Sediment and Nutrient Exports for the Burdekin River Catchment, North Queensland: A Comparison of Monitoring and Modelling Data

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EXTENDED ABSTRACT

Several empirical models have been developed to estimate sediment and nutrient inputs into the Great Barrier Reef lagoon, although limited monitoring data are available for their validation. The lack of monitoring data for GBR catchments limits the refinement of these models, and particularly their assumptions of tropical landscape processes. Such limitations reduce the confidence of these models for application within the Reef Water Quality Protection Plan process, such as the setting of end-of-river load targets, and scenario load forecasting based on improved catchment condition from the adoption of best management practices. The benefits of a coupled monitoring and modelling approach have been demonstrated in a number of other north Queensland catchments, such as the Tully/Murray Water Quality Improvement Plan (WQIP) (Armour et al., 2007). Improved modelling estimates have been produced for these catchments due to their smaller size, resultant less variability and the use of higher resolution input data. The considerable size of the Burdekin makes similar efforts difficult; however, this is a first attempt at comparing available monitoring data with modelling efforts for this catchment.

We present flow weighted sediment and nitrogen loads averaged over three wet seasons of monitoring data (2002/03, 2004/05 and 2005/06) from the major sub-catchments and river mouth of the Burdekin River to compare with recent SedNet and ANNEX model load estimates by CSIRO. CSIRO incorporated a number of refinements to the models based on issues identified during previous modelling runs. These refinements include improvements to the hillslope erosion component through better input data resolution (estimates of actual ground cover and improved spatial resolution of slope) and improved gully and river bank erosion components through the incorporation of field measurements from the Burdekin catchment.

In most cases, monitored and modelled comparisons of TSS loads were reasonable, although poorer comparisons occurred for some sites, explainable by limited monitoring data or coarse resolution "blanket" model assumptions, such as riparian vegetation and dam trapping capacity. The dam trapping algorithm applied to the Burdekin Falls Dam (BFD) by the SedNet model appears to be overestimating the suspended sediment and particulate nutrient trapping capacity of this dam. A modified algorithm that accounts for the dry tropical hydrology (i.e. highly episodic flows with shorter residence times than assumed by SedNet) will allow for better load estimates at the mouth of the Burdekin River. Particulate nutrient comparisons were less satisfactory, with the model seemingly overestimating monitored PN exports; the ANNEX model estimates are based on the Australian Soil Resource Information System database of nutrient concentrations in soils. This database may need refinement for these highly weathered, nutrient-poor landscapes. Reasonable comparisons were found between the modelled and monitored loads of dissolved organic nitrogen, however, comparisons were only fair for dissolved inorganic nitrogen. Further investigation of the role of inorganic nitrogen in this tropical system is warranted, and particularly, the contributions from natural sources, such as rainfall or bedrock, compared to those from land uses including fertilisers and cow excreta.

Additional monitoring data at different spatial and temporal scales are required to further test the accuracy of these models, particularly for the southern region of the Burdekin catchment, where below-average flow events have occurred within the timeframe of the monitoring project. This will allow further confidence in using modelled outputs to identify catchment point sources and consequent delivery to downstream environments, and for the setting of water quality targets.

1. INTRODUCTION

The knowledge of catchment loads along the east coast of Australia has never been as important since the introduction of the Reef Water Quality Protection Plan for the Great Barrier Reef in 2003 (Anon, 2003). The major motive for load studies has been to estimate material loading to the GBR and several empirical models have been developed to estimate catchment exports (e.g. Moss et al., 1992; Neil et al., 2002; Brodie et al., 2003). Knowledge of the loads of materials transported through waterways is critical in water quality studies to understand catchment processes, to identify pollutants of greatest concern, to set water quality targets, to quantify changes in water quality due to in-catchment management actions and to assess the validity of predictive models.

Considerable research attention has focused on the large Burdekin River catchment (130,035 km^2) which has been identified as a significant contributor of suspended sediments and nutrients to the GBR lagoon (Belperio, 1979; Furnas, 2003; Mitchell et al., 2006). However, this research has focused on the end-of-river with comparatively little study on the sources of these terrestrial materials from within the catchment. This limitation has been addressed by recent modelling (Bartley et al., 2004; Fentie et al., 2006; Post et al., 2006) and monitoring (O'Reagain et al., 2005; Bainbridge et al., 2006) efforts which have been conducted at the sub-catchment scale. This research has identified the high variability of load contributions from the major sub-catchments of the Burdekin which reflects the highly variable climate, geology, vegetation and topography of this large semi-arid catchment (Bainbridge et al., 2006). This research also helps to identify priority catchment areas for on-ground remedial works. In addition, the monitoring project provides the opportunity to refine the model outputs through a better understanding of catchment processes that influence material loading. The refinement of these models provide a powerful approach to assess the water quality outcomes due to the implementation of best management practices currently recommended for the major industries of the Burdekin Region (rangeland grazing: Coughlin et al., 2006; sugarcane cultivation on the coastal plain: Thorburn et al., 2007) through the Burdekin Water Quality Improvement Plan (WQIP). Improved modelling will also assist in the setting of achievable end-of-river targets to account for the high variability within this region.

The benefits of a coupled monitoring and modelling approach have been demonstrated in a number of other north Queensland catchments, including Weany Creek (a small sub-catchment of the upper Burdekin; Bartley et al., 2007), the Douglas Shire (Bartley et al., 2006) and the Tully/Murray WQIP (Armour et al., 2007). Improved modelling estimates have been produced for these catchments due to their smaller size, resultant less variability and the use of higher resolution input data. The considerable size of the Burdekin makes similar efforts difficult; however, this is a first attempt at comparing available monitoring data with modelling efforts for this catchment.

We compare monitored and modelled suspended sediment and nitrogen species loads for five major Burdekin sub-catchments and the end-of-river sites. We evaluate the performance of the latest SedNet and ANNEX model run (Post et al., 2006) for the Burdekin catchment against flow weighted loads averaged over three monitored wet seasons (2002/03, 2004/05, 2005/06). Recommendations are made for future refinements of the model.

2. METHODS

2.1. Monitoring data

In the 2003 wet season, sampling sites were established at five major sub-catchments of the Burdekin River (upper Burdekin, Cape, Belyando, Suttor and Bowen Rivers), which capture the major contributing arms of this system (Figure 1). This project was established by the Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University for the Burdekin Dry Tropics NRM (BDTNRM) group to investigate the sources of sediment and nutrients within the Burdekin River catchment. A site at the end of the Burdekin River (Inkerman Bridge) was also established to determine the proportion of sediment and nutrients from each of these major sub-catchments to the mouth of the river, and to determine the resultant loads of these materials to the receiving marine environment. Sampling sites were positioned at locations accessible during wet season conditions, and to represent the greatest sub-catchment area possible. Sites were also positioned at Natural Resources and Water (NRW) flow gauging station locations (Table 1), except for the Suttor River, where a gauging station was only established in 2006. Flow estimates were calculated for this site by subtracting flows at the Belyando River (Gauge 120301B) from flows at the Suttor River at St Anns (120303A).

ACTFR staff collected surface grab samples (where possible from the centre of the stream profile) across the flow hydrograph. The samples were transported back to the ACTFR Freshwater Laboratory for analysis of total suspended sediments (TSS) and nutrient species. An automated ISCO sampler was installed by BDTNRM on the Bowen River site and samples were collected by CSIRO Land and Water and sent to the Queensland Health Scientific Services for analysis (refer to Bainbridge et al., 2006 for detailed field and laboratory methodology). River flow data (hourly cumecs) were obtained from the NRW Hydrographers.

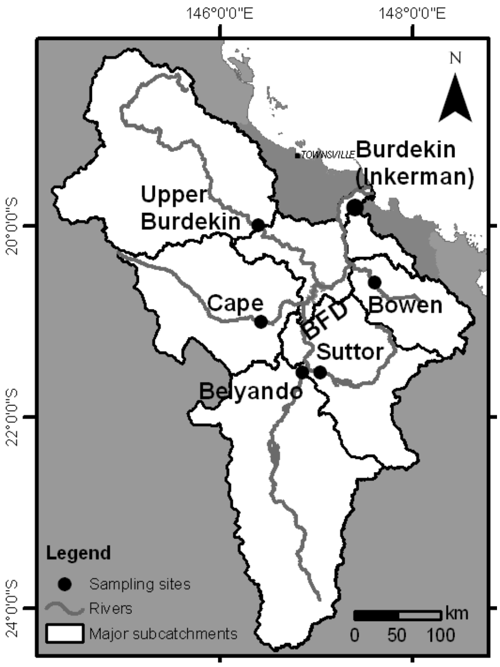

Figure 1. Location of the Burdekin River major sub-catchment and end-of-river sampling sites.

Table 1. Details of the Burdekin River sampling sites.

Site	Location	Catchment Area (km^2)	GPS Location		Gauge Station (NRW)
			Lat	Long	
Upper Burdekin	Sellheim Rail Brg	36, 260	-20.0	146.3	120002A
Cape River	Gregory Dev Rd	16, 075	-20.6	146.3	120302B
Belyando River	Gregory Dev Rd	35, 410	-21.3	146.5	120301B
Suttor River	Bowen Dev Rd	10, 670	-21.5	147.1	120310A Est. 2006
Bowen River	Myuna Station	7, 105	-20.4	147.4	120205A
Burdekin River	Inkerman	129, 875	-19.6	147.4	120006B (Clare)

The concentration and stream flow data were entered into the NRW Brolga Program to calculate loads using the linear interpolation technique (see Lewis et al., this proceeding). Load data calculated for the major Burdekin sub-catchments and end-of-river sites monitored over three wet seasons (2002/03; 2004/05 and 2005/06) have been averaged and adjusted to mean annual flow (as specified by the SedNet model) for direct comparison with SedNet and ANNEX modelling results. A comparison of suspended sediment and nitrogen (particulate, dissolved organic and dissolved inorganic phases) loads have been provided in section 3. Due to the scope of this paper, loads for the phosphorus species have not been included, but can be referred to in Mitchell et al. (2007). It should be noted that load data were not available for some earlier wet season sites, and in this instance average monitored data are only based on 1-2 wet seasons. The 2003/04 wet season was not included due to the poor wet season and sporadic sampling. Due to the errors and uncertainty inherent in the calculation of loads (e.g. flow measurements, field sampling, laboratory analysis and the load method itself) we consider that monitored and modelled load estimates within 30% of each other are reasonable.

2.2. SedNet and ANNEX model data

SedNet and ANNEX model comparison data are sourced from Post et al. (2006). A number of issues previously identified as improvements needed in the SedNet and ANNEX models (e.g. land use, bank height and dissolved nutrient data) and additional modifications to the model were incorporated by CSIRO during this latest run (see Post et al., 2006 for further details), including:

- Improved estimates of hillslope erosion through (i) a spatially variable cover factor that relates directly to estimated ground cover levels and (ii) improved spatial resolution of slope. Previous model runs have treated cover factor as a constant across rangeland areas- which dominate the Burdekin Region;
- Field measurements of gully cross-sectional areas and river channel width and depth allowed for additional improvements to the gully and river bank erosion components of the model; and
- Adjustments to dissolved inorganic nutrient point sources and to runoff entering stream links, and thus altering load predictions.

3. RESULTS AND DISCUSSION

3.1. Suspended sediments

Estimated TSS loads for the major Burdekin sub-catchments were higher in the monitored data compared with the modelled outputs, with the exception of the Cape River, where modelled TSS

Table 2. Comparison of CSIRO's MLA project SedNet modelled TSS loads (tonnes) with flow adjusted loads based on a three wet season average of monitored data for the major Burdekin sub-catchments and end-of-river

TSS tonnes	Wet Season Monitoring Data (2002-2006)						Average monitored (2002-06)	MLA Model (CSIRO)
	2002-2003	Flow adjusted	2004-2005	Flow adjusted	2005-2006	Flow adjusted		
Burdekin R @ Inkerman	-	-	2,700,000	5,685,074	500,000	2,242,446	**3,960,000**	**2,620,000**
Upper Burdekin R (Sellheim)	-	-	1,700,000	2,728,368	1,760,000	2,471,580	**2,600,000**	**1,760,000**
Cape R @ Taemas	65,000	241,968	110,000	200,879	31,200	335,529	**259,000**	**420,000**
Belyando R @ GDR	-	-	-	-	115,000	740,167	**740,000**	**810,000**
Suttor R @ BDR *	-	-	-	-	135,000	1,145,150	**1,150,000**	**220,000**
Bowen R @ Myuna	368,000	1,929,364	340,000	1,627,559	180,500	1,578,473	**1,710,000**	**580,000**

*Based on hydrograph data from Suttor R at St Anns-Belyando R at Greg Dev Rd

loads were greater by ~60% (Table 2). The SedNet model may be overestimating sediment loads for the Cape sub-catchment, with consistently low wet season sediment loads being monitored compared to the other major sub-catchments (Bainbridge et al., 2006). Other research conducted has also found this sub-catchment - which consists of generally flatter, less erodible country - to have reasonable ground and riparian vegetation cover (O'Reagain et al., 2005; Lymburner and Dowe 2006). A reasonable agreement was found between modelled and monitored TSS loads for the upper Burdekin (within ~30%) and Belyando (~10%) sub-catchments, while comparisons for the Suttor (~80%) and Bowen (~65%) sub-catchments were considerably different. The poor comparison for the Suttor River is most likely due to the lack of monitoring data for this sub-catchment, with only one small wet season monitored throughout the four year project. The comprehensive data set for the Bowen sub-catchment, generated by the BDTNRM autosampler at Myuna Station suggests that the model may be considerably underestimating sediment loads for the Bowen catchment. Whilst the SedNet model suggests that the TSS contribution from the gully erosion component is only minor compared to that of hillslope, areas of extensive gully networks have been observed in this sub-catchment (Z. Bainbridge, pers. obs.); gully erosion may therefore be an important additional contributor of sediment than is currently predicted, which may account for the higher TSS load monitored in the Bowen sub-catchment. Currently there is only low resolution input data available for gully density in this sub-catchment and further field measurements are required for input into this component of the model (Bartley pers. comm.). Bartley et al. (2004) ran the SedNet model at a finer-scale for the Bowen River catchment, which predicted 1.26Mt of sediment is being generated at the end of this river. Although the end of this catchment is ~25km downstream of the sampling site, this yield provides a more reasonable comparison (within ~25%) with the monitored load.

The model appears to be underestimating the Burdekin River end-of-catchment sediment load at Inkerman, however the comparison is still reasonable (within ~35%). The difference between the monitored and modelled loads may be partially due to the dam trapping algorithm applied to the Burdekin Falls Dam (BFD) by the SedNet model. Current SedNet modelling of the Burdekin catchment suggests that the BFD is a very efficient trap for sediment and particulate matter, trapping 77% of suspended sediment entering the dam (Fentie et al., 2006). However, field studies using sediment traps, bottom profiling and water sampling within the dam reservoir during flow events do not support this high trapping efficiency (Faithful and Griffiths, 2000; Bainbridge et al., 2006). The trapping algorithm within SedNet is based on a relationship between trapping efficiency and hydraulic residence time which may not be relevant for rivers characterised by dry tropical hydrology (i.e. highly episodic flows with shorter residence times than that assumed by SedNet) (Sherman et al., 2007). Improvements to the algorithm to account for this episodic hydrology will allow for better estimates of loads at the end-of-catchment.

3.2. Particulate nitrogen

Very poor comparisons existed between modelled and monitored loads for particulate nitrogen (PN) in the Burdekin sub-catchments, with most sites differing by over 70%, and in some cases, over 125% (upper Burdekin River, Burdekin at Inkerman and Cape River) (Table 3). The model seems to be overestimating the loads, except for the Suttor River, which was underestimated. For the Suttor and Belyando Rivers these differences may be due to the small flows that have occurred

Table 3: Comparison of CSIRO's MLA project Annex modelled PN loads (tonnes) with flow adjusted loads based on the three wet season average of monitored data for the major Burdekin sub-catchments and end-of-river

PN tonnes	Wet Season Monitoring Data (2002-2006)						Average monitored (2002-06)	MLA Model (CSIRO)
	2002-2003	Flow adjusted	2004-2005	Flow adjusted	2005-2006	Flow adjusted		
Burdekin R @ Inkerman	-	-	2,000	4,211	960	4,305	**4,260**	**9,540**
U. Burdekin R @ Sellheim	-	-	1,000	1,605	1,590	2,233	**1,920**	**6,570**
Cape R @ Taemas	132	491	110	201	36	386	**360**	**1,260**
Belyando R @ GDR	-	-	-	-	103	663	**660**	**2,350**
Suttor R @ BDR *	-	-	-	-	179	1,518	**1,520**	**480**
Bowen R @ Myuna	329	1,725	-	-	-	-	**1,730**	**2,940**

*Based on hydrograph data from Suttor R at St Anns-Belyando R at Greg Dev Rd

in these catchments. Two other possible explanations for the considerable variations seen at all sites relate to assumptions of the ANNEX model. Firstly, overestimated sediment loads in SedNet will have a carry-on effect to the particulate species of nitrogen in the ANNEX model. Secondly, the ANNEX model estimates nitrogen concentrations in soils based on the Australian Soil Resource Information System (ASRIS) database which appears to overestimate nutrient concentrations for this tropical landscape. Soils within these landscapes are highly weathered, and therefore nutrient-poor. As the modelled sediment loads were not considerably higher than the monitored sediment loads, it appears that the second hypothesis is more likely.

3.3. Dissolved nitrogen

Comparisons of the monitoring and modelled data for dissolved inorganic nitrogen (DIN) were highly variable between catchments. Comparisons for the Burdekin River at Inkerman, the upper Burdekin and the Cape River were reasonable for DIN (within ~30%) (Table 4). Poor comparisons for DIN were found in the Belyando (110%), Suttor (85%) and Bowen (55%) sub-catchments (Table 4). The poor comparisons for these sites may be explained by a lack of monitoring data. Currently the SedNet model applies a single ("blanket") coefficient for DIN in the grazing land use (~160 µg N/L), however flow weighted DIN concentrations using monitoring data from tributaries within the major sub-catchments of the

Table 4: Comparison of CSIRO's MLA project Annex modelled DIN loads (tonnes) with flow adjusted loads based on the three wet season average of monitored data for the major Burdekin sub-catchments and end-of-river

DIN tonnes	Wet Season Monitoring Data (2002-2006)						Average monitored (2002-06)	MLA Model (CSIRO)
	2002-2003	Flow adjusted	2004-2005	Flow adjusted	2005-2006	Flow adjusted		
Burdekin R @ Inkerman	-	-	1,312	2,763	350	1,571	**2,170**	**1,530**
U. Burdekin R @ Sellheim	-	-	496	796	365	512	**655**	**520**
Cape R @ Taemas	24	89	225	411	6	69	**190**	**130**
Belyando R @ GDR	-	-	-	-	16	103	**105**	**220**
Suttor R @ BDR *	-	-	-	-	68	574	**575**	**90**
Bowen R @ Myuna	82	430	110	527	49	426	**460**	**200**

Table 5: Comparison of CSIRO's MLA project Annex modelled DON loads (tonnes) with flow adjusted loads based on the three wet season average of monitored data for the major Burdekin sub-catchments and end-of-river

DON tonnes	Wet Season Monitoring Data (2002-2006)						Average monitored (2002-06)	MLA Model (CSIRO)
	2002-2003	Flow adjusted	2004-2005	Flow adjusted	2005-2006	Flow adjusted		
Burdekin R @ Inkerman	-	-	1,100	2,316	270	1,211	**1,770**	**1,650**
U. Burdekin R @ Sellheim	-	-	520	835	650	913	**880**	**650**
Cape R @ Taemas	89	331	205	374	28	303	**340**	**170**
Belyando R @ GDR	-	-	-	-	92	590	**590**	**280**
Suttor R @ BDR *	-	-	-	-	108	916	**920**	**100**
Bowen R @ Myuna	73	383	-	-	-	-	**390**	**240**

*Based on hydrograph data from Suttor R at St Anns-Belyando R at Greg Dev Rd

Burdekin are considerably variable (60-420 µg N/L) (Mitchell et al., 2007). An improved understanding of DIN concentrations within grazed sub-catchments is warranted, including contributions from cow excreta and other natural sources such as rainfall and bedrock (Bainbridge et al., 2006).

Fair comparisons (<50% difference) were found between the modelled and monitored data at all sites for dissolved organic nitrogen (DON) with the exception of the Suttor River DON loads, where there was a ~90% difference between the monitored and modelled loads (Table 5). As for TSS, limited monitoring data available for this sub-catchment may account for this difference. Similarly to DIN, an investigation into the sources and transport of DON in grazed catchments is required.

4. CONCLUSION

Although a number of refinements were incorporated into this latest model run, there are still a number of improvements recommended for the SedNet and ANNEX models. TSS load comparisons were reasonable for the upper Burdekin and Belyando sub-catchments, however comparisons for the Suttor, Bowen and Cape sub-catchments were poor. It should be noted that the modelled loads are based on long term averages (~30 years- reflecting available stream flow and rainfall data), and the monitoring data represents a small snapshot in time, and cannot account for the inter-annual variability of rainfall and flow in this region. Although the poor comparison for the Suttor River can be explained by a lack of monitoring data, there was also a considerable difference between the modelled and monitored sediment loads for the Bowen sub-catchment, which had the most intensive monitoring data. This catchment has considerable areas of gullies and exposed soils and the SedNet model in its current form may not be capturing these catchment processes. In comparison, monitoring data and other research suggests that the Cape sub-catchment is likely to be in better condition than the model is predicting, which may explain the poor comparison between modelled and monitored loads for this sub-catchment. A suitable algorithm to estimate the trapping efficiency of the BFD needs to be developed to account for this extensive reservoir, which will in turn improve the estimations of sediment and nutrient loads at the end of the Burdekin River. This comparison has also shown that particulate nutrient loads are not being estimated well for the major sub-catchments and end-of-river in the Burdekin Region. The soils database (ASRIS) which estimates particulate nutrient concentrations needs to be improved to reflect the highly weathered, nutrient-poor landscapes of the Burdekin catchment. Poor DIN comparisons also warrant further investigation of the sources and transport processes of this nutrient species. Additional monitoring data are required to further test the accuracy of the SedNet and ANNEX models, particularly in the southern region of the Burdekin (Suttor and Belyando sub-catchments) where below-average river flows have occurred during the timeframe of this monitoring project. This will allow further confidence in using modelled outputs to identify catchment point sources and consequent delivery to downstream environments, and for the setting of water quality targets for the WQIP process.

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6. REFERENCES

Armour, J., Hateley, L. and Pitt, G. (2007). (Draft) SedNet Modelling of the Tully WQIP Region. QDNRW, Mareeba.

Bainbridge, Z., Lewis, S., Brodie, J., Faithful, J., Maughan, M., Post, D., O'Reagain, P., Bartley, R., Ross, S., Schaffelke, B., McShane, T. and Baynes, L. (2006). *Monitoring of sediments and nutrients in the Burdekin Dry Tropics region: 2005/2006 wet season*. ACTFR, JCU, Townsville. 97 pp.

Bartley, R., Hartcher, M., Henderson, A., Chen, Y., & Brodie, J. (2004). *Application of the SedNet Model to the Bowen Catchment, Queensland: assessment of sediment and nutrient loads at a sub-catchment scale under different grazing scenarios*. CSIRO Land and Water Client Report.

Bartley, R., Keen, R., Hawdon, A., Disher, M., Kinsey-Henderson, A. & Hairsine, P. (2006). *Measuring rates of bank erosion and channel change in northern Australia: a case study from the Daintree River* *catchment*. CSIRO Land and Water Client Report.

Bartley, R., Hawdon, A., Post, D. and Roth, C. (2007). A sediment budget for a grazed semi-arid catchment in the Burdekin Basin, Australia. *Geomorphology*, 87, 301-321.

Belperio, A.P. (1979). The combined use of was load and bed material load rating curves for the calculation of total load: An example from the Burdekin River, Australia. *Catena*, 6, 317-329.

Brodie, J. McKergow, L.A. Prosser, I.P. Furnas, M. Hughes, A.O. Hunter, H. (2003). *Sources of sediment and nutrient exports to the Great Barrier Reef World Heritage Area*. ACTFR, JCU, Townsville, 208 p.

Coughlin, T., O'Reagain, P. and Nelson, B. (2006). *Review of current and proposed grazing land Best Management Practices for achieving water quality objectives in the Burdekin catchment.* ACTFR, JCU, and DPI&F, Charters Towers.

Faithful, J. and Griffiths, D. (2000). Turbid flow through a tropical reservoir (Lake Dalrymple, Queensland, Australia): Responses to a summer storm event. *Lakes and Reservoirs: Research and Management,* 5, 231-247.

Fentie, B., Duncan, I., Sherman, B.S., Read, A., Chen, Y., Brodie, J. and Cogle, A.L. (2006). Sediment and nutrient modelling in the Burdekin NRM region. Volume 3. *In: The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting.* Ed. A.L. Cogle, C. Carroll and B.S. Sherman. NRW, 29pp.

Furnas, M. (2003). *Catchments and corals: Terrestrial runoff to the Great Barrier Reef.* AIMS, Townsville, 334 pp.

Lewis, S., Bainbridge, Z. and Brodie, J. (Submitted). A review of load tools available for calculating pollutant exports to the Great Barrier Reef lagoon: A case study of varying catchment scales. *MODSIM Conference*, Christchurch, New Zealand, December 2007.

Lymburner L. and Dowe J. (2006). *A component of the Burdekin Coastal Catchments Initiative Report: Assessing the condition of riparian vegetation in the Burdekin catchment using satellite imagery and field surveys.* ACTFR, JCU, Townsville.

Mitchell, A., Furnas, M., De'ath, G., Brodie, J. and Lewis, S. (2006). *A report into the water quality condition of the Burdekin River and surrounds based on the AIMS end-of-catchment sampling program.* ACTFR, JCU, Townsville.

Mitchell, A., Lewis, S., Brodie, J., Bainbridge, Z. and Maughan, M. (2007). *Water quality issues in the Burdekin Region.* ACTFR, JCU, Townsville. 60pp.

Moss, A.J. Rayment, G.E., Reilly, N., Best, E.K. (1992). *A preliminary assessment of sediment and nutrient exports form Queensland coastal catchments*. QDPI.

Neil, D.T. Orpin, A.R. Ridd, P.V. Yu, B. (2002). Sediment yield and impacts from river catchments to the Great Barrier Reef lagoon. *Marine and Freshwater Research,* 53, 733-752.

O'Reagain, P.J., Brodie, J., Fraser, G., Bushell, J.J., Holloway, C.H., Faithful, J.W. & Haynes, D. (2005). Nutrient loss and water quality under extensive grazing in the upper Burdekin river catchment, North Queensland. *Marine Pollution Bulletin,* 51, 37-50.

Post, D., Bartley, R., Corfield, J., Nelson, B., Kinsey-Henderson, A., Hawdon, A., Gordon, I., Abbott, B., Berthelsen, S., Hodgen, M., Keen, R., Kemei, J., Vleeshouwer, J., MacLeod, N. and Webb, M. (2006). *Sustainable grazing for a healthy Burdekin catchment.* CSIRO Land and Water Science Report 62/06. 220pp.

Sherman, B., Brodie, J., Cogle, L., Carroll, C. (2007). *The appropriate use of catchment models for water quality target setting and land use management.* For: IAHS Symposium on Water Quality and Sediment Behaviour of the Future: Predictions for the 21st Century, 2007.

Thorburn, P., Davis, A. and Attard, S. (2007). *Best management practices to improve the quality of water leaving irrigated sugarcane farms: Guidelines for the Burdekin region*. CSIRO SE, Brisbane and ACTFR, JCU, Townsville.