Marine and Tropical Sciences Research Facility

Trapping efficiency of the Burdekin Falls Dam, North Queensland

Estimates from a three-year monitoring program

S. E. Lewis, Z. T. Bainbridge,
B. S. Sherman, J. E. Brodie and M. Cooper

Australian Government
Department of the Environment, Water, Heritage and the Arts

JAMES COOK UNIVERSITY AUSTRALIA

Reef & Rainforest RESEARCH CENTRE

The trapping efficiency of the Burdekin Falls Dam, North Queensland

Estimates from a three-year monitoring program

Stephen E. Lewis[1], Zoë T. Bainbridge[1], Bradford S. Sherman[2],
Jon E. Brodie[1] and Michelle Cooper[3]

[1] Australian Centre for Tropical Freshwater Research, James Cook University, Townsville
[2] CSIRO Land and Water, Canberra
[3] Geoscience Australia, Canberra

Supported by the Australian Government's
Marine and Tropical Sciences Research Facility
Project 3.7.2 Connectivity and risk:
Tracing materials from the upper catchment to the reef

© James Cook University, CSIRO and Geoscience Australia

ISBN 9781921359385

This report should be cited as:
Lewis, S. E., Bainbridge, Z. T., Sherman, B. S., Brodie, J. E. and Cooper, M. (2009) *The trapping efficiency of the Burdekin Falls Dam: Estimates from a three-year monitoring program.* Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns and Australian Centre for Tropical Freshwater Research (ACTFR), Townsville (31pp.).

ACTFR Report No. 09/15

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's Marine and Tropical Sciences Research Facility.

The Australian Government's Marine and Tropical Sciences Research Facility (MTSRF) supports world-class, public good research. The MTSRF is a major initiative of the Australian Government, designed to ensure that Australia's environmental challenges are addressed in an innovative, collaborative and sustainable way. The MTSRF investment is managed by the Department of the Environment, Water, Heritage and the Arts (DEWHA), and is supplemented by substantial cash and in-kind investments from research providers and interested third parties. The Reef and Rainforest Research Centre Limited (RRRC) is contracted by DEWHA to provide program management and communications services for the MTSRF.

This publication is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission from the Commonwealth. Requests and enquiries concerning reproduction and rights should be addressed to the Commonwealth Copyright Administration, Attorney General's Department, Robert Garran Offices, National Circuit, Barton ACT 2600 or posted at http://www.ag.gov.au/cca.

The views and opinions expressed in this publication are those of the authors and do not necessarily reflect those of the Australian Government or the Minister for the Environment, Water, Heritage and the Arts or Minister for Climate Change and Water.

While reasonable effort has been made to ensure that the contents of this publication are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents, and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

This report is available for download from the
Reef and Rainforest Research Centre Limited website:
http://www.rrrc.org.au/publications/research_reports.html

Reef & Rainforest RESEARCH CENTRE

Published September 2009
RRRC thanks its staff along with Stephen Lewis (JCU) and Katharina Fabricius (AIMS) for use of cover images.

Contents

List of Figures

List of Tables

Acronyms Used In This Report

ACTFR .... Australian Centre for Tropical Freshwater Research
BFD .... Burdekin Falls Dam
GBR .... Great Barrier Reef
ML .... Megalitres
NRM .... Natural resource management
NRW .... Queensland Department of Natural Resources and Water
Sednet .... Sediment network
SS .... Suspended sediment
TSS .... Total suspended sediment(s)

Acknowledgements

We are extremely grateful to Tony Bailey and Gary Caddies (SunWater) who collected the samples from the Burdekin Falls Dam overflow over the three monitored years. We thank the State Government's GBRI5 monitoring program who partly funded the collection and analysis of total suspended solid samples from the major river arms of the Burdekin. The NRW hydrographers and SunWater are acknowledged for supplying the flow data over the three monitored water years. We thank Raphael Wüst (School of Earth and Environmental Sciences) for performing the particle size analysis. We acknowledge the efforts of the ACTFR laboratory staff for analysing the TSS samples. This project was supported by the Australian Government's Marine and Tropical Sciences Research Facility and the North Queensland Dry Tropics NRM.

Introduction

The increasing global demand for water to support an ever growing human population has caused the widespread construction of large reservoirs particularly over the last fifty years (e.g. Syvitski *et al.* 2005; Vörösmarty *et al.* 2003). These large reservoirs may accumulate considerable amounts of sediments and associated nutrients (e.g. carbon, nitrogen and phosphorus), thus reducing their supply to downstream receiving environments (Syvitski *et al.* 2005; Walling and Fang, 2003). In contrast, urban development, agriculture, deforestation and mining results in the increased supply of sediments and nutrients to the downstream receiving waters. While catchment erosion has increased, there has been an overall globally reduced flux of sediments and nutrients to the coast largely due to the construction of dams (Syvitski, 2003; Syvitski *et al.* 2005). Changes to the supply of sediments and nutrients may have serious implications for coastal estuaries, coral reefs, seagrass communities and coastal fisheries and also result in geomorphological changes to the coastline (e.g. erosion and coastal retreat) (McLaughlin *et al.* 2003; Restrepo *et al.* 2006; Syvitski *et al.* 2005; Vörösmarty *et al.* 2003)

It is estimated that the total sediment flux to the Great Barrier Reef (GBR) has increased by 4-5 fold since the arrival of Europeans ~150 years ago (Brodie *et al.* 2003; Furnas, 2003; McCulloch *et al.* 2003). Therefore, the management of sediment runoff is a key goal within the Reef Water Quality Protection Plan (State of Queensland and Commonwealth of Australia, 2003). Of the waterways within the GBR catchment area, the Burdekin River contributes the largest amount of suspended sediment to the marine environment with an average annual export of 3.8 million tonnes or approximately thirty percent of the total sediment supply to the GBR (Furnas, 2003). In large, above average flow events such as the 2007/08 water year (total discharge of 26.5 million ML), the Burdekin River alone exported a total of 12.3 million tonnes of suspended sediment (Bainbridge *et al.* 2008). Therefore, the management of soil erosion in the Burdekin River catchment is a key goal for natural resource managers, although it is currently unclear of where remedial works should be prioritised within this large catchment area of ~130,000 km^2.

Current SedNet and ANNEX modelling of the Burdekin catchment suggests that the Burdekin Falls Dam (BFD) is a very efficient trap for sediment and particulate matter (Fentie *et al.* 2006; Prosser *et al.* 2002; Post *et al.* 2006). The latest models estimate that the BFD traps 77-82% of suspended sediment (SS), and 79% of particulate nitrogen and phosphorus, with negligible trapping of dissolved materials (Fentie *et al.* 2006; Post *et al.* 2006). However, field studies using sediment traps, water column/bottom profiling and water sampling within the dam reservoir during flow events do not support this high trapping efficiency (Griffiths and Faithful, 1996; Faithful and Griffiths, 2000). It is critical to have an accurate estimate of trapping within the BFD. If limited sediments are being transported past the dam then remedial works above the dam will have a negligible effect on the amount of sediment and particulate matter being delivered to the mouth of the river and to the GBR lagoon. As much of the remedial work is targeted at reducing bulk sediment loads to the GBR, works above the dam would not be undertaken for this purpose if the current dam trapping models are accurate. Moreover, the conflict between the SedNet model predictions and the field studies needs to be resolved so that SedNet and ANNEX can be used with more confidence to identify and quantify the sources of sediment to the GBR from the sub-catchments of the Burdekin. Here we present suspended sediment load data from a three-year monitoring program in the Burdekin River catchment to quantify the sediment trapping efficiency of the BFD. The three-year dataset provides insights into the dam trapping efficiency over small (2005/06), average (2006/07) and large (2007/08) flow events. Particle size data of suspended sediments collected during these events also provide insights into the sediment dynamics operating within this system.

Background

The estimation of sediment supply to the GBR is important to assess the progradation of the inner shelf of the GBR (e.g. Belperio, 1983), to quantify long-term changes in water quality, to set water quality targets and to assess the validity of predictive models such as SedNet and E_2-based models such as Watercast and EMMS. However, estimates of average suspended sediment export to the GBR show considerable variation. Estimates of average sediment export from the Burdekin River alone range between 2.4 and 9.0 million tonnes (see Lewis *et al.* 2006); although some of these estimates would not have considered the sediment retention capacity of the BFD. The influence of dams and reservoirs on sediment supply in the GBR catchments is an important consideration and may significantly reduce total sediment loads (e.g. Pringle, 1991). For example, SedNet modelling estimates of sediment load exported from the Burnett River can vary by an order of magnitude (0.18 million tonnes versus 1.4 million tonnes) with different dam trapping approximations due to the presence of the Paradise Dam and other storages in the system (Henry and Marsh, 2006).

The Burdekin River catchment is located within the dry tropics of northern Queensland. The tropics of northern Australia are renowned for highly variable seasonal and annual rainfall linked to the El Niño Southern Oscillation, tropical lows/cyclones and monsoonal activity (Lough, 2001). This extreme variability is highlighted by the historical daily, annual and event discharge records of the Burdekin River (Lewis *et al.* 2006). On average, over eighty percent of the freshwater discharged from the Burdekin River at the Home Hill (1922-1957) and Clare (1950-current) gauging stations (NRW gauge no. 120001, 120006) occurs during high flow events (Lewis *et al.* 2006). This percentage is similar within the sub-catchments of the Burdekin Region. The majority of sediments and nutrients are also transported through the Burdekin River waterways during these high flow events (see Belperio, 1979; Lewis *et al.* 2006). Therefore, an event-focused approach to water quality monitoring is required to quantify the transport of sediments and nutrients in the waterways of the Burdekin River catchment.

The BFD was constructed in 1987 largely to facilitate irrigation requirements for sugar cane and cropping in the lower Burdekin region and also to supply water to coal mines within the Bowen Basin further to the south (Kerr, 1994; Faithful and Griffiths, 2000). The dam, with a capacity of 1.86 million ML, is the largest reservoir in the State of Queensland (Faithful and Griffiths, 2000). The dam is fed by a large upstream catchment area (~115,000 km^2) and, despite its relatively large capacity, has overflowed in every wet season since construction (with one exception: see Faithful and Griffiths, 2000). Four major tributaries of the Burdekin River unite just upstream of the BFD including the Burdekin River from the north, the Cape River from the west and the Suttor and Belyando Rivers from the south. Queensland Department of Natural Resources and Water gauging stations measure stream flow on these tributaries and are located in close vicinity of major roads which cross these rivers, thereby providing optimal monitoring sites. The measurement of suspended sediment concentrations during flow events at these sites enables the calculation of loads to estimate the amount of suspended sediment entering into the BFD reservoir (Lake Dalrymple).

Field studies within Lake Dalrymple show that a turbid mid-flow layer develops during flow events due to the thermal stratification between the upper and lower water columns within the reservoir (Griffiths and Faithful, 1996; Faithful and Griffiths, 2000; M. Cooper, unpublished data). This finding, accompanied by data from bottom seismic profiling (M. Cooper, unpublished data) and sediment traps (J. Faithful, unpublished data) suggests that the majority of sediments are transported through the dam in average to large flow events. However, measurements of suspended sediments upstream and downstream of the dam to calculate sediment loads have not been undertaken and so a quantitative estimation of trapping within Lake Dalrymple has not previously been performed.

Methodology

Sample collection

Suspended sediment samples were collected over three wet seasons (2005/06, 2006/07 and 2007/08) from the Burdekin River at Inkerman Bridge (end-of-catchment; flow gauge no. 120006B), Burdekin River at Sellheim (flow gauge no. 120002C), Cape River at Gregory Developmental Road (flow gauge no. 120302B), Belyando River at Gregory Developmental Road (flow gauge no. 120301B), Suttor River at Bowen Developmental Road (flow gauge no. 120310A; Suttor River at St. Anns no. 120303A) and the BFD overflow (SunWater flow gauge) (see Bainbridge *et al.* 2006; 2007; 2008: Figure 1). As the Suttor River at Bowen Developmental Road gauge did not become operational until the 2006/07 wet season, we have used the downstream Suttor River at St. Anns (minus the Belyando River gauge) to estimate the total discharge (and thus suspended sediment load) for the Suttor River arm.

A total of 448 samples were collected and analysed for total suspended solids (TSS) throughout the three monitored wet seasons, including 86 samples from Burdekin River at Inkerman Bridge, 37 samples from Burdekin River at Sellheim, 44 samples from the Cape River, 53 samples from the Belyando River, 44 samples from the Suttor River and 184 samples from the BFD overflow. This total does not include selected duplicate samples for precision estimates and for inter-laboratory comparisons. Surface water ‘grab’ samples (top 50cm of water column) were collected with a bucket and rope following significant rainfall events which triggered stream flow. Where possible, samples were collected over the rising, peak and falling stages of the flow hydrograph (Figure 2). Samples were collected from the centre of the channel flow where possible and every effort was made to ensure samples were collected from the main flow, away from the backwash at the riverbank. The samples were then well mixed with a stirring rod before being sub-sampled into one-litre containers. The samples collected were refrigerated and transported on ice to the laboratories for analysis.

Additional opportunistic TSS samples were collected from the four major rivers above the dam to assess TSS variability across the edge to middle of the streams. During the large flows in the 2007/08 wet season, a transect of TSS samples was also taken laterally across Lake Dalrymple on 18 January 2008. On this day the water level was approximately 3.5m over the spillway implying a reservoir volume of 2.84 million ML or 153% capacity (Figure 3).

Samples were collected from the BFD overflow to determine the distribution and range of particle sizes in the sediment wash load passing through the dam. Samples were also collected from the major rivers upstream of the dam to compare particle size distribution and range with the dam overflow samples to examine the potential for deposition within Lake Dalrymple. If, for example, one upstream river arm had a considerably coarser particle size fraction than that of the dam overflow then the results would suggest that these sediments would be deposited in the dam reservoir (Lake Dalrymple).

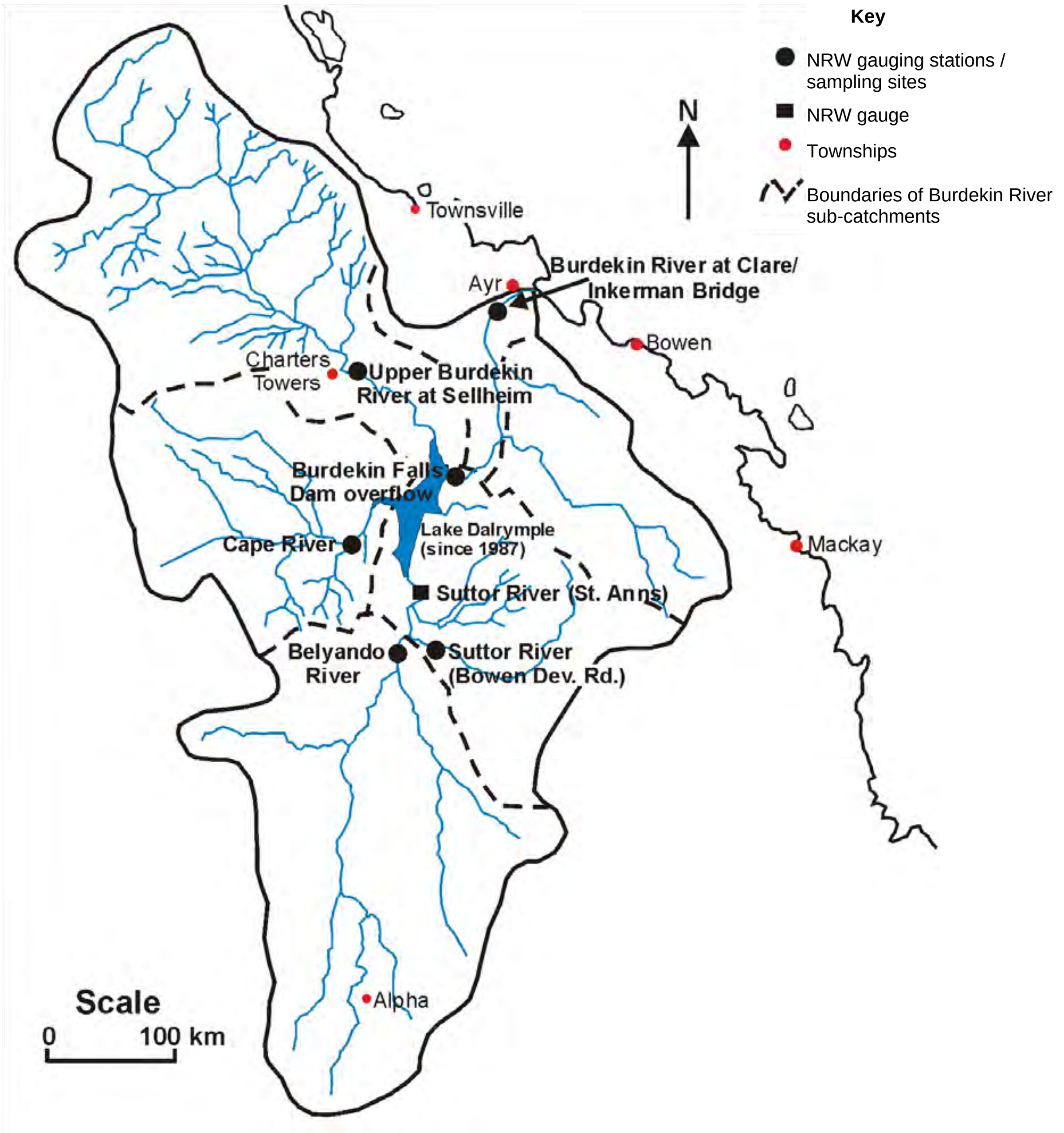

Figure 1: Map of the Burdekin catchment showing the main sampling sites for this project.

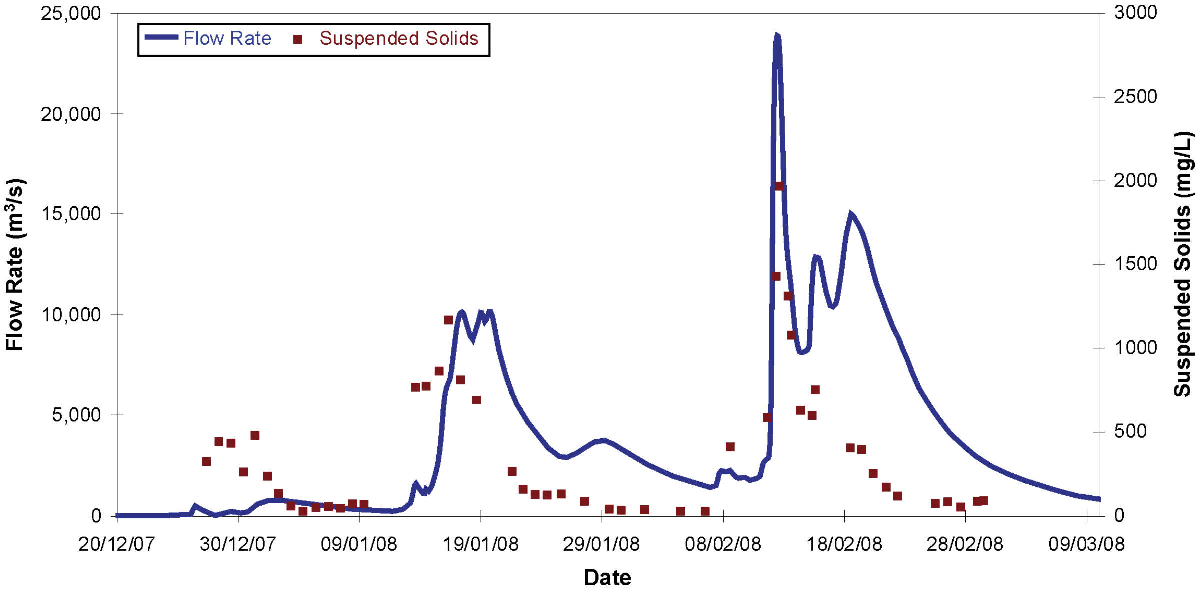

Figure 2: Flow hydrograph for the Burdekin River at Clare in the 2007/08 water year. Total suspended solid (TSS) samples (concentrations shown in mg/L) were collected from the Inkerman Bridge throughout the flow to calculate the sediment load.

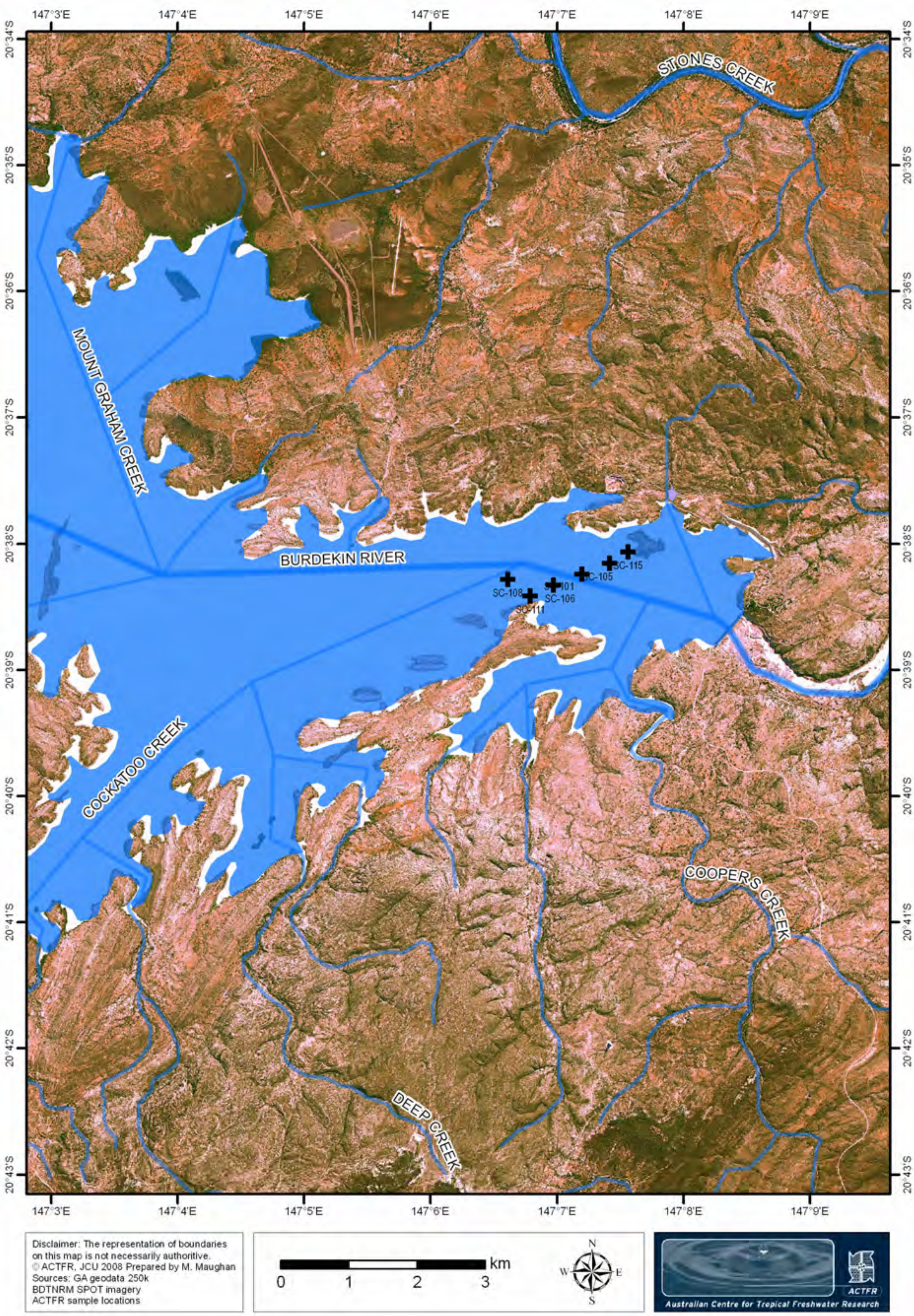

Figure 3: Suspended sediment samples were collected across the Burdekin Falls Dam reservoir on 18 January 2008 to assess the variability in concentrations across the stream profile during large flow events.

Analytical methods

Analyses of TSS were performed at the Australian Centre for Tropical Freshwater Research laboratory at James Cook University, Townsville and at the Queensland Department of Natural Resources and Water laboratory in Brisbane. Samples of known volume were filtered through pre-weighed GF/C glass fibre filter papers with a nominal pore size of 1.2 µm. The filter had been rinsed previously with reagent water and dried at 105°C for at least thirty minutes. The filter and retained matter were dried to constant weight at 105°C (APHA, 2005). TSS (in mg/L) was calculated by dividing the mass of the retained matter (in mg) by the volume of sample filtered (in L). Selected TSS samples were duplicated to assess the repeatability of the analysis. Duplicate determinations were, on average, within ten percent of each other. Duplicate samples were also analysed by separate laboratories to ensure consistency. These samples were typically within ten percent.

Particle sizing was conducted on selected water samples using a Malvern Mastersizer 2000 at the School of Earth and Environmental Sciences, James Cook University. The samples were selected to best capture the flow hydrograph over the rising, peak and falling stages. A total of 118 water samples were analysed from the sites over the three monitored wet seasons: 8 samples from Burdekin River at Inkerman Bridge, 21 samples from Burdekin River at Macrossan Bridge, 16 samples from the Cape River, 19 samples from the Belyando River, 17 samples from the Suttor River and 37 samples from the BFD overflow. Each sample was analysed at least twice and a mean was taken. Samples with similar particle size distributions collected over a single water year were averaged over flow events.

Load calculations

The collection of TSS samples near the locations of the gauging stations allows for the calculation of the mass or load of TSS exported through the sampled point of the waterway. The highest concentrations of suspended sediments typically occur during the rising limb of the flow hydrograph before concentrations become diluted with increasing flow. Therefore it is critical to sample all stages of the flow to obtain reliable load estimates. The continuous time series flow data from the stream-flow gauging stations and point source water quality data were entered into the BROLGA database, a software program designed by Queensland Department of Natural Resources and Water which calculates loads using linear interpolation. The linear interpolation technique is considered the most suitable to estimate catchment loads with the available input data (Letcher *et al.* 1999; Fox *et al.* 2005; Lewis *et al.* 2007). In some cases in the 2005/06 and 2006/07 water years, the ‘full’ event was not sampled at some of the sites and ‘tie down’ concentrations were added to capture the total flow range over these events. Concentrations were deduced by using the best estimate possible with the available data.

Approximately nine percent (~10,000 km^2) of the catchment area above the BFD is ungauged and includes waterways such as Sellheim River, Kirk River and Elphinstone Creek. Monitoring data from the Kirk River and Elphinstone Creek were used to estimate the suspended sediment event mean concentration for this catchment area. The flow contribution for this catchment area was estimated by developing a water budget using the BFD overflow data coupled with the capacity of the dam prior to the event flows.

Results

Flows over the monitoring period

Three different sized flows passed through the Burdekin River at Clare gauging station (120006B) over the three-year monitoring period (Table 1). According to the classifications of Lewis *et al.* (2006), 2005/06 was a 'small flow', 2006/07 was a 'large flow' and 2007/08 was a 'very large flow'. For the catchments above the BFD, all streams had below average flows in the 2005/06 water year. In the 2006/07 water year, the Burdekin River at Sellheim and Cape Rivers had average flows while the Suttor and Belyando Rivers had below average flows. All contributing rivers had above average flows in the 2007/08 water year (Table 1).

Table 1: Summary of total flows (in million ML) during the 2005/06, 2006/07 and 2007/08 water years.

Site	Catchment area (km^2)	Total flow (million ML)			Gauging record average flow*
		2005/06	2006/07	2007/08	
Burdekin River at Sellheim	36,138	2.4	4.1	6.2	4.5
Cape River at Taemas	15,861	0.09	0.74	2.4	0.74
Belyando River at Gregory Dev. Rd	35,054	0.24	0.19	2.0^	0.78
Suttor River at St. Anns#	17,246	0.27	0.37	4.9	0.82
Burdekin Dam overflow	114,258	1.4	5.1	16.7	N/A
Below dam	15,337	0.6	3.4	9.8	N/A
Burdekin River at Clare	129,595	2.0	8.5	26.5	8.6

Suttor at St. Anns minus Belyando at Gregory Devevelopmental Road.

* From Lewis *et al.* 2006.

^ Gauge data inaccurate, new estimate of 4.6 million ML used later in report.

Suspended sediment concentrations across the stream profiles

Opportunistic suspended sediment samples were collected across the river profiles in order to ascertain a better understanding of sediment dynamics within the four major river arms above the BFD and to improve uncertainty estimations of sediment loads. Over the three-year monitoring program, edge versus middle TSS concentrations for the Cape, Belyando and Suttor Rivers have all been within ±10%. However, the Burdekin River at Sellheim site has displayed greater variability. While the right bank and middle of the Burdekin River have been within ±10% during experiments conducted over each of the three years, the left bank has consistently yielded considerably lower TSS concentrations compared to the middle. In particular, in peak flow conditions during the 2007/08 wet season, TSS concentrations between the left bank and middle were outside 100% (320 mg/L versus 1550 mg/L) and in 2006/07 comparisons were offset by ~40%. This offset can be explained by the confluence of the Fanning River with the Burdekin River which is approximately three hundred metres upstream of this sampling point. Samples collected another two hundred metres downstream of this left bank in 2005/06 showed TSS concentrations to be within ±10% across the river profile. Provided that this left bank is avoided in sampling efforts then the variability in suspended sediment concentrations at this site would be within ±20%.

The transect sampled across Lake Dalrymple (Figure 3) during the large flows in 2007/08 showed TSS concentrations to be within ±20% of each other. Therefore, we suggest that load estimates for the BFD overflow to be within ±20%.

Suspended sediment loads over the monitoring period

2005/06 water year

The small flows entering into Lake Dalrymple in the 2005/06 water year were predominately from the upper Burdekin River arm (79% of the estimated total inflow to the dam). A total of 1.76 million tonnes of suspended sediment was calculated to pass through the Burdekin River at Sellheim site during 2005/06 which is estimated to make up 86% of the total suspended sediment load entering into Lake Dalrymple (Table 2). Prior to the flows in the 2005/06 water year, the BFD was at 56.3% capacity, however, three small inflow events occurred in January (two events) and March which filled the dam to 97.3% capacity before a flow event in April caused the dam to overflow (Figure 4). There is some discrepancy in the water budget between the total inflow and overflow waters which suggests that the dam was at only twelve percent capacity prior to event flows in the catchment area (compared to the actual readings of 56.3%), a difference of 580,000 ML which is unaccounted for (Table 2). Some of this water would have been used for dam release (~2000 ML), although there is still ~300,000 ML of water unaccounted for when the water budget for the April event is considered (Table 3). The dam was at 97.3% capacity prior to the April flow event although the inflow/overflow budget suggests that the dam was only at 81% (Table 3).

We calculated that in the 2005/06 water year a total of 2.05 million tonnes of sediment entered the dam while only 0.24 million tonnes passed over the spillway (Figure 4; Table 2). This result suggests that the BFD trapped approximately 88% of the suspended sediment entering from the upstream catchments in the 2005/06 water year. Because of the relatively small suspended sediment/stream flow contributions from the Cape, Belyando and Suttor Rivers compared to the Burdekin River, the highest amount of uncertainty in this trapping estimate would be from the sediment load calculated for the Burdekin River. This river was well sampled in the 2005/06 water year and the uncertainty in these loads is estimated within ±20% (see Lewis *et al.* 2007). Therefore, we estimate that the range of sediment trapping in Lake Dalrymple to be between 86 and 90% in this water year. However, the unaccounted water budget would further extend this uncertainty range. The water overflowing from the BFD contributed 70% of the total flow passing through the Burdekin River at Clare gauge (end-of-catchment site) and ~50% of the total suspended sediment load. The April flow event alone contributed a total of 1.08 million tonnes of sediment of which 0.24 million tonnes was exported over the dam spillway (Table 3). Therefore we calculate that the dam trapped 78% of suspended sediment in this event, while all of the suspended sediment delivered in the previous flows would have been trapped with the exception of the extremely fine particles with a slow settling time.

2006/07 water year

The 2006/07 water year was marked with above average flows from the Cape River and Burdekin River at Sellheim arms with small flows in the Belyando and Suttor Rivers. Similarly to the previous 2005/06 water year, the Burdekin River contributed a large proportion (75%) of the total inflow to the dam (Table 4). The total water budget measured for 2006/07 appears to be more acceptable than the previous water year with an estimated 5.6 million ML flowing into the dam and 5.1 million ML of water spilling over the dam wall (Table 4). This suggests that the dam capacity was 75% prior to the event flows, consistent with the readings measured by SunWater at the BFD.

Again the Burdekin River at Sellheim arm contributed the majority of the total suspended sediment load (2.8 million tonnes: 88%) delivered to Lake Dalrymple and so the contribution of the other rivers would have a negligible influence on dam trapping. Overall, we estimate that a total of 3.2 million tonnes of suspended sediment entered Lake Dalrymple while 1.2 million tonnes of suspended sediment passed over the dam spillway (Table 4; Figure 5). This result suggests that 62.5% of sediment was trapped by the BFD in the 2006/07 water year. We estimate that the uncertainty in the Burdekin River load contribution to be within ±20% and so the range in the dam trapping would be between 55-68%. The water flowing over the BFD spillway contributed 60% to the total flow at the Burdekin River at Clare gauging station, although the suspended sediment passing over the dam contributed just 20% to the total end-of-catchment suspended sediment load (Table 4).

Table 2: Catchment loads for the 2005/2006 water year (red text indicates estimated data).

2005/06 water year	Total flow (ML)	Proportion of total flow	Sediment load (million tonnes)	Proportion of sediment load	EMC (mg/L)
Burdekin River @ Sellheim	2,400,000	**79%**	1.76	**86%**	**730**
Cape River @ Taemas	90,000	**3%**	0.03	**1%**	**350**
Belyando River @ Gregory Dev. Road	240,000	**8%**	0.12	**6%**	**480**
Suttor River @ St. Anns*	270,000	**9%**	0.13	**6%**	**480**
Other above dam (e.g. Kirk R. Elphinstone Ck. Sellheim R.) estimate	30,000	**1%**	0.01	**0.5%**	**360**
Inflow to Dam	3,030,000	**100%**	2.05	**100%**	**680**
Burdekin Falls Dam overflow	1,400,000	**70%**	0.24	**48%**	**170**
Catchments below dam (e.g. Bowen & Bogie Rivers)	600,000	**30%**	0.26	**52%**	**430**
Burdekin River @ Clare	**2,000,000**	**100%**	**0.50**	**100%**	**250**

* Suttor at St. Anns gauge minus Belyando at Gregory Developmental Road.

Table 3: Catchment loads for the April event in the 2005/06 water year (red text indicates estimated data).

2005/06 April event only	Total flow (ML)	Proportion of total flow	Sediment load (million tonnes)	Proportion of sediment load	EMC (mg/L)
Burdekin River @ Sellheim	1,400,000	**80%**	0.93	**86%**	**660**
Cape River @ Taemas	50,000	**3%**	0.01	**1%**	**280**
Belyando River @ Gregory Dev. Road	110,000	**6%**	0.06	**6%**	**500**
Suttor River @ St. Anns*	180,000	**10%**	0.07	**6%**	**390**
Other above dam (e.g. Kirk R. Elphinstone Ck. Sellheim R.) estimate	15,000	**1%**	0.01	**1%**	**330**
Inflow to Dam	1,755,000	**100%**	1.08	**100%**	**300**
Burdekin Falls Dam overflow	1,400,000	**70%**	0.24	**48%**	**170**
Catchments below dam (e.g. Bowen & Bogie Rivers)	600,000	**30%**	0.26	**52%**	**430**
Burdekin River @ Clare	**2,000,000**	**100%**	**0.50**	**100%**	**250**

* Suttor at St. Anns gauge minus Belyando at Gregory Developmental Road.

Table 4: Catchment loads for 2006/07 water year (red text indicates estimated data).

2006/07 water year	Total flow (ML)	Proportion of total flow	Sediment load (million tonnes)	Proportion of sediment load	EMC (mg/L)
Burdekin River @ Sellheim	4,100,000	**75%**	2.80	**88%**	**680**
Cape River @ Taemas	740,000	**13%**	0.18	**5%**	**240**
Belyando River @ Gregory Dev. Road	194,400	**4%**	0.09	**3%**	**480**
Suttor River @ St. Anns*	365,000	**7%**	0.10	**3%**	**270**
Other above dam (e.g. Kirk R. Elphinstone Ck. Sellheim R.) estimate	171,300	**2%**	0.04	**1%**	**350**
Inflow to Dam	5,570,700	**100%**	3.20	**100%**	**580**
Burdekin Falls Dam overflow	5,100,000	**60%**	1.20	**20%**	**240**
Catchments below dam (e.g. Bowen & Bogie Rivers)	3,400,000	**40%**	4.94	**80%**	**1450**
Burdekin River @ Clare	**8,500,000**	**100%**	**6.14**	**100%**	**720**

* Suttor at St. Anns gauge minus Belyando at Gregory Developmental Road.

2007/08 water year

Large, above average flows occurred in all four river arms during the 2007/08 water year with the Burdekin (37%) and Suttor/Belyando (41%) Rivers contributing the highest proportions of water delivered to Lake Dalrymple (Table 5). Similarly to the 2006/07 water year, the water budget seems reasonable, with the dam at 86.3% capacity (on 24 December 2007) prior to the event flows. However, a discrepancy existed for the Belyando River gauge which recorded a discharge of 2.0 million ML of water from a catchment area of 35,000 km^2 (i.e. 57 ML per km^2). If this discharge is correct then a total of 3.6 million ML of water came from an area of only 6,400 km^2 (at 560 ML per km^2). When the discharge per square kilometre is considered then it becomes apparent that the Belyando River gauge (Belyando River at Gregory Devevelopmental Road, 120301B) contributed significantly more water than what was recorded. Rainfall records show that similar volumes were recorded over the Belyando and Suttor catchments over the two events. The Belyando River catchment received considerably more rain in the January event (typically 200-300 mm) than the Suttor (typically ~100 mm) while the Suttor River catchment received more rain in the February event (typically 200-300 mm) than the Belyando catchment (typically 50-100 mm). The area within the 6,400 km^2 catchment area received ~200 mm over both the January and February events. The Suttor River at Bowen Dev. Rd gauge (no. 120310A) contributed a total flow of 1.3 million ML from a catchment area of 10,900 km^2 (=120 ML per km^2), while the downstream Suttor River gauge (St. Anns: gauge no. 120303A) recorded 6.9 million ML from a catchment area of 52,000 km^2 (130 ML per km^2). The Belyando River makes up about 70% of the gauged area at the Suttor River at St. Anns station and so the Belyando River contribution should have been closer to 130 ML per km^2 compared to 57 ML per km^2 as measured by the gauge. The large wet season flows of 2007/08 in the southern Burdekin catchments caused considerable overbank flows which appear to have been underestimated by the Belyando River flow gauge. When 130 ML per km^2 is used to estimate the discharge for the Belyando River, a total of 4.56 million ML is calculated to have been delivered from this river in the 2007/08 wet season. We have used this discharge for the Belyando River.

Even with the large flows in all four major catchments above the BFD, the Burdekin River again contributed the majority of the suspended sediment load (4.7 million tonnes: 83%). We estimate that the total suspended sediment delivery to the BFD in 2007/08 was 5.67 million tonnes with 2.40 million tonnes passing over the dam spillway (Table 5; Figure 6). This result suggests that 58% of sediment delivered to the dam was trapped within Lake Dalrymple. If we assume that the uncertainty in the sediment loads delivered from the Belyando and Suttor Rivers was as high as ±60% (because of possible discrepancies in the water budget), then the range in dam trapping estimates would be between 55-60%. Likewise if we assume that the uncertainty in the Burdekin River load was ±20% then the dam trapping efficiency calculations would range between 49-64%.

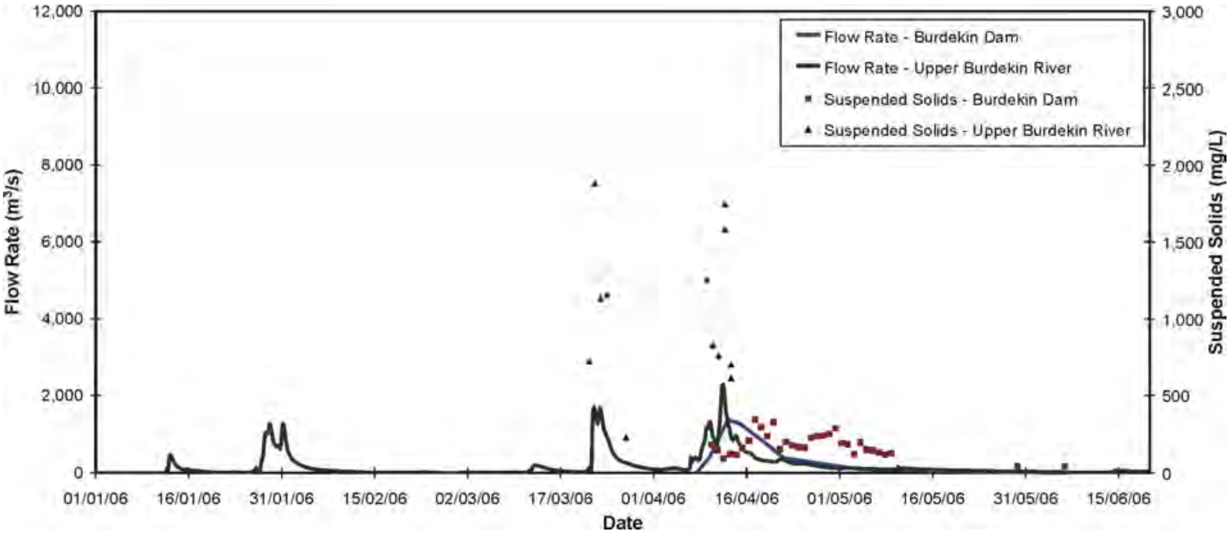

Figure 4: Flow hydrograph for the Burdekin Falls Dam overflow in the 2005/06 water year. Concentrations (in mg/L) of TSS samples collected over the flow are also shown.

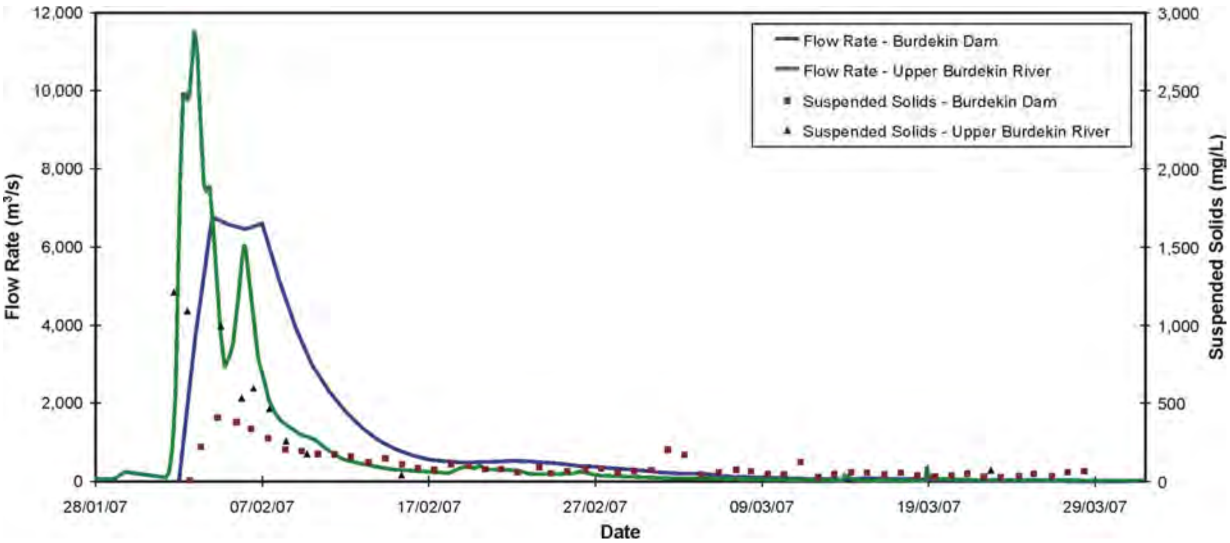

Figure 5: Flow hydrograph for the Burdekin Falls Dam overflow in the 2006/07 water year. Concentrations (in mg/L) of TSS samples collected over the flow are also shown.

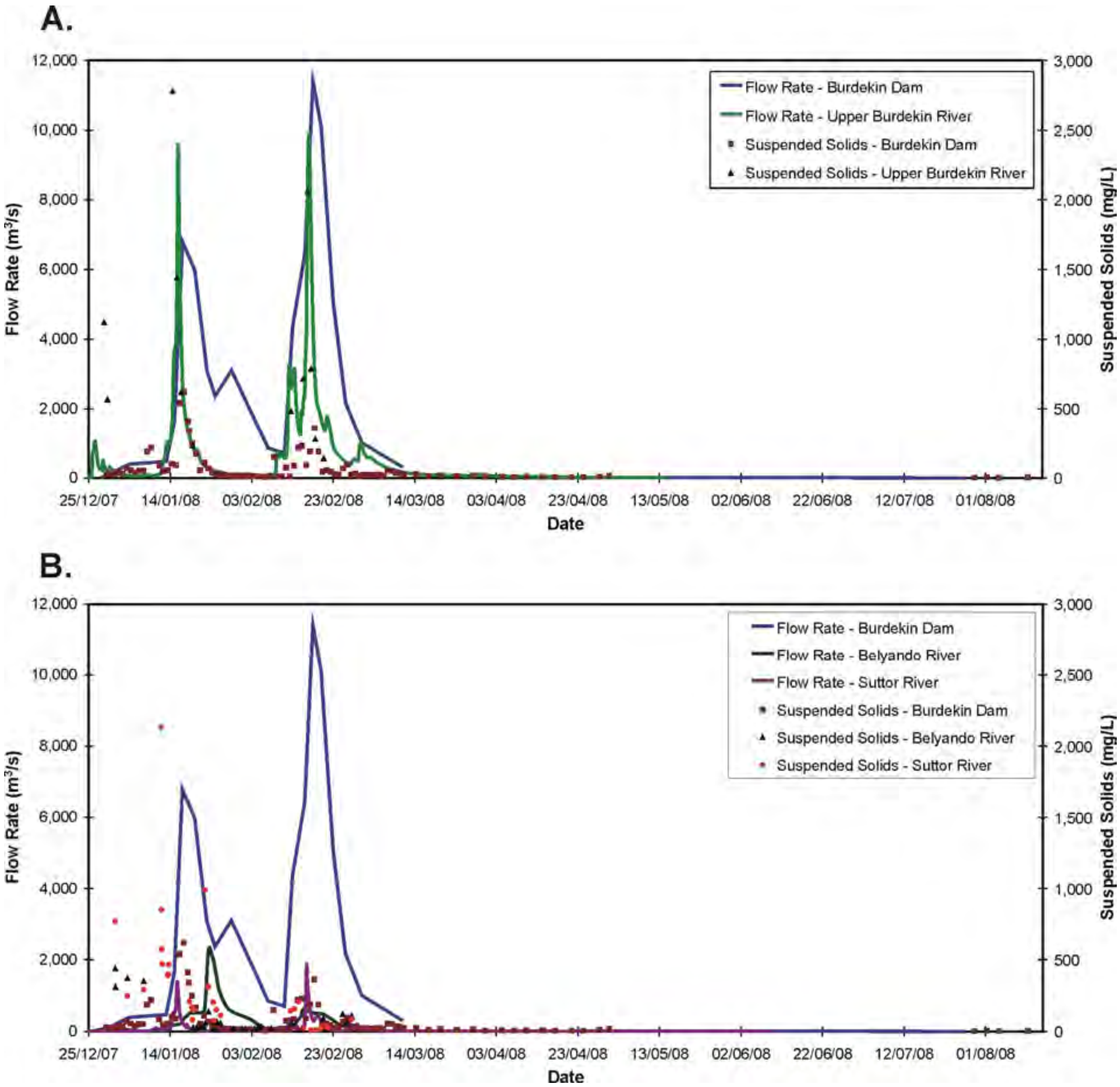

Figure 6: Flow hydrograph for the Burdekin Falls Dam overflow in the 2007/08 water year coupled with flows from the upper Burdekin River (A) and the Belyando and Suttor Rivers (B). Concentrations (in mg/L) of TSS samples collected over the flow are also shown.

Table 5: Catchment loads for 2007/08 water year (red text indicates estimated data).

2007/08 water year	Total flow (ML)	Proportion of total flow	Sediment load (million tonnes)	Proportion of sediment load	EMC (mg/L)
Burdekin River @ Sellheim	6,200,000	**37%**	4.70	**83%**	**760**
Cape River @ Taemas	2,400,000	**14%**	0.32	**6%**	**130**
Belyando River @ Gregory Dev. Road	4,560,000	**27%**	0.23	**4%**	**50**
Suttor River @ St. Anns*	2,370,000	**14%**	0.28	**5%**	**120**
Other above dam (e.g. Kirk R. Elphinstone Ck. Sellheim R.) estimate	1,424,600	**8%**	0.14	**2%**	**100**
Inflow to Dam	16,954,600	**100%**	5.67	**100%**	**370**
Burdekin Falls Dam overflow	16,700,000	**63%**	2.40	**20%**	**140**
Catchments below dam (e.g. Bowen & Bogie Rivers)	9,800,000	**37%**	9.9	**80%**	**1010**
Burdekin River @ Clare	**26,500,000**	**100%**	**12.30**	**100%**	**460**

* Suttor at St. Anns gauge minus Belyando at Gregory Developmental Road.

Our data indicate that, during large to very large flow events, the TSS load delivered over the dam spillway makes up only a small proportion (~20%) of the total load exported from the Burdekin River (Tables 3 and 4). However, the results for the 2005/06 water year highlight the possible variability in the system, with the suspended sediment load delivered over the BFD making up a higher proportion (~50%) to the end-of-catchment load in this wet season (Table 2). The size of the flows in the sub-catchments of the Burdekin River are almost exclusively influenced by rainfall (i.e. very little groundwater/base flow) and so the relative contribution from each sub-catchment from year to year is dependant on the spatial variation of seasonal rainfall.

Particle size distributions over the monitoring period

The particle size results show high variability over single flow events across all major river arms and also the BFD overflow. This result suggests that different sources of suspended sediment are being transported from different lithologies/catchment areas during flow events. All four major river arms upstream of the BFD drain considerable catchment areas and also contain several different rock/soil types (Figure 7). The range of particle size for samples collected from the BFD overflow (0.04 to 710 μm: Figure 8) closely match the size distributions measured for the four major upstream rivers (Figure 9a-d) with no upstream river containing sizes coarser than what was exported over the dam spillway. Generally, the dominant particle size fraction measured at all sites was in the fine to medium silt range particularly when the distributions were unimodal (4 to 25 μm), although a finer clay fraction was also evident in all samples especially when a bimodal pattern was apparent. Likewise, the end-of-catchment site (Burdekin River at Inkerman Bridge) largely showed a particle size distribution dominated by clay and fine silt particles (Figure 9e).

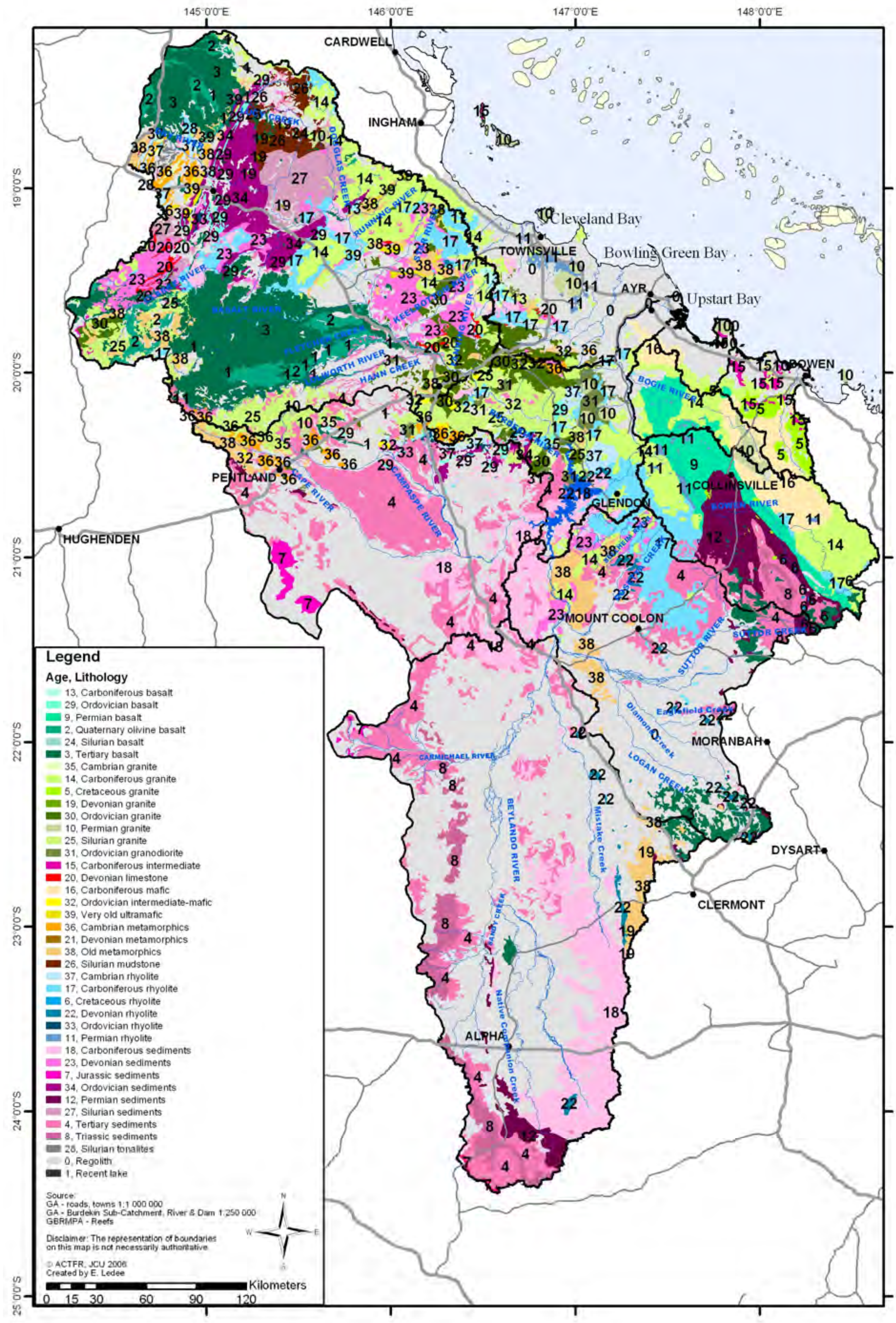

Figure 7: Geological map showing the many different rock types within the Burdekin River catchment.

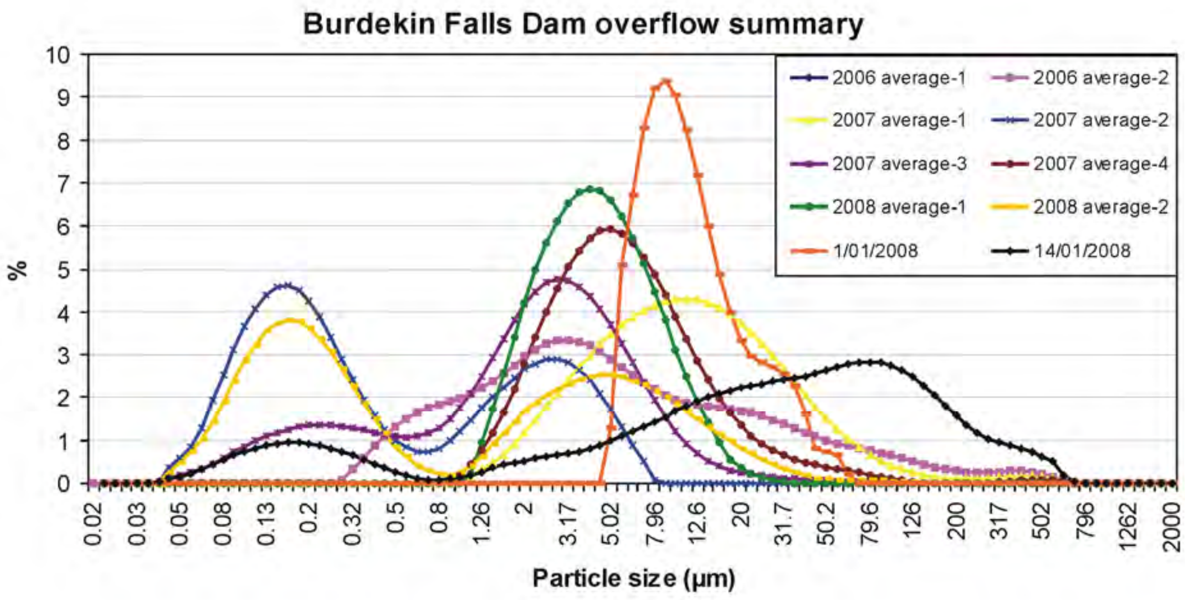

Figure 8: Particle size distributions of suspended sediment samples collected during flood events from the Burdekin Falls Dam overflow over the three-year monitoring period. The particle size distribution patterns that were similar have been averaged so that all distribution patterns are represented for each particular year.

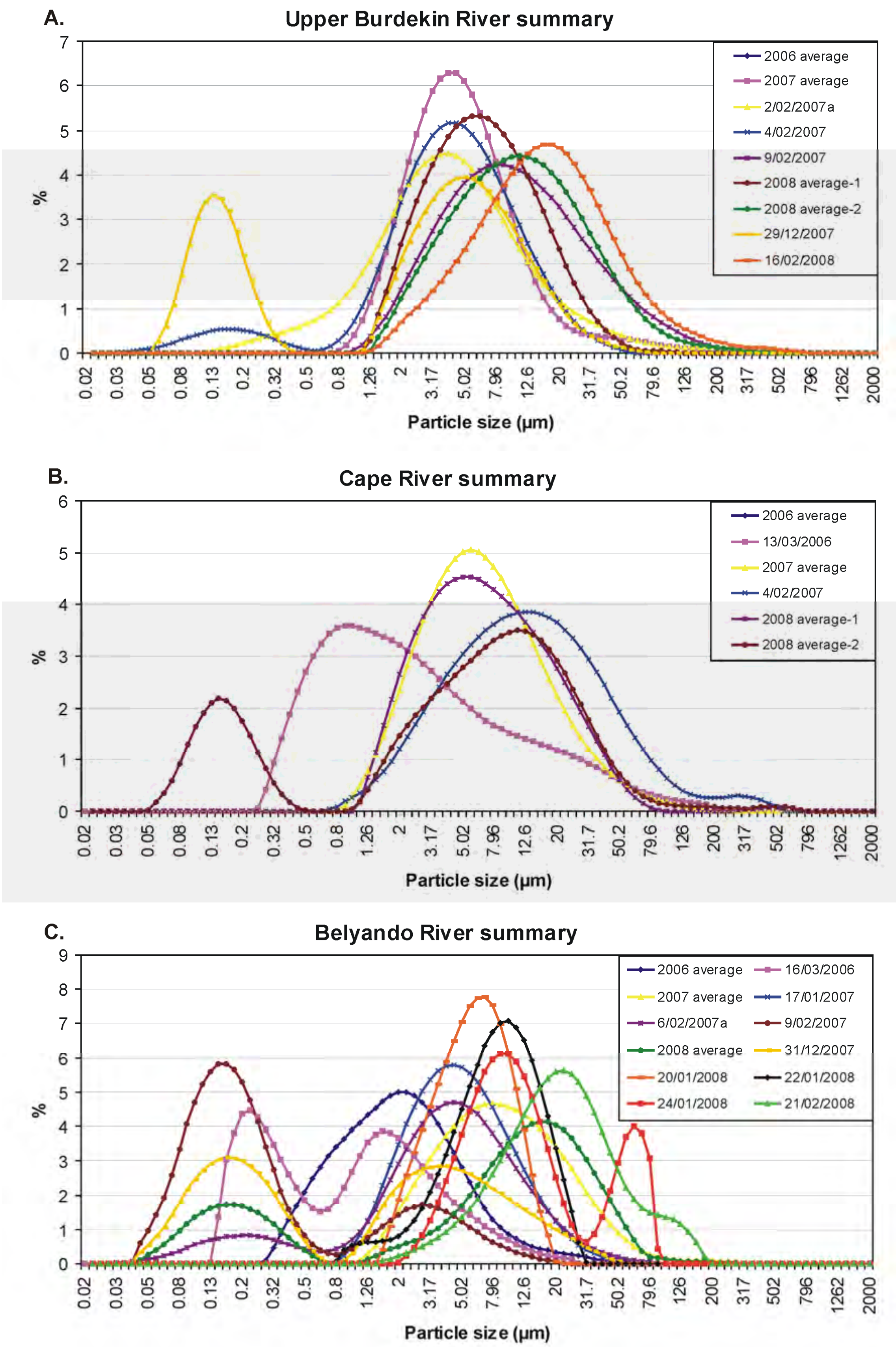

Figure 9: Particle size distributions of suspended sediment samples collected during flood events for the upper Burdekin River at Sellheim (A), Cape River (B) and Belyando River (C) over the three-year monitoring period. The particle size distribution patterns that were similar have been averaged so that all distribution patterns are represented for each particular year.

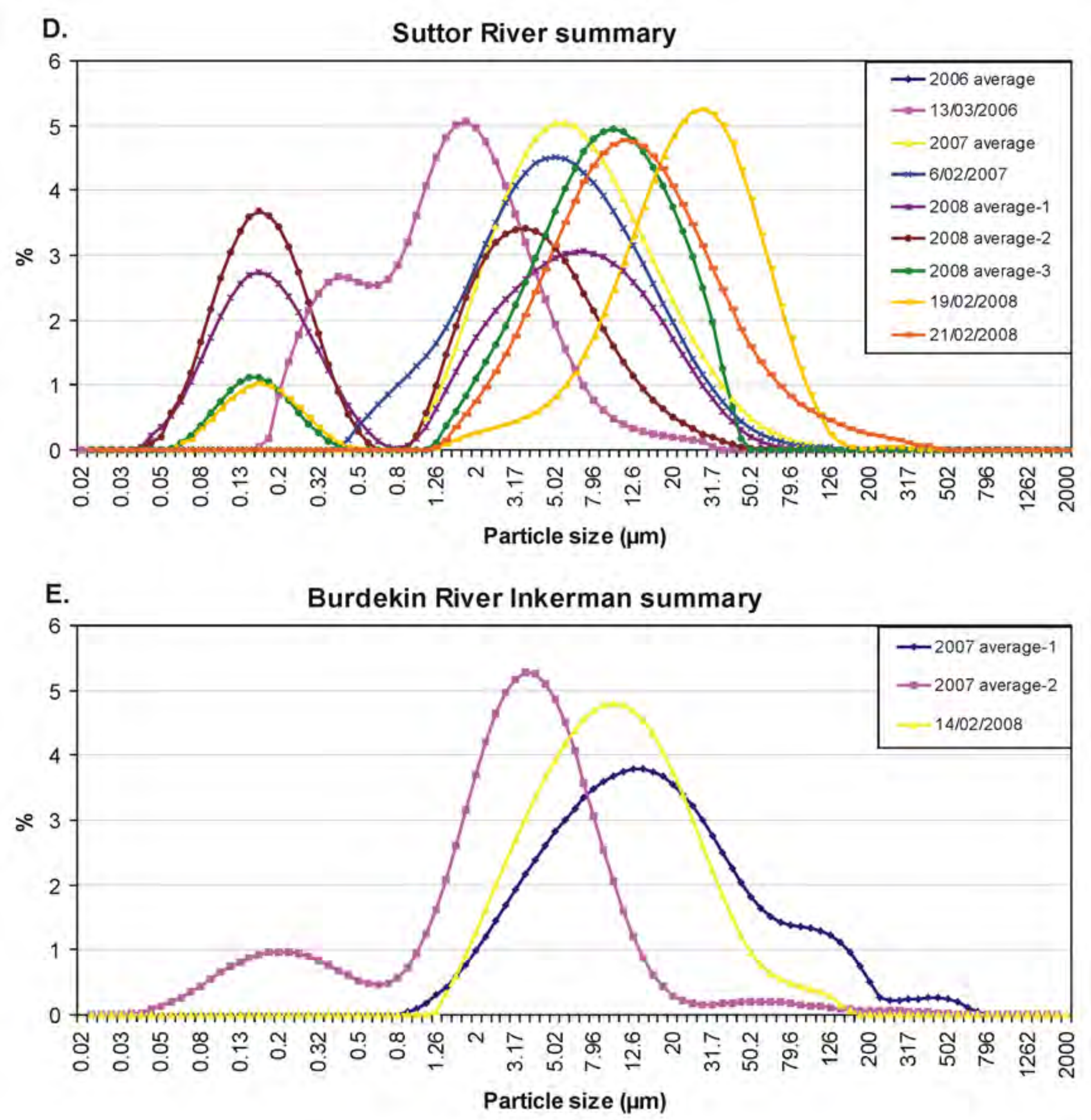

Figure 9 (continued): Particle size distributions of suspended sediment samples collected during flood events for the Suttor River (D) and Burdekin River end-of catchment (E) over the three-year monitoring period. The particle size distribution patterns that were similar have been averaged so that all distribution patterns are represented for each particular year.

Discussion

A unique dataset has been gathered from the sampling of three highly variable sized flow events in the Burdekin catchment over the 2005/06, 2006/07 and 2007/08 water years. The flow volumes spilling over the BFD over these years was 1.4 (small), 5.1 (large) and 16.7 (very large) million ML, respectively. This high variation in discharge over these three years provides a good indication of the sediment trapping efficiency of the BFD over different sized flow events.

Our data show that edge and middle TSS samples from the four major upstream rivers are typically within ±10%, with the exception of the Burdekin River at Sellheim due to the nearby upstream confluence of the Fanning River tributary. However, provided that this knowledge is incorporated in sampling efforts then TSS results should be within ±10% laterally across the river profile. Previous results from the Burdekin River at Inkerman Bridge (end-of-catchment site) show possibly higher variability in TSS concentrations vertically through the water column (Amos *et al.* 2004). Therefore, we suggest that, provided representative samples have been collected over the river flow hydrograph, load estimates should be within ±20% (taking into account in-stream TSS variability of ±10-15% and laboratory error of ±10%).

However, apparent discrepancies in flow measurements may cause uncertainty in load estimates to be considerably higher. In particular, large flows such as those in the 2007/08 water year caused considerable overbank flows which were hundreds of metres wide and well outside of the main defined channel in the Belyando, Suttor and Cape River arms. As a result, these flows may not have been adequately captured by the flow gauges. In particular, the Belyando River peak flow in 2007/08 was observed to be flowing much faster than previous flow events (S. Lewis, personal observation). Similar problems have been encountered for the Tully River of which overbank flow is a common occurrence, and was measured to account for an additional forty percent of total discharge in the 2006/07 water year (Wallace *et al.* 2008). At this stage, the uncertainty in flow measurements in the Burdekin River catchment is considered to be unquantified, although flow estimations for the more channelised Burdekin tributaries such as the Burdekin River and measurements from the BFD wall should be accurate.

Our measurements suggest that the sediment trapping efficiency of the BFD was 88% in 2005/06, 62.5% in 2006/07 and 61% in 2007/08. The higher trapping efficiency in the 2005/06 water year is a product of relatively small catchment flows and also due to a lower dam level prior to the onset of this wet season. The consistency in the trapping efficiency estimates in 2006/07 and 2007/08 of ~60% (± 10%) suggest that this is probably more reflective of an 'average' trapping estimate. Therefore, we suggest that SedNet models are overestimating the trapping efficiency of the BFD. Indeed, if the latest SedNet model incorporated 60% dam trapping then the average annual export of 3.5 million tonnes (Kinsey-Henderson *et al.* 2007) is close to the estimate of Furnas (2003: 3.8 million tonnes) and also to the flow-normalised loads (using the discharge records specified by SedNet) calculated over nine years of monitoring data (4.6 million tonnes: Bainbridge *et al.* 2008).

The sediment trapping algorithm within the SedNet model is based on a well-established relationship between trapping efficiency and the ratio of reservoir capacity to annual inflow for 'normal ponded reservoirs' which receive runoff that is more evenly distributed throughout the year than is the case for the Burdekin River. We believe this algorithm may not be relevant for the BFD, which experiences strong thermal stratification and highly episodic flows and therefore shorter residence times than is assumed by the SedNet model (see Faithful and Griffiths, 2000). Moreover, in high flow events the Burdekin Dam reservoir would act more like a river than a dam.

In contrast, the estimates that most suspended sediments would pass over the dam spillway based on physical measurements of turbidity and water column temperature appear to have underestimated the trapping capacity of the BFD. The turbid mid-flow layer that develops in Lake Dalrymple during event flows (Faithful and Griffiths, 2000) may only rarely reach the surface waters and pass over the dam. In fact, during the large flows of the 2007/08 water year, the surface TSS concentrations measured across Lake Dalrymple were close to the TSS concentration collected in the dam overflow waters.

Our data also show that the vast majority (~80%) of the suspended sediment load delivered to the BFD is derived from the Burdekin River arm. This finding supports the results of Cooper *et al.* (2006) who, using trace element and isotopic tracing methods, found that the bottom sediments within Lake Dalrymple were from the upper Burdekin River. Therefore, the management to reduce bulk suspended sediment delivery to the dam should focus on the upper Burdekin River catchment area. In addition, the available data indicate that, in large flows, the majority (80%) of the total suspended sediment load exported from the Burdekin River is sourced from the catchment area below the BFD. This area below the dam only comprises ten percent of the total Burdekin catchment area. Although, additional data are required to support these results, based on the current findings, remedial works to reduce the 'bulk' suspended sediment load exported from the Burdekin River should focus on the catchment area below the dam. However, we note that this assertion only relates to the management of the 'bulk' suspended sediment supply and not to specific sediments which may travel further in the marine environment (i.e. dispersive clays) and thus may be more ecologically important.

The particle size distribution data indicate that wash load (mud fraction= clays and silt size particles) suspended sediment is being sampled exclusively in the surface samples collected from the four major river arms upstream of the BFD. Since no particles in the four upstream river arms were coarser than those measured in the dam overflow waters, all particles have the potential to remain in the wash load and pass over the dam spillway. Previously it was thought that most of the 'fine-grained' particles were derived from the southern Belyando and Suttor River arms of the Burdekin (Faithful and Griffiths, 2000), however, our data show that similarly fine particles can also be derived from the upper Burdekin and Cape Rivers. However, the composition of the clays may be different across catchments (see Faithful and Griffiths, 2000). The particle size distribution measured in the rivers of the Burdekin catchment and the dam overflow ranged from clay to medium sand sized particles. The high variability in the particle size distribution occurring over single flow events in all streams (i.e. change from unimodal to bimodal distribution) suggest that different sources of sediments are being eroded in the catchment areas and reflect the different 'parcels' of water passing through the catchment over time. Some studies have suggested that the bimodal distribution is related to organic materials (Cooper *et al.* 2005), although Faithful and Griffiths (2000) found that organics comprised typically <20% of the suspended solid fraction. Further study is required to determine the origin of the bimodal particle size distribution.

Our improved knowledge of suspended sediment loads (and associated uncertainty), sediment trapping efficiency of the BFD and the average proportion of the suspended sediment load delivered from the BFD to the end-of-catchment allows us to construct a sediment budget for the Burdekin River (Table 6). In the sediment budget we have assumed that the current sediment load is 4.6 million tonnes which is based on the flow-normalised loads from nine years of TSS monitoring data (Bainbridge *et al.* 2008). We have incorporated uncertainty into this budget by estimating that the Burdekin Dam overflow contributes between 20-40% to the end-of-catchment sediment load (as suggested by our monitoring data). We have also used our 60% trapping efficiency estimates for the dam to estimate the suspended sediment load for the pre-dam construction. Finally we have used the indications from Ba/Ca ratios in coral records (McCulloch *et al.* 2003) which suggest that the suspended sediment load has increased by five fold to estimate the pre-European load.

The suspended sediment load estimates show high variability which highlights the high uncertainty for the Burdekin River. Much of this uncertainty comes from the estimates of suspended sediment load and the water budgets from the catchment area below the BFD. These figures suggest that total suspended sediment delivery from the Burdekin River has decreased by thirty percent on average, since the construction of the BFD. This may be evident in coral core records but this has not yet been analysed.

Table 6: Estimated Burdekin River suspended sediment budgets over pre-European, pre BFD and current conditions for above and below the BFD.

Suspended sediment load	**Total export (million tonnes)**	**Export above dam (million tonnes)**	**Export below dam (million tonnes)**	**Kinsey-Henderson *et al.* (2007) SedNet with 60% trapping**
Current mean load (2008)	4.6	0.91 - 1.8	2.7 - 3.6	3.5
Pre dam mean load (1976 - 1986)*	5.9 - 7.3	2.3 - 4.6	2.7 - 3.6	
Pre European mean load (pre 1850)*	1.2 - 1.5	0.46 - 0.91	0.55 - 0.73	

* Assume constant rainfall regime; Assumes pre-European load five-fold less than current (see McCulloch *et al.* 2003).

Conclusions

Suspended sediment concentrations were measured during event flow conditions to calculate a sediment budget for the Burdekin Falls Dam and to determine the sediment trapping efficiency of Lake Dalrymple. Our results indicate that in average-to-large flow events in the Burdekin River catchment, approximately sixty percent (±10%) of suspended sediments are trapped by the Burdekin Falls Dam. The results also show that the upper Burdekin River arm of the catchment consistently contributes a large proportion of suspended sediments (>77%) delivered to the Burdekin Falls Dam even with the larger flows that occurred in the Belyando-Suttor catchments in the 2007/08 water year.

These results provide the first real quantitative estimates of dam trapping and contrast with previous studies which predicted that the majority of washload suspended sediments would pass through the dam, or recent SedNet models which predict ~80-90% dam trapping. Our results also suggest that the majority of the sediment load (~80%) exported from the Burdekin River mouth is largely derived from the catchment area below the Burdekin Falls Dam. However, we caution that this finding only pertains to the management of 'bulk' suspended sediment export and not to the specific composition of sediment particles (e.g. fines) which may be more important to receiving water bodies.

References

APHA (2005) *Standard methods for the examination of water and wastewaters*. 21st edn. American Public Health Association (APHA), American Water Works Association and Water Environment Federation, Washington, USA.

Amos, K. J., Alexander, J., Horn, A., Pocock, G. D., and Fielding, C. R. (2004) Supply limited sediment transport in a high-discharge event of the tropical Burdekin River, North Queensland, Australia. *Sedimentology* 51: 145-162.

State of Queensland and Commonwealth of Australia (2003) *Reef water quality protection plan for catchments adjacent to the Great Barrier Reef World Heritage Area*. Queensland Department of the Premier and Cabinet, Brisbane (http://www.reefplan.qld.gov.au/library/pdf/reefplan.pdf)

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: Interim report for the 2005/2006 wet season*. ACTFR Report 06/13 for Burdekin Dry Tropics NRM. Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University, Townsville (http://www.actfr.jcu.edu.au/idc/groups/public/documents/technical_report/jcudev_015428.pdf)

Bainbridge, Z., Lewis, S. and Brodie, J. (2007) *Event-based community water quality monitoring in the Burdekin Dry Tropics Region: 2002-2007.* ACTFR Report No. 07/22 for the Burdekin Dry Tropics NRM. Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University, Townsville (Volume 1: http://www.actfr.jcu.edu.au/idc/groups/public/documents/technical_report/jcudev_016590.pdf and Volume 2 http://www.actfr.jcu.edu.au/idc/groups/public/documents/technical_report/jcudev_016591.pdf)

Bainbridge, Z. Lewis, S. Davis, A. Brodie, J. (2008) *Event-based community water quality monitoring in the Burdekin Dry Tropics Region: 2007-2008 wet season update*. ACTFR Report No. 08/19 for BDTNRM. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville (http://www.actfr.jcu.edu.au/idc/groups/public/documents/technical_report/jcuprd_052060.pdf)

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.

Belperio, A. P. (1983) Terrigenous sedimentation in the central Great Barrier Reef lagoon: A model from the Burdekin Region. *BMR Journal of Geology and Geophysics* 8: 179-190.

Brodie, J., McKergow, L. A., Prosser, I. P., Furnas, M., Hughes, A. O. and Hunter, H. (2003) *Sources of sediment and nutrient exports to the Great Barrier Reef World Heritage Area*. ACTFR Report No. 03/11. Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University, Townsville (http://www.actfr.jcu.edu.au/idc/groups/public/documents/technical_report/jcudev_015447.pdf)

Cooper, M., Faithful, J. and Shields, G. (2005) Sediment dynamics of a large tropical river system: The Burdekin River and Lake Dalrymple, Australia. *10th International Symposium on the Interactions Between Sediments and Water*, Bled Slovenia, 28 August – 2 September 2005 (http://www.rmz-mg.com/letniki/rmz52/rmz52_0169-0226.pdf)

Cooper, M., Shields, G., Faithful, J. and Zhao, J. (2006) Using Sr/Nd isotopic ratios to determine sediment sources in the Burdekin Falls Dam, Queensland, Australia. *Geochimica et Cosmochimica Acta* 70: A112.

Faithful, J. W. and Griffiths, D. J. (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., Cogle, A. L., Sherman, B., Read, A., Chen, Y. and Brodie, J. (2006) Sediment and nutrient modelling in the Burdekin Basin. Chapter 6 In: Cogle, A. L., Carroll, C. and Sherman, B. S. (eds.) *The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting*. Queensland Department of Natural Resources, Mines and Water, Brisbane.

Fox, D. R. Etchells, T. and Tan, K. S. (2005) *Protocols for the optimal measurement of nutrient loads.* A report to West Gippsland Catchment Management Authority, Australian Centre for Environmetrics (http://www.gcb.vic.gov.au/gippslandlakes/documents/Protocols_for_the_optimum_measurement_of_Nutrient_Loads.pdf)

Furnas, M. (2003) *Catchments and corals: Terrestrial runoff to the Great Barrier Reef.* Australian Institute of Marine Science, Townsville, 334 pp.

Griffiths, D. J. and Faithful, J. W. (1996) Effects of the sediment load of a tropical north-Australian river on water column characteristics in the receiving impoundment. Arch. *Hyrobiol. Suppl. 113. Large Rivers* 10: 147-157.

Henry, N. and Marsh, N. (2006) *Modelling of sediment and nutrient transport: Burnett Catchment*. Environmental Protection Agency, Brisbane, Queensland.

Kerr, J. D. (1994) *Black Snow and Liquid Gold: A History of the Burdekin Shire*. Burdekin Shire Council, Ayr, Queensland. 320 pp.

Kinsey-Henderson, A., Sherman, B. and Bartley, R. (2007) *Improved SedNet modeling of grazing lands in the Burdekin catchment.* CSIRO Land and Water Science Report 63/07 for the Burdekin Dry Tropics NRM, September 2007.

Letcher, R. A., Jakeman, A. J., Merritt, W. S., McKee, L. J., Eyre, B. D. and Baginska, B. (1999) *Review of techniques to estimate catchment exports*. Environmental Protection Agency Technical Report, EPA Sydney (ISBN: 0731327098).

Lewis, S., Brodie, J., Ledee, E. and Alewijnse, M. (2006) *The Spatial Extent of Delivery of Terrestrial Materials from the Burdekin Region in the Great Barrier Reef Lagoon*. ACTFR Report No. 06/02 for the Burdekin Dry Tropics NRM. Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University, Townsville (http://www.actfr.jcu.edu.au/idc/groups/public/documents/technical_report/jcudev_015422.pdf)

Lewis, S. E., Bainbridge, Z. T. and Brodie, J. E. (2007) A review of load tools available for calculating pollutant exports to the Great Barrier Reef lagoon: A case study of varying catchment areas. In: Oxley, L. and Kulasiri, D. (eds.) *MODSIM 2007 International Congress on Modelling and Simulation.* Modelling and Simulation Society of Australia and New Zealand, December 2007, pp. 2396-2402 (ISBN: 978-0-9758400-4) (http://www.mssanz.org.au/MODSIM07/papers/44_s23/AReviewofLoads23_Lewis_.pdf)

Lough, J. M. (2001) Climate variability and change on the Great Barrier Reef. In: Wolanski, E. (ed.) *Oceanographic processes of coral reefs – Physical and biological links in the Great Barrier Reef*. CRC Press, Boca Raton, p 269-300.

McCulloch, M. T., Fallon, S., Wyndham, T., Hendy, E., Lough, J. and Barnes, D. (2003) Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. *Nature* 421: 727-730.

McLaughlin, C. J., Smith, C. A., Buddemeier, R. W., Bartley, J. D. and Maxwell, B. A. (2003) Rivers, runoff, and reefs. *Global and Planetary Change* 39: 191-199.

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.

Pringle, A. W. (1991) Fluvial sediment supply to the north-east Queensland coast, Australia. *Australian Geographical Studies* 29: 114-138.

Prosser, I. P., Moran, C. J., Lu, H., Scott, A., Rustomji, P., Stevenson, J., Priestly, G., Roth, C. H. and Post, D. (2002) *Regional patterns of erosion and sediment transport in the Burdekin River catchment*. CSIRO Land and Water Technical Report No 5/02, February 2002.

Restrepo, J. D., Zapata, P., Diaz, J. M., Garzón-Ferreira, J. and Garcia, C. B. (2006) Fluvial fluxes into the Caribbean Sea and their impact on coastal ecosystems: The Magdalena River, Colombia. *Global and Planetary Change* 50: 33-49.

Syvitski, J. P. M. (2003) Supply and flux of sediment along hydrological pathways: Research for the 21st Century. *Global and Planetary Change* 39: 1-11.

Syvitski, J. P., Vörösmarty, C. J., Kettner, A. J. and Green, P. (2005) Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science* 308: 376-380.

Vörösmarty, C. J., Meybeck, M., Fekete, B., Sharma, K., Green, P. and Syvitski, P. M. (2003) Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planetary Change* 39: 169-190.

Wallace, J., Stewart, L., Hawdon, A. and Keen, R. (2008) The role of coastal floodplains in generating sediment and nutrient fluxes to the Great Barrier Reef Lagoon in Australia. *International Journal of Ecohydrology and Hydrobiology* 8: 183-194.

Walling, D. E. and Fang, D. (2003) Recent trends in the suspended sediment loads of the world's rivers. *Global and Planetary Change* 39: 111-126.

Further Information

Marine and Tropical Sciences Research Facility
PO Box 1762
CAIRNS QLD 4870

This document is available for download at http://www.rrrc.org.au/publications/research_reports.html

Credits: RRRC thanks its staff, Stephen Lewis (JCU) and Katharina Fabricius (AIMS) use of images.