SEDIMENT BUDGETS FOR CANE LANDS AND GRAZING LANDS IN NORTHERN QUEENSLAND, AUSTRALIA, AND THEIR USE TO TARGET APPROPRIATE MEASURES TO CONTROL SEDIMENT EXPORT

C.H. Roth[A, formerly C], *F. Visser*[B] *and D.A. Post*[C]
[A] ACIAR, Canberra, Australia.
[B] Laboratory for Experimental Geomorphology, Catholic University of Leuven, Leuven, Belgium.
[C] Davies Laboratory, CSIRO Land and Water, Townsville, Australia

Abstract
Large areas of the catchments discharging into the Great Barrier Reef Lagoon (GBRL) along Queensland's north-east coast are used for sugar production (coastal plains) or cattle grazing (semi-arid savannas in the uplands). The main concern with the export of sediments is the loss of associated nutrients, and the potential harm these materials might cause in freshwater and marine ecosystems of the GBRL.

Many landholders are aware of these issues, but there is still a lack of understanding on the exact amounts and sources of sediments and nutrients leaving cane lands and grazing lands. Mainly, landholders lack information on practical solutions to reducing sediment export and where to target the most appropriate erosion control measures.

In response, studies were undertaken to better understand sources, transport pathways and sinks of sediments in cane lands and grazing lands as a means to better target erosion control measures. This was done by developing detailed sediment budgets for representative catchments in cane lands in the Herbert catchment and degraded grazing lands in the Burdekin catchment. Data to construct the sediment budgets was obtained through monitoring of erosion and deposition in the different landscape elements, the determination of sediment discharge at the mouth of the study areas and spatial modelling using the sediment transport model, SedNet.

We present the results of these sediment budgets, and we discuss the range of soil conservation measures that can be derived from them, in particular the value of being able to clearly demonstrate to landholders which key erosion and deposition processes dominate where in the landscape, and how to best target appropriate erosion control measures.

Additional Keywords: hillslope erosion, gully erosion, sediment budget

Introduction
The impact of current land use on sediment and nutrient delivery from catchments draining into to the Great Barrier Reef lagoon (GBRL) continues to be considered of significant concern (Williams *et al.* 2001; Furnas 2003). Past work indicates that rates of sediment and nutrient delivery have on average increased about 4-fold since European settlement (Neil *et al*. 2002; Furnas 2003). Extensive cattle grazing of native savannah woodland is the predominant land use, and excessive grazing pressure leading to soil degradation and sediment export is seen as a major problem in many grazing areas (Roth *et al*. 1999). Cane growing, while restricted to the coastal plains, has also been recognised as a significant source of sediment and nutrient export (Bramley and Roth 2002).

This has led to a range of soil erosion studies being conducted in various locations of the GBRL catchments, both in grazing lands (McIvor *et al.* 1995; Scanlan *et al.*1996) and in cane lands (Sallaway 1979; Prove *et al.*1995). However, work to date has focussed on small scale erosion plot studies, which provide useful data on plot scale hillslope (sheet) erosion rates. This has focussed management response to the paddock or farm block, irrespective of whether soil leaving individual fields actually reaches streams and is effectively lost from the landscape, or whether there may be other significant sources of erosion outside studied field scale runoff plots (e.g. headlands, drain banks, gullies) also requiring management interventions.

Developing sediment budgets at small watershed or larger catchment scale is one approach to avoid these above shortcomings. Leopold *et al.* (1966) and Dietrich and Dunne (1978) are some of the earliest authors of sediment budgets. Since then numerous researchers have applied this approach, which provides a convenient means of presenting and analyzing erosion, deposition and sediment yields of river catchments (Walling 1999; Prosser *et al.* 2001). The sediment budget approach has particular advantages for resource management purposes. The budget principle ensures that all components in a catchment sediment transport system are examined, so that important sediment fluxes can be identified and management appropriately targeted. In addition it can provide information about the interactions between components of the system and therefore an understanding of how the system will respond to changes (Reid and Dunne 1996).

In doing so, it becomes possible to identify the key sediment sources **and** sediment sinks that should be best targeted for remedial action if the objective is to minimise net loss of soil and nutrients from managed landscapes. In this paper we present two case studies from the Herbert and Burdekin catchments of the GBRL to illustrate the merits of sediment budgets.

Materials and Methods

General methodology of developing sediment budgets is provided by Reid and Dunne (1996). Based on their work, we identified three general principles for the sediment budget approach taken here:

1. The study areas need to be well-defined hydrologically and large enough to capture all geomorphologically relevant landscape elements at sufficient scale to encompass all major transport processes.
2. The monitoring methods used need to simultaneously quantify erosion and deposition rates within all landscape elements; in practice this is sometimes not achievable, so that direct field measurements have to be complemented by process analysis using modelling.
3. Sediment budgets should be tested against an independent method; e.g. total net soil loss for a study area determined by budget against results obtained from gauging sites at the outlet of the study area.

Two experimental watersheds that fulfilled the above requirements were selected, one representing cane land in the Herbert River catchment (~ 100 km NW of Townsville, North Queensland), and one known to typify one of the erosion hotspots in grazing lands of the Burdekin River catchment (~80 km south of Townsville).

Cane land study site in the Herbert River floodplain

In the Lower Herbert, the study area chosen comprised a 5.4 km^2 portion of Ripple Creek sub-catchment, of which 3.2 km^2 is the alluvial plain used for cane growing and the remainder is characterised by adjacent forested slopes of the Mt Leach Range. The Ripple Ck alluvial plain is representative of large areas of the Herbert River floodplain grown to cane, with heavy alluvial clays requiring intensive surface drainage (mainly Gleysols and Planosols - FAO, 1988; corresponding to Hydrosols, Chromsols and Dermosols - Isbell, 1996). Cane land elements in the Lower Herbert managed by cane growers typically comprise ratoon and plant crop fields (~3:1 ratio), headlands, water furrows within fields, small and large farm drains. Drainage boards are responsible for the management of main drains.

A range of monitoring methods had to be developed and implemented in order to capture the breadth of processes and to employ the most appropriate methods in each individual situation and best suited to each scale of measurement. Details are provided by Visser (2003). Broadly speaking, four general monitoring strategies were employed:

- Paddock scale run-off flumes on ratoon and plant cane fields (to determine the net loss at paddock scale; flume plot area ~ 1 ha);
- Spatially distributed grab sampling (during major events; targeted at capturing runoff from individual cane land elements);
- Cross-sectional measurements in drains and water furrows using a profiler (pre and post wet season);
- Erosion pin arrays on headlands and in drain banks (~ 100 pins per array; measurements with electronic callipers pre and post wet season).

This was complemented by stream gauging to determine sub-catchment sediment discharge as an independent measure of net sediment export. Measurements were carried out in the 1999-2000 and 2000-2001 wet seasons (Dec-May; with 2740 and 1349 mm of rain, respectively; long term Dec-May average is 1807 mm).

Grazed study site in the Burdekin River catchment

In the Burdekin River catchment the watershed selected was Weany Creek, 13.5 km^2 in size. It is located in the Upper Burdekin about 15 km west of the township of Mingela, and is typical of the excessively grazed hilly country on Granodiorite-derived red duplex soils (Chromic Acrisols, FAO 1988; Red Chromosols, Isbell 1996). These areas have historically had high rates of sheet and gully erosion.

Again, a range of monitoring methods were employed to capture the different erosion and deposition processes at their respective scales, including:

- Micro runoff plots, to assess runoff and sediment generation rates for different cover and surface conditions;
- Hillslope erosion troughs, to quantify hillslope sheet erosion (bedload and suspended sediments);
- Cross-sectional measurements in flow lines using a profiler (pre and post wet season);
- Erosion pin arrays (~ 100 pins per array; measurements with electronic callipers pre and post wet season), to determine erosion and deposition of within different components of gullies;
- GPS surveys, to determine gully head advance rates;
- Gully network surveys, using aerial photo interpretation and ground-truthed categorisation of gully phases.

In addition, we used a modification of the SedNet sediment transport model developed by Prosser *et al*. (2001) to extrapolate the measurements and construct the watershed budget. The model is based on a simple conceptualisation of hydrological transport and deposition processes within a GIS spatial modelling framework. Amongst other factors, SedNet assisted us in determining bank erosion, for which we had no direct measures (details are provided by Prosser *et al.* 2001). This was complemented by stream gauging to determine sub-catchment sediment discharge as an independent measure of net sediment export. Measurements were carried out in the 1999-2000, 2000-2001 and 2001-2002 wet seasons (Dec-May; with 789, 367 and 576 mm of rain, respectively; long term Dec-May average is ~600 mm). Details of the monitoring and modelling methodologies used in this study are provided in Roth *et al.* (2003).

Results and Discussion

The sediment budget from the cane land study site is summarised in Table 1. For all landscape elements where both erosion and deposition data were acquired there is a clear indication that both processes occur simultaneously. The balance between the two determines whether a landscape element is a net source or a net sink for sediments. Across the two seasons monitored, minor drains were consistently acting as sediment sinks. Conversely, water furrows, ratoon and plant cane fields were consistently seen to be net sediment sources. The other elements varied between the two years. However, on average, headlands and Ripple Drain also act as net sinks.

Based on unit area values (t/ha in Table 1), on average water furrows and major farm drains are the main source of sediments (net erosion rate 19 t/ha and 9 t/ha, respectively) and minor drains are clearly the most efficient sinks (net deposition rate 35 t/ha). However, once the areal extent of each element is accounted for by multiplying it with the unit area net erosion or deposition rate, the ranking of sources and sinks shifts somewhat. In absolute terms, water furrows and plant cane fields by far constitute the most important source of sediment within the study area (425 and 376 t, respectively), while headlands and minor drains turn out to be the main sinks (105 and 74 t, respectively). These results clearly indicate that cane blocks are not necessarily the main sediment source, and that significant scope exists to minimise sediment export by targeting appropriate management options at other cane land elements, e.g. the elimination of water furrows in the case of laser-levelling blocks that contain water furrows.

Ratoon blocks, although protected by a trash blanket, still act as a net sediment source. This is because in reality trash does not fully cover all parts of the paddock, in particular if disturbed by ripping or cultivation practices. At the same time, unit area erosion rates from ratoon blocks are in the same order of magnitude as the unit area soil loss from the forested uplands (~1 t/ha) and probably reflect background levels. Taking into account the relative areal extent of each landscape element and using the data in Table 1, it is possible to calculate a mean weighted unit area soil loss rate for cane land. This yields an average cane land soil loss rate of 2.6 t/ha. Considering the high rainfall, this can be considered to be a comparatively low value. Irrespective, the budget indicates that there is room for further improvement.

Mean total sediment load obtained from the gauging station data at the Ripple Drain outlet was 1350 t, which compares reasonably well to 1037 t calculated using the budget approach in Table 1. This match provides us with sufficient confidence to use the sediment budget for scenario analysis purposes in a simple spreadsheet approach. Results of the following scenarios are presented in Table 1:

Scenario 1: Headland management is improved by maintaining better ground cover (reduced frequency of slashing) and repairing damaged headlands; we assume this leads to a decrease in headland erosion by 33% and in increase in headland trapping efficiency of 20%, increasing unit area net deposition rate from 5 t/ha to 12 t/ha;

Scenario 2: The area of paddocks with water furrows is halved by laser-levelling of fields and elimination of water furrows; this reduces the total sediment loss from –475 t to –212 t, which is slightly offset by a proportional increase in net erosion from ratoon and plant cane fields (due to furrow area becoming additional paddock area);

Scenario 3: In this case the assumption is made that growers and the drainage board decide to address bank erosion of main drains and major farm drains by reshaping and revegetating 25 % of the eroding sections of main drains and by establishing protective ground cover on 50% of eroding banks of farm drains, respectively; this measure reduces erosion from the main drain (Ripple Drain) accordingly, leading to an increase in net deposition from 40 to 85 t and 22 to 76 t, respectively.

Table 1. Average measured net sediment erosion and deposition rates for cane land components, and the calculated reduction of sediment export for a range of management scenarios (see text for descriptions; –ve values represent erosion and +ve values deposition).

Sediment sources and sinks	Measured average 99-00 and 00-01		Scenario 1		Scenario 2		Scenario 3	
	t/ha	t	t/ha	t	t/ha	t	t/ha	t
Headlands erosion	*12*	*271*	*8*	*179*	*12*	*271*	*12*	*271*
Headlands deposition	*17*	*367*	*20*	*441*	*17*	*367*	*17*	*367*
Headlands net	5	105	12	278	5	105	5	105
Water furrows erosion	*42*	*960*	*42*	*960*	*42*	*480*	*42*	*960*
Water furrows deposition	*23*	*517*	*23*	*517*	*23*	*258*	*23*	*517*
Water furrows net	-19	-425	-19	-425	-19	-212	-19	-425
Ripple Drain erosion	*86*	*187*	*86*	*187*	*86*	*187*	*64*	*140*
Ripple Drain deposition	*104*	*227*	*104*	*227*	*104*	*227*	*104*	*227*
Ripple Drain net	19	39	19	39	19	39	40	85
Major drain erosion	*60*	*207*	*60*	*207*	*60*	*207*	*30*	*104*
Major drain deposition	*52*	*178*	*52*	*178*	*52*	*178*	*52*	*178*
Major drain net	-9	-29	-9	-29	-9	-29	22	76
Minor drain erosion	*21*	*43*	*21*	*43*	*21*	*43*	*21*	*43*
Minor drain deposition	*55*	*117*	*55*	*117*	*55*	*117*	*55*	*117*
Minor drain net	35	74	35	74	35	74	35	74
Ratoon fields	-1.1	-136	-1.1	-136	-1.1	-145	-1.1	-136
Plant cane fields	-3.8	-376	-3.8	-376	-3.8	-386	-3.8	-376
Fallow[a]	-2.4	-74	-2.4	-74	-2.4	-74	-2.4	-74
Forested uplands	-1.0	-216	-1.0	-216	-1.0	-216	-1.0	-216
Total (Input - Storage)		-1037		-865		-844		-887
Relative sediment export (%)		100		83		81		86

[a] estimated

As shown in the bottom row of Table 1, even partial adoption of simple measures like improved management of headlands (scenario 1) or the gradual elimination of water furrows following laser-levelling (scenario 2, which is a widely adopted practice to enhance surface drainage in the Lower Herbert) provide scope of reducing sediment export by as much as 20%. Repairing eroding drain banks is an equally effective measure in the scenarios tested here (reduction of sediment export by about 16%), but is likely to be far more expensive. This little exercise clearly demonstrates the value of developing sediment budgets as a tool to better understand the key soil erosion and sediment transport processes and to place them into a landscape context. The spreadsheet behind Table 1 is easily used in a workshop or shed meeting environment and would allow growers to explore for themselves what the best options would be. It also demonstrates that significant initial improvements can be achieved with relatively low demands on grower resources.

Table 2 shows the sediment budget for Weany Creek, which is the grazed catchment studied. The average export of sediments from Weany Creek is predicted to be 874 tonnes per year, corresponding to an unit area sediment discharge of 0.65 t/ha per year. This can be considered to be a low value, and reflects the below average rainfall experienced in two of the three monitoring years. The ratio of sediment export to sediment delivery is 71%, typical of headwater streams (Wasson, 1994). Gully erosion accounts for 60% of sediment delivery, and is thus the greatest source. Most of this material originates from a small band along the creek and drainage lines. This is significant, as to date erosion measurements have tended to focus on sheet erosion from hillslopes (McIvor *et al.*, 1995; Scanlan *et al.*, 1996), which according to our data account for only 35% of the delivery to stream (52% of suspended sediment). Suspended sediment export determined in the budget (830 t, Table 2) compares reasonably well to 546 t as determined from the stream gauging data, considering the lower than average rainfall in two out of the three years of the study. Current research looking at bank erosion is this catchment may refine/alter these estimates in the future.

Table 2. Sediment budget for a grazed watershed (Weany Creek) in the Upper Burdekin.

Budget component	Bedload (t/year)	Suspended sediments (t/year)	Total sediments (t/year)
Hillslope delivery	0	432	432
Gully erosion :			
- *Gully head advance*	*(66)*	*(66)*	
- *Slumping and slope erosion - heads*	*(153)*	*(153)*	
- *Slope erosion – middle sections*	*(104)*	*(104)*	
- *Slope erosion - valleys*	*(47)*	*(47)*	
Total gully erosion	370	370	740
Streambank erosion (calculated by SedNet)	28	28	56
Total sediment delivery	398	830	1228
Sediment stored in streambed	354	0	354
Total sediment export	44	830	874

Based on the above comparison, we have sufficient confidence in the sediment delivery model for it to be used in scenario analysis to predict the impact of a number of grazing management scenarios (see Table 3). Assuming that the grazier chooses to target specific areas for rehabilitation, i.e. presumably those areas that have the lowest levels of cover, the question is where will that grazier get the best value for money in terms of reducing sediment export?

The results in Table 3 show that it is not necessary to manage the entire watershed for sediment reduction; a targeted intervention solely along the creek lines is likely to yield sufficient sediment reduction. Overall, the budget indicates that focussing solely on hillslope erosion might not be appropriate, given the high gully erosion. However, as shown by Roth *et al.* (2003), reducing grazing pressure to increase ground cover levels to >75 % will eventually lead to a significant reduction in runoff as soil surface condition improves and soil hydrological function is restored. The reduction in runoff in turn is likely to reduce gully incision. This hydrological feedback is not yet included in the sediment transport model, and hence the results of the scenario analysis are probably an underestimate.

Table 3. Results of scenario analysis using SedNet and the sediment budget data in Table 2.

Scenarios	Total sediment export (t)	Relative sediment export (%)
Current situation (Table 2):	830	100
Case 1: Increase cover to >60% over the entire catchment (1,350 ha):	425	51
Case 2a: Increase cover to >60% on 118 ha of footslopes adjacent to drainage lines (404 ha):	634	76
Case 2b: Increase cover to >60% on 107 ha of midslopes (431 ha):	747	90
Case 2c: Increase cover to >60% on 103 ha of ridges (422 ha):	800	96

Conclusions

The results of the two contrasting case studies clearly illustrate the need to simultaneously determine erosion and deposition at a scale larger than the immediate farm block or hillslope, which is the scale erosion plots have traditionally focussed on. As landholders invariably manage more than just farm blocks or hillslopes, restricting erosion measurements to plots risk missing some of the key processes, which may result in suboptimal soil conservation responses. This is particularly the case if significant opportunities are overlooked to either reduce erosion rates (e.g. eliminating sources, like furrows in the cane system studied) or increase sediment trapping (by enhancing sinks, e.g. headlands) within fields or beyond the field boundary, as was demonstrated for our cane land study. Depending on the spatial distribution of the critical sources, sediment budget information can also help to identify the most efficient location to target interventions (e.g. valley bottoms in the case of the grazing study).

The study was also able to demonstrate that sediment budgets determined for small catchments can provide very tangible information for landholders. If developed in conjunction with modelling tools, they can also form the basis of more robust scenario analysis tools that lend themselves to participatory involvement by landholders. Given that landholders' resources for soil conservation measures are usually limited, better targeting of the right management options at the critical sources and sinks of sediments would seem a more efficient and strategic approach to control sediment export.

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