Estimating sediment loads in Great Barrier Reef catchments: balance between modelling and monitoring

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Abstract

In catchments adjacent to the Great Barrier Reef World Heritage Area, there is growing concern that sediments and nutrients being exported from the land are having a detrimental effect on coral reef communities. Monitoring programs have been initiated in the Burdekin catchment to determine rates of sediment runoff and to provide important base line data against which to evaluate any future effect of land management changes. Due to the spatial limitations and high cost of field monitoring, modelling has also been carried out to determine the current sediment loads across the Burdekin catchment. This paper presents a comparison of some of the measured and modelled sediment load data. The data suggest that there is good agreement between end of sub-catchment measured and modelled sediment loads. However, more detailed process based field monitoring has highlighted that the model does not necessarily accurately represent the different erosion processes contributing to the end of catchment loads, at least during drought conditions. The field data also suggest that there is a significant delay between changes in land condition and end of catchment sediment loads, and further work is needed to quantify the temporal lag between land management change and water quality response.

Keywords

Burdekin, grazing, sediment erosion

Introduction

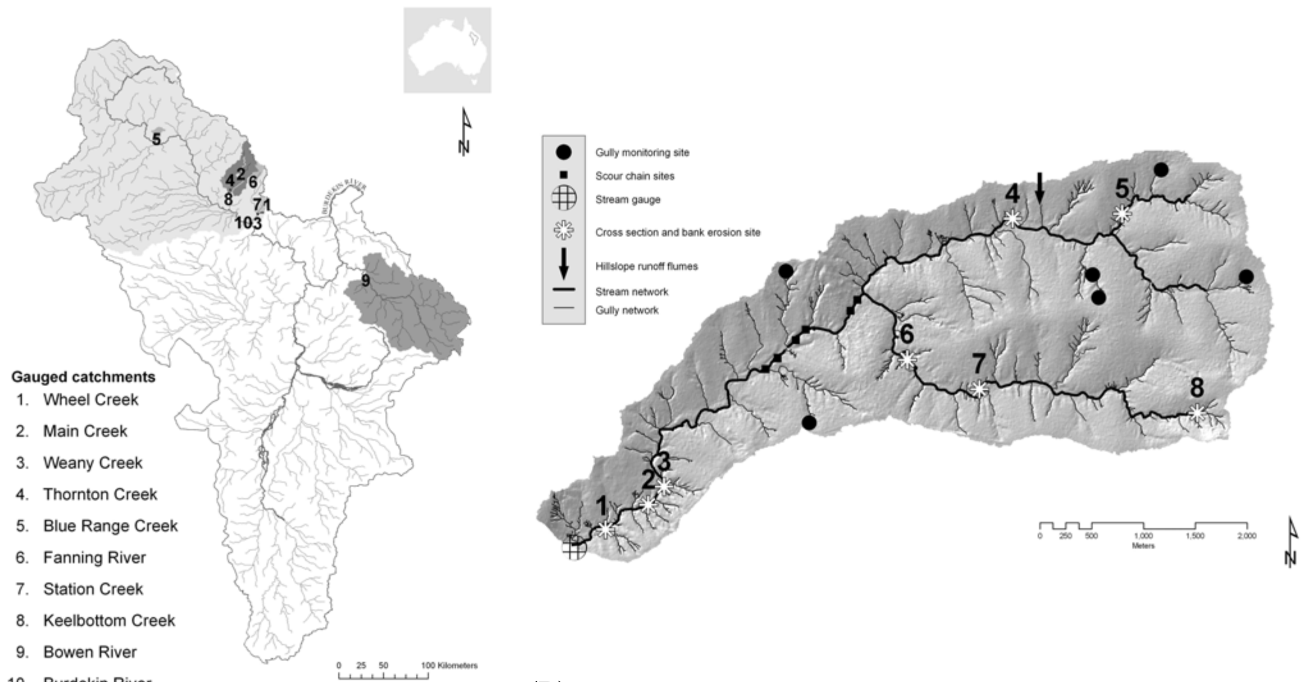
Sediment and nutrient loads from catchments adjacent to the Great Barrier Reef (GBR) World Heritage Area in Queensland, Australia, have increased since European settlement (McCulloch *et al.*, 2003; Neil *et al.*, 2002). Recent research suggests that these increased loads are having a detrimental effect on coral reef systems (e.g. Fabricius *et al.*, 2005). In an effort to reduce this impact, the Reef Water Quality Protection Plan (RWQPP) was signed by the Queensland and Federal Governments in October 2003 with the overall aim of 'halting and reversing the decline in water quality entering the reef within 10 years'. To facilitate the implementation of the RWQPP, regional Natural Resource Management (NRM) catchment bodies are required to determine the major land uses and processes responsible for the excess loads, and set appropriate water quality targets. This, in theory, will then provide a bench mark for the assessment of improved land management practices over time.

Due to the large area and short time frame involved with the RWQPP, water quality targets and evaluations of land use change have been determined using catchment modelling, primarily in the form of the SedNet model (e.g. Brodie *et al.*, 2001; Cogle *et al.*, 2006; McKergow *et al.*, 2005). SedNet is a spatial model that produces catchment scale sediment budgets by predicting various erosion and deposition processes within a river link network (Prosser *et al.*, 2001b; Wilkinson *et al.*, 2004). The SedNet model is considered to be robust when applied at large scales (>10,000 km^2) and has been shown to perform well when evaluated against end of catchment load monitoring and tracing data in catchments with rivers that have regular flow (e.g. Bartley *et al.*, 2004). There has, however, been no similar comparison for ephemeral rivers such as those in the dry tropics. In this paper we: (1) compare measured and modelled sediment load data for six sub-catchments in the Burdekin River (14 - 36,000 km^2); and (2) evaluate a within catchment sediment budget derived from field monitoring and modelling for the Weany Creek catchment (14 km^2) in the Upper Burdekin. The Burdekin and Fitzroy River basin, are considered to be the largest contributors of sediment to the GBR lagoon (McKergow *et al.*, 2005). The implications of these results are then discussed within the context of target setting and land management change dry tropical rangeland grazing.

Field sites and methods

Catchment scale monitoring
Over the last 7 years, a range of organisations including Meat and Livestock Australia, the Department of Defence and the Burdekin Dry Tropics Board have funded the installation and maintenance of 10 sub-catchment water quality monitoring stations in the Burdekin River basin (Figure 1A). At each station, stage height was measured at 1 minute intervals when the stream depth was above the event threshold (varies for each site). Water depth was measured using a Greenspan ps700 pressure transducer. The gauge sites were surveyed to determine the mean cross-section dimensions. Turbidity and velocity were recorded using a McVann turbidity meter and Starflow Ultrasonic Doppler Velocity meter. A tipping bucket rain gauge was located adjacent to the gauge at each site. Water samples were collected during events using an ISCO automatic water sampler and samples were returned to the laboratory for analysis of turbidity, total suspended solids (TSS), nitrogen, phosphorus and, at some sites, sediment size distribution. Strong relationships exist at most sites between turbidity and TSS (see Post *et al.*, 2006 for more details). The relationship between suspended sediment and turbidity was used to determine flow weighted suspended sediment concentration (after Grayson *et al.*, 1996). These suspended sediment data, along with the velocity and channel dimensions, were used to calculate the sediment loads during events. The event based sediment loads were then totalled for each wet season to provide an annual suspended sediment yield at the catchment outlet.

The sediment loads reported for Weany Creek in this paper differ from those presented in Kinsey-Henderson *et al.*, (2005) and Bartley *et al.*, (In Press) due to a larger data set and improved analysis techniques. Examination of the uncertainty bounds on the relationship between turbidity and TSS, measurements of velocity, and variations in velocity across the stream (data not shown) suggest that the estimates of suspended sediment fluxes from the end of the Weany Creek catchment have errors associated with them in the order of ±50%. This error is considered to be similar for all of the monitored catchments.



(B)

(A)

Figure 1. (A) map of the Burdekin sub-catchments currently monitored for sediment loads and (B) the Weany Creek catchment showing the location of the hillslope, gully and bank erosion measurement sites.

Sub-catchment scale monitoring
The 10 monitoring sites shown in Figure 1A are useful for measuring end of catchment loads, however, more detailed studies are required to determine which erosion processes are contributing to these loads. To obtain

a better understanding of the sediment budget for these grazed semi-arid landscapes, a range of hillslope, gully, bank and channel bed monitoring sites were set up in Weany Creek (Figure 1B). Weany Creek catchment is 14 km^2 and has been grazed for more than 100 years. The catchment was chosen for monitoring due to its location in an area identified as having high erosion rates (Prosser *et al.*, 2001a), but also because of the willingness of the landholders to trial sustainable grazing practices. The details of the field equipment and methods used in this study are presented in detail in Bartley *et al.*, (In Press; 2006). An overview of the processes, methods and timescales of data collection is given in Table 1.

Table 1. Overview of processes, methods and timescales over which data were collected.

Process/variable measured	Method used	Period data was collected
Net hillslope sediment loss	Flumes	2002-2005
Gully head cutting	Erosion pins	six years for three gully heads (1999-2005) and one year for five gullies
Gully side wall erosion/deposition	Pins and cross-sections; GPS with Wild TC total station	six years for one gully system (1999-2005) and one year for five gullies
Erosion/deposition of gully floor	Pins, x-sects and scour chains	six years for one gully system (1999-2006) and one year for five gullies
Bank erosion	Erosion pins	2002-2005
Channel sediment storage	Bench marked cross-sectional change	2002-2005
Sediment yield at catchment outlet	Gauging station	2000-2005*

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

Catchment and sub-catchment scale modelling

The SedNet model has been run in the Burdekin River basin and sub-catchments at a range of scales. The most recent model runs for the entire Burdekin region (>130,000 km^2) are described in detail in Post *et al.*, (2006). The SedNet model was also applied at a much smaller scale for the Weany Creek catchment (13.5 km^2) to help evaluate the impact of changed grazing regimes on sediment loads (Kinsey-Henderson *et al.*, 2005). The Weany Creek model used a DEM based on colour aerial photos at 25 cm resolution. Weany Creek is a headwater catchment and does not have a distinct floodplain, therefore the model set-up used for this catchment was slightly different to the catchment scale model described in Wilkinson *et al.*, (2004). The model described in Kinsey-Henderson *et al.*, (2005) acknowledged the limited data available to parameterise the model, and best estimates of erosion rates for a number of processes (e.g. bank erosion) were used.

Results and discussion

Catchment scale comparison between measured and modelled sediment loads

Six of the ten monitoring sites had two or more years of data suitable for calculating loads. Unfortunately the data were collected during some of the driest years on record, therefore a direct comparison with the long term average data used in SedNet is not necessarily appropriate. However, a comparison of results will allow us to test whether the measured and modelled results are in the same order of magnitude and therefore suitable for long term average load predictions and target setting. There is a good agreement between the measured and modelled sub-catchment sediment loads (Table 2 and Figure 2). SedNet is over-predicting sediment load in 5 out of 6 catchments, but, this is expected given the lower rainfall years available for calculating measured loads. This analysis suggests that SedNet is suitable for estimating average end of catchment sediment loads at a range of spatial scales.

Sub-catchment scale comparison of measured and modelled sediment loads

As shown in the previous section, there is a reasonable match between the modelled and measured sub-catchment load data in the Burdekin catchment. However, this does not mean you can assume the same level of accuracy when interpreting the erosion process data. It is also possible that the right predicted yield is obtained for the wrong reasons. Table 3 presents the sediment budget for Weany Creek as measured by the SedNet model (Kinsey-Henderson *et al.*, 2005) and from field monitoring data (Bartley *et al.*, In Press). Both the modelled and field measured sediment budgets have very similar fine sediment loads of 830 and 784 t/yr, respectively. Both these load estimates are within 30% of the suspended sediment flux measured at the end of the catchment (Table 3). However, there are large differences in the relative proportion of each of the erosion processes contributing to the end of catchment loads. The main differences between the modelled and measured sediment budgets are that: (1) approximately 17% of the hillslope erosion measured in Weany

Creek is comprised of coarse material (> 2 mm), whereas the SedNet model assumes there is no coarse sediment component from hillslope erosion; (2) the model assumes that gullies are net erosion sources, whereas the measured data suggest they are net depositional features, at least during drought periods; (3) measured stream bank erosion is 5 times higher than initially estimated by the model; (4) the channel bed is a net source of coarse sediment rather than a net sink as predicted by the model; (5) the amount of measured sediment being exported from the catchment is dominated by coarse material (>2 mm), although this assessment is considered to be biased due to a lack of monitoring sites located in some of the depositional zones (see Bartley *et al.*, In Press for more details).

Table 2. Monitoring and modelling results for 6 gauged sites in the Burdekin catchment ranked according to catchment size. It is estimated that there is ±50% error associated with the measured load estimates.

	Measured data					Modelled data
Site # in Fig. 1	**Site name**	**Catchment area (km²)**	**Data collection period (year wet season started)**	**Years of data**	**Mean suspended sediment yield (Kt/yr)**	**Mean suspended sediment yield (Kt/yr)**
3	Weany Creek	14	1999-2005	7	0.54	0.83
4	Thornton Creek	85	2001-2005	5	2.9	3.2
7	Station Creek	148	2001-2005	4	7.98	9.8
8	Keelbottom Creek	1170	2002-2005	4	18.2	71.1
9	Bowen@ Myuna	7200	2003-2005	2	375.2	584.4
10	Burdekin@ Macrossan	36390	2001-2005	5	1987.4	1755.8

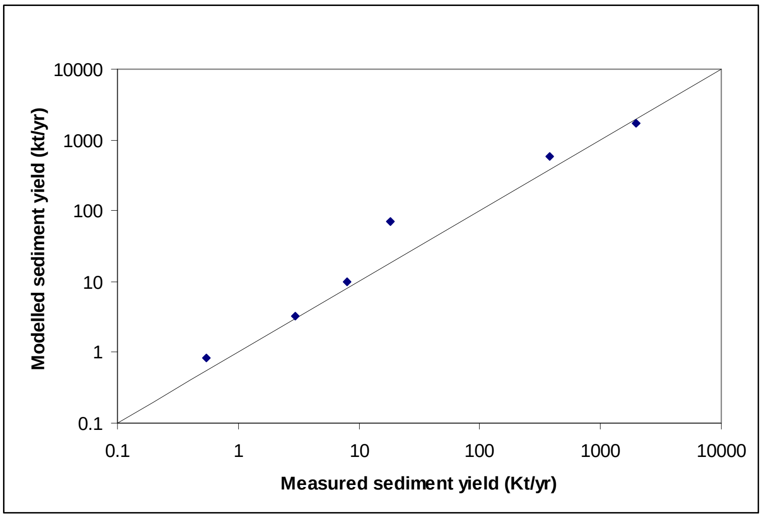


Figure 2. Measured versus modelled sediment loads for six Burdekin River sub-catchments.

It is important to stress that the comparison between modelled and measured results presented in Table 3 is influenced by the different time periods of the two methods. The measured sediment budget was developed during an extremely low rainfall period and therefore this budget is representative of drought conditions (average runoff of 17.46 mm/yr for 2003-2005). The modelled results are based on a slightly wetter rainfall period (~ 49.36 mm/yr of runoff for 2000-2002). The measured sediment budget may look more similar to the modelled budget if the data were collected during a higher rainfall period. For example, during higher rainfall periods, the gullies may become a net sediment source as predicted by the model, and similarly the stream bed may become a net sediment sink. However, the model does not currently account for deposition in gully systems, only erosion. Nor does the model represent the channel bed as a net sediment source regardless of the hydrological conditions. This is because the model is designed to represent long term changes only. Therefore caution must be used when using the model at small scales and during drought conditions in dry tropical environments.

The measurement data suggest a range of possible explanations for sediment movement in dry-tropical catchments. It could be that the large store of coarse sediment being mobilised from the stream bed in Weany Creek is a result of historically higher hillslope erosion rates (see Bartley *et al.,* 2006), and the sediment that was deposited in the channels and gullies over the last 100 years of grazing is now leaving the catchment. Alternatively, it could be that in dry years sediment is deposited in gullies, but there is not enough flow energy for the sediment to reach the stream channels, and subsequently the bed of the stream erodes. In higher runoff years sediment from the gullies is delivered downstream and deposited in the streams. Without above average rainfall data it is difficult to determine the exact process. Regardless, this data suggests that there will be a temporal delay between management actions employed to reduce sediment loads in river systems, and the observed sediment loads at the end of the catchment. This is primarily a function of the variable rainfall in these catchments. Further work using sediment tracing and dating techniques would help quantify sediment residence times for these catchments and estimate the likely delay between land management change and end of catchment water quality.

Table 3. Comparison of the modelled and field measured sediment budgets for the Weany Creek catchment as compared with the suspended sediment yield measured at the catchment outlet. Positive values represent erosion and negative values deposition. In the measured sediment budget sediment export was calculated by summing the individual erosion processes.

Budget Component	**Modelled** sediment budget (t/yr)	**Field measurement** based sediment budget (t/yr)
Years for which the budget was developed (year wet season started)	1999-2001	2002-2004
Hillslope delivery	432 (0% coarse)	592 (17% coarse)
Gully erosion	740	-1178
Stream bank erosion	56	311
Sediment stored in streambed	-354	4479[a]
Sediment exported	874	4205
- proportion coarse, > 0.2 (as % of total load)	44 (5%)	3421 (81%)
- proportion fines, <0.2 mm (as % of total load)	*830 (95%)*	*784 (19%)*
Suspended sediment load measured at catchment gauge (t/yr)[b]	597	553

[a] considered an overestimate due to a lack of measurement data from several depositional zones; [b] the load data presented in this table differ from previously published work (e.g. Bartley *et al.*, In Press; Kinsey-Henderson *et al.*, 2005) due to improved data analysis techniques and larger data sets.

Conclusion

There is a need for robust catchment scale sediment and nutrient budget models to help with water quality target setting and land management scenario analysis in the GBR region. This paper has shown that there is good agreement between modelled and measured end of catchment sediment loads at a range of scales in the Burdekin catchment. However, more detailed field monitoring in a headwater catchment of the Burdekin has highlighted that that the models do not adequately represent the erosion processes contributing to the end of catchment loads, however, this is potentially due to low rainfall conditions during data collection. This research highlights how long term catchment scale monitoring projects are crucial for understanding the process of sediment transport within catchments. It also emphasises that models such as SedNet will continually evolve as new data and process understanding becomes available. Any load based predictions and associated water quality targets made using these models will change over time. Water quality targets should therefore be presented using a range of values rather than single load values.

The field monitoring in Weany Creek also highlighted that there is likely to be a temporal delay between the erosion event in the catchment, and the delivery of sediment from the catchment due to storage of material in channel and gully systems in dry years. Research using sediment tracing and dating techniques would be useful for quantifying the residence times of both fine and coarse sediment, which is crucial for understanding the link between land management change and the downstream impacts on receiving water bodies. Further work looking at the impact of different climate regimes (drought versus wet periods) would also provide an insight into how end of catchment loads, and thus water quality targets, may be expected to change with time.

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