy (d3)	Stocking rate= 27.58 cows/ha Rotation= 9 day rotation, grazed on two consecutive nights then left for 9 days	Receives ponded dairy effluent. 29mm one day prior to simulation.	Tolga (brown dermosol)
6	Barron	Rainforest (r1)	* 5B – regenerating edge	nil	Tolga (brown dermosol)
7	Barron	Rainforest (r2)	*5B This forest makes up 3% of all residual rainforest on the Tablelands	nil	Quincan (red ferrosol)
8	Johnstone	Rainforest (r3)	* 5B	nil	Pin Gin (red ferrosol)

N.B. Stocking rates are expressed in adult animal equivalents. 1AE= 400kg steer.
*5B shrub layer 3 metres , highly deciduous, drier end of spectrum , 1300-1600mm rain/year, trees to 45m.

Sample Collection and Analysis

Two types of runoff samples were taken. The first was collected in 1litre autoclave jars at approximately three minute intervals from a trapdoor in the side of a "flume" that delivered the flow to the tipping buckets. Samples were weighed in the field, chilled and transported to the laboratory in a portable fridge. Once deposition had occurred the supernatant was extracted in the laboratory by suction. The remaining sediment was oven dried in autoclave jars at 40°C. When dry, all sediment samples were re-weighed for the calculation of total soil loss. The second runoff sample was collected in nutrient neutral bottles at 5-minute intervals from the tipping bucket mechanism. These samples were transported to the laboratory and frozen for nutrient analysis.

Nutrient analysis of samples was conducted at the Department of Natural Resources Analytical Chemistry Laboratories at Mareeba and Indooroopilly. Dissolved NH_4-N and NO_3-N were measured with a segmented flow analyser. For NH_4, a modification of the method of Searle (1974), which uses the indophenol reaction with salicylate and sodium dichloroisocyanurate, was used. The method of Eaton et al. (1995) was used to analyse for NO^3-N. This procedure uses copperised cadmium reduction to convert NO_3 to NO_2 under alkaline conditions. Kjeldahl N was determined by continuous flow analysis after digestion by a variation of the Kjeldahl procedure, as described by Lennox and Flanagan (1982) and Bran & Luebbe (1990), to digest and solubilise N compounds as ammonium. The ammonia was measured with the indophenol reaction (Searle, 1974). Sediment bound concentrations of NH_4-N and NO_3-N were measured by extracting a sample of sediment in 2M KCL in a 1:20 soil/solution ratio. Concentrations were measured using a Technicon Auto Analyzer. The standard range for NO_3 – N was 0.25mg/L to 8.0 mg/L and for NH_4-N was 0.125 mg/L to 4.0mg/L. ASPAC reference soils were included in the batch of extracts. Further details of the above methods are given in The Australian Laboratory Handbook of Soil and Water Chemical Methods (Rayment and Higginson, 1992). Vegetative cover was recorded as canopy and contact by visual assessment. Abundance of species and mass dry weight were also recorded. Slope of each plot was surveyed by a member of the simulation team.

Results and Discussion

Results for sediment and dissolved nitrate are summarised in Table 2 and will be discussed in this paper. Mean sediment concentration ranged between 23.3 mg/L at dairy farm three (d3), experimental plot 5a, to 4181 mg/L at beef farm two (b2), experimental plot 2a. Sediment concentration at site 2a was over seven times greater than the concentration found at the experimental plot with the second highest concentration (2c – 537.70 mg/L), and can be attributed to the presence of a cattle track on this plot. The high level of erosion that occurred in this rainfall simulation on a cattle track suggests that cattle tracks and "playgrounds", which are a significant feature of grazing farm landscapes, can be a major contributor to sediment and nutrient losses in runoff and need to be targeted in management practices. In terms of nitrate concentration the cattle track data was comparable with all other sites and therefore is included in the nitrate concentration comparisons. No relationship was found between slope and nitrate or sediment concentration. There was also no relationship found between cover (both percent and mass dry matter) and nitrate or sediment concentration.

Table 2: Summary of sediment and dissolved nitrate loss from each experimental plot

Site/ Landuse	Hillslope position	Slope (%)	Total runoff (mm)	Mean sediment concentration (mg/L)	Mean sediment loss (kg/ha/ hour)	Mean sediment loss (kg/ha/mm runoff)	Mean nitrate concentration (mg/L)	Mean nitrate loss (kg x 10^{-3}/ ha/hour)	Mean nitrate loss (kg x 10^{-3}/ ha/mm runoff)
1a / b1	ucs	14	2.2	263.90	5.81	2.64	0.07	1.5	0.7
1b / b1	mrs	19	26.4	614.00	13.51	0.51	0.09	23.8	0.9
1c / b1	mrs	19	26.90	150.10	3.30	0.12	0.08	21.5	0.8
1d / b1	lts	6	12.97	211.90	4.66	0.36	0.42	54.5	4.2
2a / b2	mrs	13	51.30	4181.00	91.98	1.79	0.18	92.3	1.8
2b / b2	ucs	15	30.30	333.70	7.34	0.24	0.10	30.3	1.0
2c / b2	mrs	18	12.90	537.70	11.83	0.92	0.13	16.8	1.3
3a / d1	ucs	8	28.20	300.00	6.60	0.23	0.03	8.5	0.3
3b / d1	mrs	12	101.10	165.50	3.64	0.04	0.38	384.2	3.8
3c / d1	lts	10	15.80	46.10	1.01	0.06	0.32	50.6	3.2
4a / d2	mrs	5	55.30	59.00	1.30	0.02	0.36	199.1	3.6
4b / d2	ucs	1.3	9.50	421.80	9.28	0.98	0.16	15.2	1.6
5a / d3	mrs	7	47.70	23.30	0.51	0.01	0.59	281.4	5.9
6a / r1	mrs	2	6.30	474.60	10.44	1.66	0.17	10.7	1.7
7a / r2	ucs	5	21.40	78.70	1.73	0.08	0.05	0.5	0.5
8a / r3	ucs	6	29.20	319.90	7.04	0.24	0.08	23.4	0.8

ucs = upper convex slope; mrs = mid rectilinear slope; lts = lower toeslope

Management effect

The effect of stock and field management on nitrate and sediment concentration was assessed by comparing results from experimental plots located on the mid rectilinear segment of the hillslope catena. This was done in an effort to exclude any effect that may be occurring as a result of catena position. Figure 1 displays sediment concentrations from different management techniques. The highest sediment concentration (excluding the cattle track) was 537.70 mg/L from experimental plot 2c at b2 (see Table 2). This farm had a low level of management in comparison to all other farm sites and the high sediment concentration is a result of this management. The second highest sediment concentration was at the rainforest one (r1) site. However, it should be noted that rainforest sites had substantially higher infiltration rates and lower runoff co-efficients than other land-uses. As such, the contribution to waterway pollution is not proportional. It was surprising to find that dairy farm one (d1), the organic farm, had higher sediment concentration than both dairy farm two (d2) or dairy farm three (d3). Figure 2 displays the influence of management on nitrate concentration. Not surprisingly the dairy farm that had been treated with effluent one day prior to simulation (d3) had the highest nitrate concentration. This result indicates the importance of timing of nutrient application, as a large runoff event soon after nutrient application would result in large quantities of the nutrient moving into surface waters. Another interesting result was that d1, the organic dairy farm had similar nitrate concentrations to d2 where inorganic fertilisers were applied. The rainforest (r1) produced nitrate concentrations comparable to both of the beef farms.

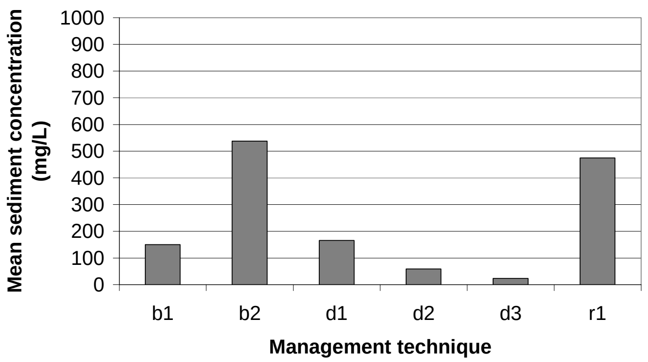

Figure 1. Comparison of sediment concentrations from different management techniques.

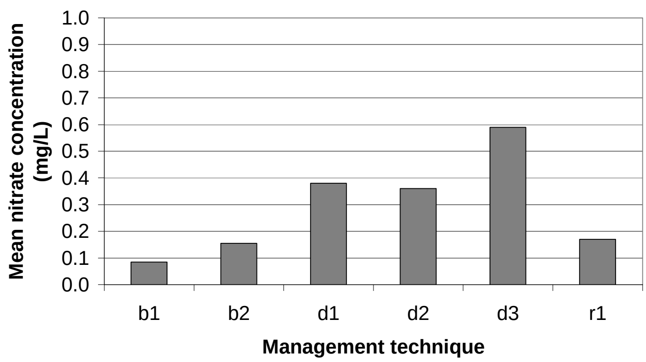

Figure 2. Comparison of nitrate concentrations from different management techniques

Catena effect

As the simulations were carried out in the higher order drainage units, it was observed that the landscape was subject to an expanding incisionary phase of drainage line development. While this process was obviously active in the virgin rainforest, stream rejuvenation, caused by base level lowering at points in the landscape such as cross road drainage, is actively incising older deposits and deepening pre-settlement drainage lines.

Thus, a catena effect was confirmed for runoff and nutrient concentrations. Nitrate concentrations, were found to increase from upper convex to mid rectilinear to lower toeslope positions (Figure 3). This pattern can be attributed to the movement and temporary storage of infiltrated rainfall that moves in the shallow subsurface in either preferential pathways called throughflow lines or spills over the edges of perched water tables associated with laterite formations in this landscape. This process thus provides another explanation for the enrichment of the rising limbs of runoff hydrographs as well as the base flow of streams of the Atherton Tableland. It can also be hypothesised that this process which is active at the continental scale accounts for the enrichment of ocean water at sites commonly known as “wonky-holes” on the Great Barrier Reef (Gagan et al. 2002).

Interaction

To examine the interaction of management and catena effect the entire data set was analysed. Once again b2 had a higher sediment concentration than any of the other farm sites even when data from the cattle track experimental plot was excluded (Figure 4). Suprisingly, rainforest one (r1) had similar sediment concentrations to the b2 farm and higher than other farms. Similarly rainforest three (r3) had sediment concentrations similar to beef one (b1). Although it must be noted that more rain was required to produce runoff and erosion in the rainforests than at the farms, this is still an interesting result. At the dairy farms it is interesting that when the management and catena effect are combined d2 has a higher sediment concentration than d1. When experimental plots were divided according to land-use (Figure 5) beef farms had the highest sediment concentrations, followed by rainforests, followed by dairy farms.

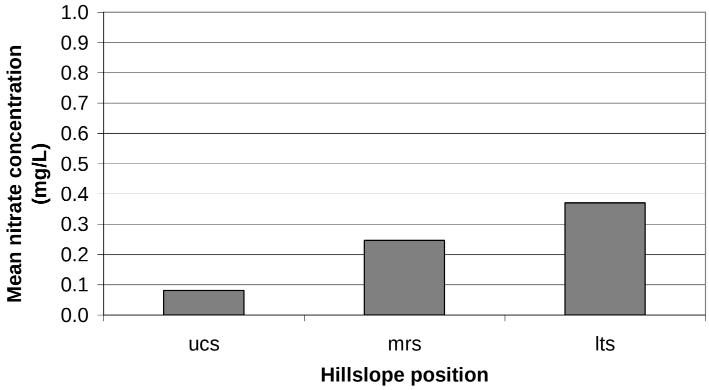

Figure 3. Comparison of nitrate concentrations at different hillslope positions

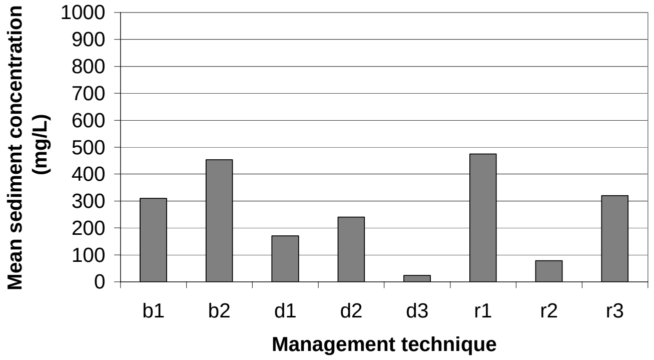

Figure 4. Comparison of sediment concentration at farms with different management techniques.

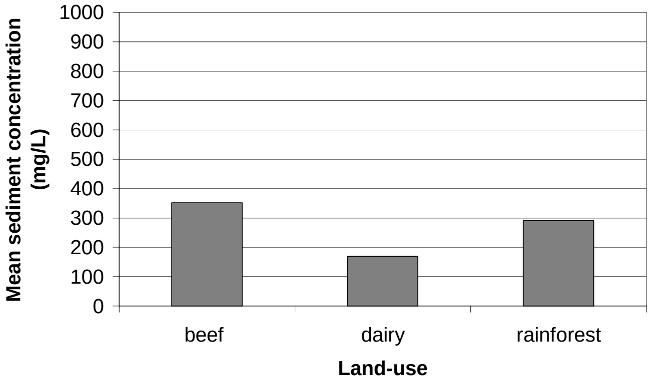

Figure 5. Comparison of sediment concentration at different land-uses

In terms of nitrate concentrations, d3 continued to have the highest after management and catena effects were combined, however b2 had higher concentrations than the other dairy sites (Figure 6). D1 (organic dairy farm) and d2 (mineral fertiliser dairy farm) continued to have similar nitrate concentrations whilst r1 had similar concentrations to b1. Overall dairy farms had the highest nitrate concentrations at 0.31 mg/L whilst beef farms and rainforests had similar nitrate concentrations at 0.15 mg/L and 0.10 mg/L respectively.

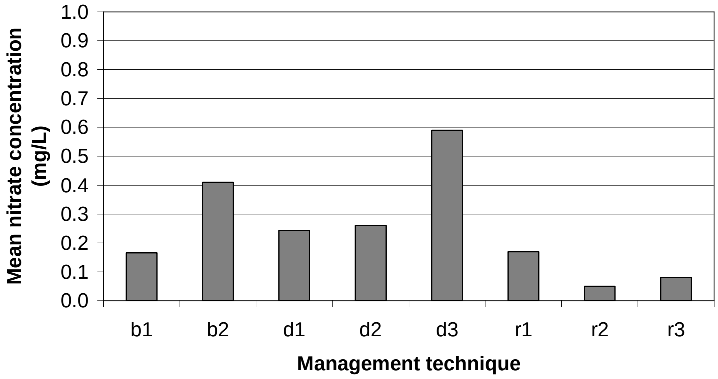

Figure 6: Comparison of nitrate concentration at farms with different management techniques.

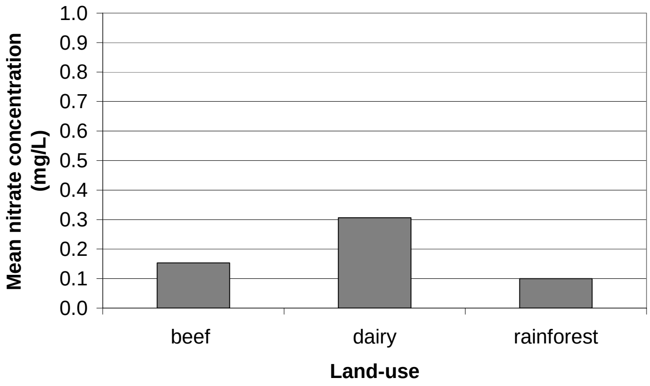

Figure 7: Comparison of nitrate concentration produced from different land-uses.

Conclusions

The results indicate that landscape factors may often override good management practice and therefore in order to reduce sediment and nutrient loss farms must be designed and managed according to landscape features. They also emphasize the fact that if experiments are to be carried out to understand factors such as nutrient and sediment movement they need to be designed on a landscape scale rather than point scale. It was interesting to find that sediment and nitrate concentrations from organic farming were not necessarily lower than concentrations from other farm management systems. Perhaps the most unexpected result of this study was that the concentration of nitrate and sediment in the runoff generated from rainforest site was as high as that of beef farm. However this may not be interpreted to mean that the two land use equally contribute to stream pollution as rainforest have a much higher infiltration rate and lower runoff coefficient than the beef farm.

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