Modelling, Monitoring and Sediment Tracing in the Tully River Catchment, North Queensland: a Comparison of Techniques

Hateley, L. R. [1], J. D. Armour [1], J. Brodie [2], J. Faithful[2], G. L. Pitt, [1] and P. N. Nelson [3]

[1] Queensland Department of Natural Resources and Water
[2] Australian Centre for Tropical Freshwater Research, James Cook University, Townsville
[3] School of Earth and Environmental Sciences, James Cook University, Cairns

Email: louise.hateley@nrw.qld.gov.au

Keywords: *SedNet, sediment, water quality monitoring, sediment tracing*

EXTENDED ABSTRACT

The Great Barrier Reef (GBR) lagoon is an internationally significant ecosystem, located off the Queensland coast. The Reef Water Quality Protection Plan aims to halt and reverse the decline in water quality entering the reef. One of its actions requires the development of Water Quality Improvement Plans (WQIP). As sediment is one the key pollutants identified within the Tully catchment, its sources and the impact of changed management need to be identified as part of the WQIP.

A range of techniques are available to ascertain the various sources and volumes of sediment being delivered and transported in a catchment. Three techniques include modelling, water quality monitoring and sediment tracing. Each has its advantages and disadvantages but when carried out simultaneously can provide valuable information. We compare and contrast these techniques as part of the WQIP research component. Catchment scale models such as the Sediment and River Network Model (SedNet) can provide an understanding of how catchments function by constructing a sediment budget.

The three studies showed similar results relating to sediment erosion and transport. The total modelled sediment load supplied to streams was 183 kt/yr. Hillslope erosion was the dominant process with 116 kt/yr or 64% of the total sediment supply. Contributions from bank and gully erosion were 57 kt/yr (31%) and 10 kt/yr (5%) respectively. Monitored Total Suspended Solid (TSS) concentrations from all sub-catchments were generally low; most < 25 mg/L. Forest sites were consistently lower than disturbed sub-catchments such as sugarcane and bananas. A comparison of mean monitored TSS concentrations and modelled annual mean concentrations from SedNet showed reasonable agreement. Results from sediment tracing showed that hillslope erosion was dominant contributor to suspended sediment (75%) comparing well with modelled and monitored data. In terms of landuse, the results from the three studies generally show that a high proportion of sediment is coming from sugarcane. However, the SedNet model over estimated the sediment load derived from forest sources. It is acknowledged that the Revised Universal Soil Loss Equation is not particularly suitable for the prediction of hillslope erosion from steep naturally forested areas under wet tropical conditions.

These techniques assist to build robust knowledge about catchment behaviour. Modelling has the major advantage that it is fairly easy, cost effective and has the ability to run ‘what if’ scenarios that the other techniques cannot. Total suspended sediment concentrations in the Tully River are low in comparison with other north Queensland rivers despite a high rainfall. This is probably because most of the Tully WQIP region is relatively undisturbed forest. Of the suspended sediment being transported by the river, most originated from agricultural landuse. This comparison of studies corresponds well with other erosion and water quality studies in the Wet Tropics. Understanding sediment sources will assist with the targeting of limited resources towards reducing soil erosion.

1. INTRODUCTION

The Great Barrier Reef (GBR) lagoon is an internationally significant ecosystem, located off the Queensland coast. It is listed as a World Heritage Area for its outstanding natural values, and its social and economic benefits to the region are widely recognised. It is evident that the export of nutrients, sediment and pesticides to the GBR lagoon has increased since European settlement (Baker 2003; Brodie *et al.* 2003). The majority of research suggests that pollutants from land-based sources are affecting inshore reefs and seagrass areas of the GBR lagoon (Fabricius *et al.* 2005; Hutchings *et al.* 2005).

The Reef Water Quality Protection Plan (Reef Plan 2003) aims to halt and reverse the decline in water quality entering the reef within 10 years (Anon 2003). One of its actions requires Local Governments and Natural Resource Management (NRM) bodies to develop Water Quality Improvement Plans (WQIP). The aim of a WQIP is to determine environmental values and water quality objectives, and to develop a longer-term strategy for achieving reef water quality. As sediment is one the key pollutants identified within the Tully catchment, its sources and the impact of changed management need to be identified as part of the WQIP.

The sediment transported by a river will often be derived from a range of sources within a catchment. Factors influencing the amount and type of sediment supply to channels include vegetation cover, rainfall intensity, slope, soil type and texture, and landuse (Bridge 2003). Sediment sources can be defined spatially (e.g. sub-catchment) or by group (e.g. landuse, geology) or by process (e.g. surface erosion vs. sub-surface erosion). Surface erosion is also known as hillslope or sheet erosion and sub-surface erosion is referred to as bank or gully erosion.

Suspended sediment is generally the dominant component of the total load and is the category of focus in this study. The suspended load consists mostly of clay, silt and very fine sand (<63 µm) transported in suspension through the water column. Australian rivers are dominated by suspended sediment, with bedload accounting only for a small fraction of the total load (Rieger and Olive 1988). The finer fractions of suspended sediment generally travel the furthest, contain most pollutants and are difficult to manage using current soil erosion mitigation measures (Motha *et al.* 2003). Bridge (2003) states that most transport and deposition is assumed to occur during flood events, as concentrations and transport rates of sediment generally increase with discharge.

A range of techniques are available to ascertain the various sources and volumes of sediment being delivered and transported in a catchment. Three techniques include modelling, water quality monitoring and sediment tracing. Each has its advantages and disadvantages but when carried out simultaneously can provide valuable information. We compare and contrast these techniques as part of the WQIP research component.

Catchment scale models such as the Sediment and River Network Model (SedNet) can provide an understanding of how catchments function by constructing a sediment budget. A sediment budget identifies and quantifies the sources, pathways and sinks of sediment in a catchment (Wilkinson *et al.* 2004). Sediment budgets offer a way to integrate catchment processes into a transparent logical framework. They also allow for transparent comparisons of 'what if' scenarios that represent changes to catchment management (Armour *et al.* 2007).

Soil erosion and sediment transport processes can be measured by direct or indirect procedures. A direct method to measure sediment transport is the monitoring of sediment concentration in channels at different points in the catchment. Intense monitoring of sub-catchments can give some information on sources, but it is expensive and labour intensive. Sediment tracing is an indirect way of estimating soil erosion and the relative importance of a number of potential sources contributing to the sediment load of a channel (Collins *et al.* 1997). The sediment tracing technique is relatively simple and compares properties of the sediment in question with the same properties of potential sources (Collins *et al.* 1997). The fingerprinting technique allows the relative contribution of sources to be identified. The main assumption is that the suspended sediment has one or more properties in common with the sediment source.

2. STUDY AREA

The Wet Tropics bioregion of Far North Queensland, Australia, covers a coastal strip of 20,500 km^2, between 16°S and 19°S. The Tully WQIP region is situated in the southern part of the Wet Tropics region, covering 1,680 km^2 (8%) (Figure 1). The region contains the Tully, Murray and Hull Rivers, their tributaries and several creeks that drain directly into the GBR lagoon. The topography of the Tully WQIP region varies from steep mountainous areas in the west to the floodplain in the east.

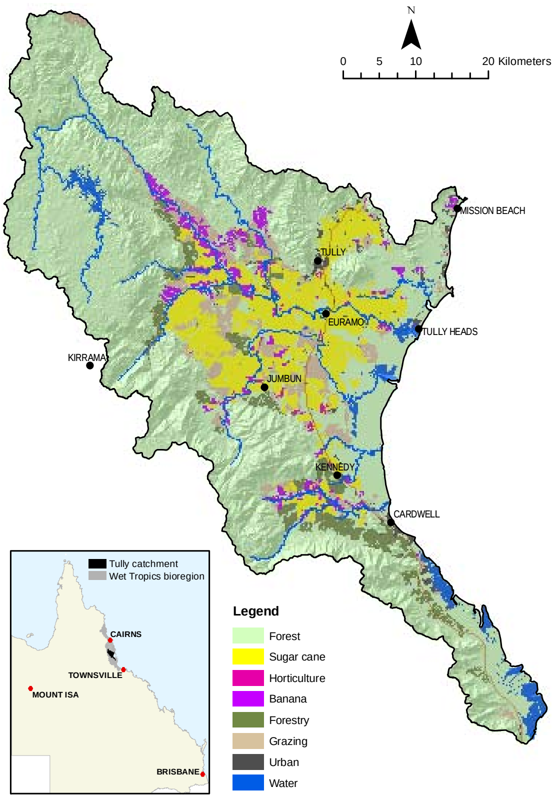

Figure 1. Landuse in Tully TWQIP region with Wet Tropics Bioregion shown in inset (Datasets: courtesy DNRW)

The climate of the WQIP region is characterised by wet summers and mild relatively dry winters (Johnson 1998). The Tully WQIP region has a mean annual rainfall of 2,000 to over 4,000 mm depending on the location. Most of the rainfall (60-80%) occurs during a distinct wet season (December to April) (Furnas 2003). The Tully River is a small coastal river with a high-energy hydrological regime, in which most suspended sediment is transported to the coast (McKergow *et al.* 2005). It also has the highest discharge per unit area of any Australian drainage basin (Furnas 2003).

Landuse in the Tully WQIP region is dominated in area by natural forest (71%), followed by sugarcane (13%), grazing (5%), forestry (4%) and horticulture (mainly bananas) (3%) (QLUMP 2004, draft). The remaining landuse categories are urban and water (4%). Natural forest is mostly confined to the steep, mountainous areas.

3. METHOD

3.1. SedNet model

We used the hydrological computer model, SedNet, to calculate sediment loads in the Tully WQIP region from a range of datasets. It is a long term, annual average model and is not suitable for the prediction of short term events. This project is a development of the Short Term Modelling project for catchments draining to the GBR using SedNet/ANNEX (Hateley *et al*. 2006). That study revised earlier work of the National Land and Water Resources Audit (Young *et al*. 2001) and Brodie *et al.* (2003).

The sediment budget was derived from soil erosion on land (hillslope erosion), the density of gullies in the landscape (gully erosion) and riverbank erosion. Sediment from these three sources is the input to the river network and is then routed through the river network accounting for losses to floodplain, riverbed and reservoir deposition along the way. A detailed description of the modelling algorithms and concepts is available (Wilkinson *et al.* 2004).

Major improvements to datasets were made, compared to Hateley *et al*. (2006) A 25 m Digital Elevation Model (DEM) was used rather than a 100 m DEM. Landuse data was derived from QLUMP 2004 and recent expansion of plantation forestry, rather than QLUMP 1999. C and K factors of the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.* 1997) were recalculated based on improved data and to more closely match water quality observations reported in Faithful *et al.* (2006, In Prep.). A number of scenarios were also developed which simulated the impact of improved management practices in sugarcane and bananas and riparian restoration.

3.2. Water quality monitoring

A water quality monitoring program for the Tully Water Quality Improvement Plan was undertaken over two wet seasons (2005/06 and 2006/07) (Faithful *et al.* 2007, Faithful *et al.* In Prep.). Sixteen quality monitoring sites were located within the Tully WQIP region, where a high proportion of the upstream contributing area is attributed to a single landuse (Faithful *et al.* 2007). Major landuse categories include forest, sugarcane, bananas, grazing, urban and plantation forest. Catchments of mixed landuse categories were also monitored. The monitoring program sampled large flow events with the capacity to transport large amounts of sediment. Monitoring sites were located close to gauging stations where possible. Total suspended solids were first captured on pre-weighed Whatman GF/C filter membranes and oven dried at 103-105^{o}C for 24 hours before being re-weighed to determine the dry total suspended solid (TSS) weight (Faithful *et al.* 2007). The model results were compared with two years of monitoring data, noting that output from a long term, average annual model is being compared with data from only two wet seasons. However, this is an obvious method of comparison with the model outputs. Six monitoring sites that coincided with nodes in the model were selected. For each node, the modelled annual sediment loads were divided by the modelled annual flow to calculate an annual mean concentration for comparison with the event mean concentration of the monitoring (Armour *et al.* 2007).

3.3. Sediment tracing

The sediment tracing methodology was described by Collins *et al.* (1997). In summary, three main steps are involved in the sediment tracing approach. First is the classification of source material into discrete landuse categories which included: forest, sugarcane, grazing, bananas and channel sources (bank erosion). Ninety-four source samples were collected within the Tully catchment (Hateley 2007). Second is the selection of properties capable of discriminating between the landuse categories. Finally, suspended sediment properties are compared to the properties of the various sources in order to determine the relative contribution from each source, using discriminant function analysis and a mixing model. A grain size correction factor was applied in the mixing model.

Suspended sediment was collected from channels to reflect contemporary sediment transport through the landscape. Suspended sediment was collected from the Tully River at Euramo, Davidson and Jarra Creeks near their confluences with the Tully River during the 2005/2006 wet season. (Hateley 2007).

4. RESULTS

4.1. SedNet model

The total sediment supply to streams in the Tully-Murray catchment was 183 kt/yr (Armour *et al.* 2007). Hillslope erosion was the dominant process with 116 kt/yr, or 64%, of the total sediment supply. Contributions from bank and gully erosion were 57 kt/yr (31%) and 10 kt/yr (5%), respectively. There was 150 kt/yr of suspended sediment generated and 119 kt/yr (79%) exported to the coast (Figure 2). Most of the total exported sediment (128 kt/yr) was suspended sediment (93%). Modelled proportions of exported suspended sediment (119 kt/yr) by the major landuse categories shows that forest represents the biggest proportion 57% (68 kt/yr), followed by sugarcane 24% (29 kt/yr), grazing 8% (10 kt/yr), horticulture (mainly bananas) and forestry 5% each (6 kt/yr) and urban 1% (1 kt/yr).

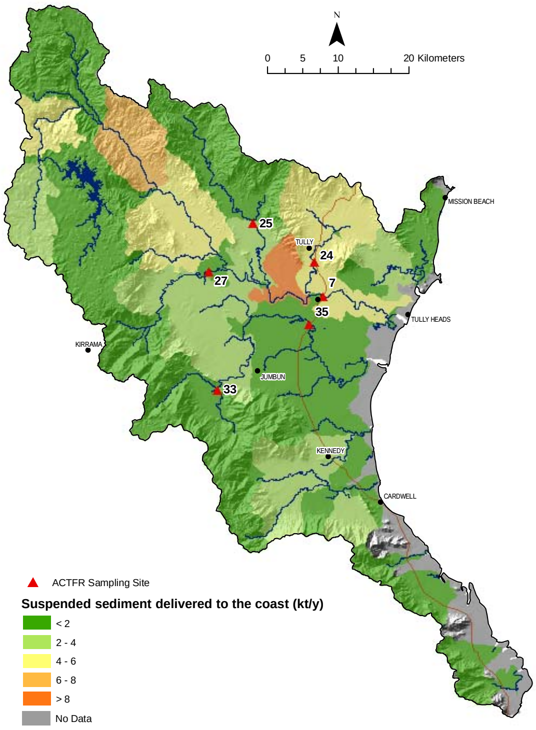

Figure 2. Contribution of suspended sediment to the coast (hillslope, bank and gully) and location of selected water quality sampling sites.

Simulating adoption of zero tillage for sugarcane was estimated to reduce suspended sediment from this landuse by 44%, from 29 kt/yr to 16 kt/yr. A similar scenario for bananas was estimated to reduce suspended sediment from the industry by 65%, from 57 kt/yr to 20 kt/yr. Simulating restoration of 20% of the most degraded streams sections (SedNet links), mainly 3rd and 4th order, with the lowest amount of riparian cover back to 100% cover (124 km) reduced bank erosion by 14 kt/yr or 24% from the present condition.

The Tully River mean annual flow was 2,700,000 ML/yr at Euramo, the most downstream gauging site, and this compares well with 2,925,000 ML/yr from 32 years of monitoring by NRW.

4.2. Water quality monitoring

TSS concentrations from all sub-catchments were generally low when compared to drier larger catchments such as the Burdekin (Faithful *et al.* 2007, Faithful *et al.* In Prep.), most being < 25 mg/L. Forest sites had consistently lower TSS concentrations than disturbed sub-catchments, such as sugarcane and bananas (Faithful *et al.* 2007). Higher concentrations of TSS were recorded during periods of higher flow (Faithful *et al.* 2007).

A comparison of mean TSS concentrations in flow events at sub-catchment sites selected on the basis of landuse with modelled annual mean concentrations from SedNet shows reasonable agreement (Table 1). The most obvious differences were at Murray River (Jumbun, site 33), where SedNet predicted sediment concentrations of 53 mg/L compared to 5 mg/L in the monitored results. However, both values are low (Armour *et al.* 2007). This sub-catchment drains undisturbed forest.

Table 1. Comparison of monitoring and modelling data for suspended sediments (mg/L) for six of the Tully WQIP sub-catchment sites.

Predominant landuse	***Suspended sediment (mg/L)***	
	Monitored (EMC)	SedNet (AMC)
Tully River (#7) Mixed landuse	42	30
Banyan Creek (#24) Urban	17	40
Murray River (#35) Sugarcane	11	41
Davidson Creek (#27) Grazing	30	42
Jarra Creek (#25) Banana	17	10
Murray River (#33) Forest[a]	5	53

EMC = Event Mean Concentration
AMC = Annual Mean Concentration
[a] sub-catchment contains approximately 90 ha of bananas at lower end

4.3. Sediment tracing

When attributed to landuse source categories, the contribution to the suspended sediment (averaged over all three sampled channels) was: sugarcane 58%, channel (bank erosion) 25%, grazing 12%, bananas 4% and forest 0% (Figure 3) (Hateley 2007). The relative area of each landuse within the catchment was forest 75%, sugarcane 12%, grazing 6% and bananas 3%. Therefore sugarcane, which comprised the largest proportion of disturbed land in the catchment, also contributed the highest proportion of suspended sediment. This was despite the average slope of sugarcane lands being the lowest of all categories (<2%). Sugarcane also occupied the biggest area of land within a 5 km upslope area of each of the suspended sediment sites and had finer particles on average than the other landuse categories.

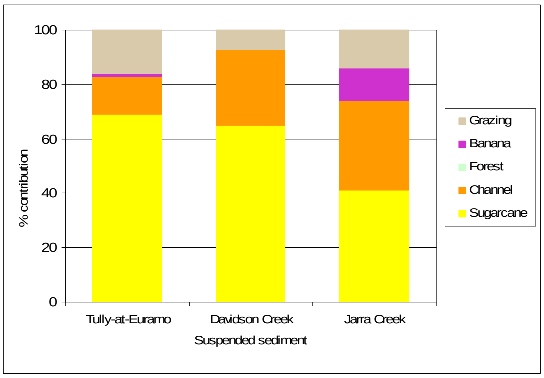

Figure 3. Percent contribution of suspended sediment from landuse sources (Hateley 2007).

The forest, sugarcane, grazing and banana categories could be grouped together to represent surface or hillslope erosion, versus the channel category, which represented subsurface or bank erosion. The average contribution for the three suspended sediment sites was 75% from hillslope erosion and 25% from bank erosion (Hateley 2007).

5. DISCUSSION

The three studies showed similar results relating to sediment erosion and transport. For example, SedNet calculated that 78% of suspended sediment was generated by hillslope erosion (Armour *et al.* 2007) and this agreed well with an average of 75% measured by the sediment tracing study (Hateley 2007). In another example, the SedNet model predicted bank erosion to contribute 31% to suspended sediment and the sediment tracing study measured 25%. Wallbrink *et al.* (2001) separated hillslope and bank erosion in a Wet Tropics catchment and found that hillslope erosion contributed 70% of sediment to Berner Creek in the Johnstone catchment. Landuse in this catchment was dominated by grazing (61%) followed by cropping (20%) and forest (19%) (Wallbrink *et al.* 2001).

Suspended sediment concentrations calculated from SedNet outputs were low (10-53 mg/L). The improved datasets have resulted in a lower suspended sediment contribution 119 kt/yr (Armour *et al.* 2007) compared to 186 kt/yr reported in Hateley *et al.* (2006). However, SedNet is generally over-predicting when compared to the two years of monitoring data, noting that a long-term annual average model is being compared with water quality data from only two wet seasons. A long-term water quality investigation (13 years) of the Tully River also showed low concentrations of suspended sediment in comparison to other north Queensland rivers (Mitchell *et al.* 2006).

The results from the modelling, monitoring and sediment tracing studies show that a high proportion of sediment is arising from sugarcane-dominated watersheds. Other studies have shown that sediment export per unit area (t/ha) from sugarcane is often higher than from forested land and other landuse categories (Bramley and Roth 2002; Faithful *et al.* 2006; Faithful *et al.* 2007). In the drier Herbert catchment of north Queensland, the highest TSS concentrations were found in natural channels draining sugarcane (Bramley and Roth 2002).

Although water quality monitoring and sediment tracing studies have shown that forest contributed little or no suspended sediment compared to other landuse categories, SedNet calculated that 57% of suspended sediment was derived from forest (Armour *et al.* 2007). However, it is acknowledged that the RUSLE is not particularly suitable for the prediction of hillslope erosion from steep naturally forested areas under wet tropical conditions (Armour *et al.* 2007).

These techniques assist to build robust knowledge about catchment behaviour. Modelling has the major advantage that it is fairly easy, cost effective and has the ability to run ‘what if’ scenarios that the other techniques cannot. For example, simulating the effect of incorporating zero tillage into sugarcane practises is estimated to reduce erosion in sugarcane by 44% (Armour *et al.* 2007).

6. CONCLUSION

Total suspended sediment concentrations in the Tully River are low in comparison with other north Queensland rivers. This, despite a high rainfall, is probably because most of the Tully catchment is relatively undisturbed forest. Of the suspended sediment being transported by the river, most originated from agricultural landuse. These results correspond well with other erosion and water quality studies in the Wet Tropics.

Landuse and channel erosion was split into two major erosion processes, hillslope erosion and bank erosion. Hillslope erosion contributed the most suspended sediment and sugarcane was the dominant contributing landuse, followed by grazing and banana growing. No contribution was detected from forest landuse in the monitoring and sediment tracing studies, even though it covered the largest proportion of the catchment, and had the steepest slopes. The contribution of bank erosion to suspended sediment warrants it being raised as an important catchment issue. Understanding sediment sources will assist with the targeting of limited resources towards reducing soil erosion.

In the short term, this information is crucial for developing realistic pollutant load targets for the protection of the GBR lagoon at the regional, catchment and sub-catchment scale. In the long term, this work can contribute to the development of monitoring tools that will help to gauge the effectiveness of best management practice.

7. REFERENCES

Anon (2003) Reef Water Quality Protection Plan: for catchments adjacent to the Great Barrier Reef World Heritage Area, Queensland Department of Premier and Cabinet, Brisbane.

Armour, J., L. Hateley, G. Pitt (2007) 'SedNet ANNEX modelling in the Tully-Murray catchments.' Dept. Natural Resources and Water, Mareeba, Qld.

Baker, J. (2003) A Report on the Study of Land-Sourced Pollutants and Their Impacts on Water Quality in and Adjacent to the Great Barrier Reef, Science Panel, Brisbane, Qld.

Bramley, R.G.V., C.H. Roth (2002) Land-use effects on water quality in an intensively managed catchment in the Australian humid tropics. *Marine and Freshwater Research* **53**, pp. 931-940.

Bridge, J.S. (2003) 'Rivers and Floodplains: forms, processes and sedimentary record'. (Blackwell Science: Oxford, UK).

Brodie, J., A.W. Mitchell, J. Faithful, S. Lewis, M. Maughan, L. Hateley, J. Armour, J.R. Reghenzani (2007) 'Water Quality Issues in the Tully Region.' Australian Centre for Tropical Freshwater Research, 04/07, Townsville, Qld.

Brodie, J., L. McKergow, I.P.Prosser, M. Furnas, A.O.Hughes, H. Hunter, (2003) Sources of Sediment and Nutrient Exports to the Great Barrier Reef World Heritage Area. ACTFR Report 03/11. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Collins, A.L., D.E. Walling, G.J.L. Leeks (1997) Source type ascription for fluvial suspended sediment based on a quantitative composite fingerprinting technique. *Catena* **29**, pp. 1-27.

Fabricius, K., G. De'ath, L. McCook, E. Turak, D.M. Williams (2005) Changes in algal, coral and fish assemblages along water quality gradients on the inshore Great Barrier Reef. *Marine Pollution Bulletin* **51**, pp. 384-398.

Faithful, J.W., J. Brodie, A. Hooper, P. Leahy, G. Henry, W. Finlayson, and D. Green (2006) An Assessment of the Quality and Sources of Agricultural Runoff from Plot-Scale Watersheds on a Banana Farm and Cane Farm in the Wet Tropics, Queensland – November 2002 to July 2006, ACTFR Report No. 05/03.

Faithful, J., L. Liessmann, J. Brodie, E. Ledee, D. Sydes, M. Maughan (2007) 'Water quality characteristics of water draining different land uses in the Tully/Murray Rivers region. December 2005 to June 2006'. Australian Centre for Tropical Freshwater Research, 06/25,Townsville.

Faithful, J., J. Brodie, L. Liessmann, D. Sydes, M. Maughan (2007) 'Water quality characteristics of water draining different land uses in the Tully/Murray Rivers region over two consecutive wet seasons'. Australian Centre for Tropical Freshwater Research, 07/--,Townsville.

Furnas, M. (2003) 'Catchments and corals: terrestrial runoff to the Great Barrier Reef'. (Australian Institute of Marine Science: Townsville).

Hateley, L. (2007) Fingerprinting Sources of Sediment in the Tully River Catchment, North Queensland, Unpublished Honours Thesis, James Cook University, Cairns, Queensland.

Hateley, L., J. Armour, G. Pitt, B.S. Sherman, A. Read, Y. Chen, J. Brodie, and A.L. Cogle (2006) Sediment and nutrient modelling in the Far North Queensland NRM region. Vol. 2. *In* The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting. Eds A.L. Cogle, C. Carroll and B.S. Sherman. Department of Natural Resources, Mines and Water. QNRM06138.

Hutchings, P., M. Peyrot-Clausade, A. Osnorno (2005) Influence of land runoff on rates and agents of bioerosion of coral substrates. *Marine Pollution Bulletin* **51**, pp. 438-447.

Johnson, D.P. (1998) 'An Ecological and Physical Assessment of the Condition of Streams in the Drainage Basins of the Tully and Murray Rivers.' Department of Natural Resources, Resource Sciences Centre, Brisbane, Qld.

McKergow, L.A., I.P. Prosser, A.O. Hughes J. Brodie (2005) Sources of sediment to the Great Barrier Reef World Heritage Area. *Marine Pollution Bulletin* **51**, pp. 200-211.

Mitchell, A., J., Reghenzani, M. Furnas, J. Brodie, and S. Lewis (2006). Nutrients and suspended sediments in the Tully River: Spatial and temporal trends. ACTFR Report. No. 06/10, 115 pp.

Motha, J,A., P.J. Wallbrink, P.B. Hairsine, R.B. Grayson (2003) Determining the sources of suspended sediment in a forested catchment in southeastern Australia. *Water Resources Research* **39**, pp. 1-14.

QLUMP (2004) Department of Natural Resource and Water. Queensland Land Use Mapping Program,http://www.nrw.qld.gov.au/science/lump

Renard, K.G., Foster, G.A., Weiss, D.K., M^{c}Cool, D.K. & Yoder, D.C. (1997) *Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation*, United States Department of Agriculture, Washington DC.

Rieger, W.A., Olive LJ (1988) Channel Sediment Loads: Comparisons and Estimation. In 'Fluvial Geomorphology of Australia'. (Ed. R. F. Warner) pp. 69-86. (Academic Press: NSW).

Wallbrink, P.J., C. Martin, C. Wilson (2001) Contribution of sediment and sediment bound P from different landuses to two contrasting streams in temperate and tropical Australia, In 'Proceedings *3rd Australian Stream Management Conference*'. Brisbane, 27-29 August 2001. pp. 617-623.

Wilkinson, S., R.A. Henderson, Y. Chen, B. Sherman, (2004) 'SedNet user Guide'. Client Report, CSIRO Land and Water, Canberra.

Young, W.J., I.P. Prosser, A.O. Hughes, (2001) Modelling nutrient loads in largescale river networks for the national land and water resources audit. CSIRO Land and Water, 14 pp.