Nutrients and suspended sediment discharged from the Johnstone river catchment during cyclone Sadie

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Abstract

Flood-waters of cyclone Sadie were sampled intensively at three sites in the Johnstone River system to assess nutrient and suspended sediment concentrations and loads discharged to the Great Barrier Reef Marine Park. Very high flow rates were recorded during the flood event. Concentrations of suspended sediment and nutrients rose markedly and were very much higher than measured under baseflow conditions. However, water quality rapidly improved as flood-waters subsided. Almost 200 000 tonnes of suspended sediment were discharged from the river system over the four day flood event, as well as 858 tonnes of nitrogen, 314 tonnes of phosphorus and 2214 tonnes of organic carbon. The suspended sediment load accounted for 97% of the phosphorus discharged and 84% of the nitrogen, but only 45% of the organic carbon. Sources of the suspended sediment were not determined but may have included soil erosion in the catchment (both rural and urban), stream-bank erosion and mobilisation of stream-bed sediments. Management strategies to minimise soil/sediment movement in the catchment should be very effective in reducing both sediment and nutrient loads discharged in flood-waters to the Great Barrier Reef.

Introduction

Considerable concern has been raised in the scientific community and elsewhere, that discharges of nutrients and sediments from many Queensland coastal rivers may be harming the Great Barrier Reef (GBR). Until recently however, there has been little quantitative information available on what nutrient and sediment loads are being discharged by rivers to waters of the GBR, and on specific land use practices linked to these discharges.

A detailed study of water quality and stream nutrient and suspended sediment (SS) fluxes in the Johnstone River system in north Queensland which commenced in early 1991 is now addressing these issues (Hunter 1993). The study was initiated as part of a Queensland Government pilot study for Integrated Catchment Management in the Johnstone catchment. Principal objectives of the study are to:

- quantify fluxes of nutrients and SS moving downstream in the Johnstone River system and into waters of the GBR;
- assess sources and relative contributions from different land use practices to the measured flows, and
- assess water quality (for nutrients and SS) at strategic locations in the Johnstone catchment.

A feature of the study is its emphasis on intensive monitoring at key sites to quantify fluxes during periods of high stream flow, when most movement of SS and associated nutrients is likely to occur (e.g. Cullen et al. 1978; Cosser 1989). Major stream rises occurred in the Johnstone catchment in

association with Cyclone Sadie and caused serious flooding in coastal parts of the catchment. These conditions provided an ideal opportunity to quantify nutrient and SS fluxes during one of the biggest floods experienced in the lower catchment in recent years.

Methods

Study location

The Johnstone River system drains an area of 1634 km^2 in the wet tropics of north Queensland. Major streams are the Johnstone and South Johnstone Rivers, both rising in the south-eastern section of the Atherton Tableland and discharging through a common estuary at Innisfail to waters of the central GBR (Fig. 1). The principal towns are Innisfail, Malanda and Millaa Millaa.

Coastal parts of the catchment receive approximately twice the annual rainfall of tableland areas, with long-term averages of 3546 mm and 1672 mm at Innisfail (1881-1993) and Malanda (1916-1993), respectively (source: Bureau of Meteorology). The catchment area and annual discharge of the Johnstone River are respectively about twice those of the South Johnstone River; with a mean annual discharge from the combined river systems of approximately 3 million megalitres.

Approximately 50% of the catchment has been cleared, with most remaining native rain forest now listed on the World Heritage register. The major land uses on cleared land are grazing (dairy and beef, 26%) and cropping (predominantly sugarcane and bananas, 14%).

Sampling during cyclone Sadie

Innisfail received 648 mm of rainfall over the three day period from 30 January to 1 February 1994, as a result of cyclone Sadie. Much less rain fell in upper parts of the catchment, Malanda receiving 212 mm over the same period. Major flooding occurred only in coastal parts of the catchment. The cyclone followed a three year period of predominantly below-average rainfall and river flows in the catchment.

Six of the sites monitored in the long-term study were selected for priority sampling during the Sadie event (Fig. 1): the Johnstone River at Innisfail (NI) and at Tung Oil (NT); the South Johnstone River at Innisfail (SI) and upstream of South Johnstone Mill (SU); Fisher Creek at Nerada (FN) and Taylor Creek at Waraker (TW).

Intensive sampling was undertaken manually during the event at SU, SI and NI but very few samples were taken at NT since a bridge wash-out early in the event prevented further access to the site. Samples were taken at SI and NI from the Jubilee and Geraldton bridges, respectively, while SU was sampled from a tram bridge just downstream of the gauging station. The main flood event peaked during daylight hours at the 3 sites, allowing both rising and falling stages to be intensively sampled in relative safety. The flood peak was the highest recorded at SU and at that stage flood-waters were 300 mm below the tram bridge decking (H McDermott pers. comm.). Rainfall samples were collected periodically at SU, SI and NI in acid-washed rain gauges located away from overhanging vegetation.

Automatic sampling units located at FN and TW failed to adequately sample the event. The sampler at TW failed completely; while all sample bottles at FN were filled during early stages of the event, prior to the main flood peak.

Depth-integrated samples were taken using P61, D49 and/or locally-made "horizontal gulp" samplers (Wong et al. 1992). At each sampling time, across-stream variability in SS/nutrient concentrations was measured by sampling at three points along each bridge (at approximately the 1/4, 1/2 and 3/4 points across the stream). On one occasion at Tung Oil (30 January, from 1637 to 1807 h) variability with depth was assessed by sampling with a P61 sampler suspended from a cable across the river (Wong et al. 1992) to sample at depths of approximately 0.9 and 3.5 m at three points on the stream transect.

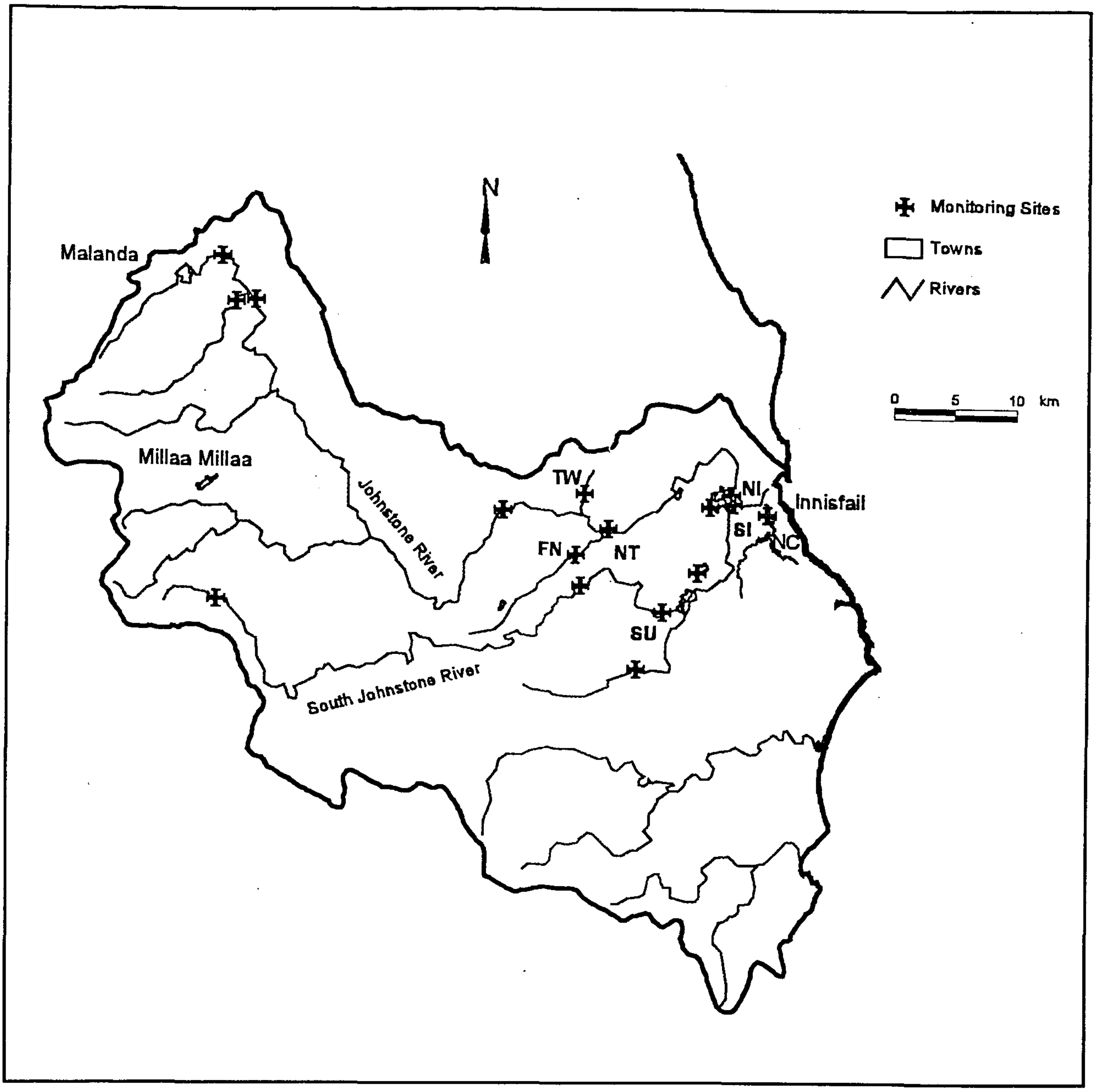

Fig. 1. Location of monitoring sites in the Johnstone River catchment. Sites sampled during cyclone Sadie are marked with the relevant site codes (see text).

Chemical analysis

Samples were filtered on site (using pre-combusted, acid-washed Whatman GFF filters) and both filtered and non-filtered subsamples were held in acid-washed polyethylene bottles. Samples were stored in portable refrigerators and frozen as soon as possible. An additional one litre sample was taken for SS analysis.

Parameters measured included SS, total phosphorus (P), total nitrogen (N), Kjeldahl N (TKN), ammonium, oxidised N (nitrate plus nitrite), filterable reactive P and organic carbon (OC). Details of analytical methods are given in Hunter (1993) and broadly followed those described in APHA (1989). Particulate concentrations of TKN and total P were derived by difference between results for paired filtered and non-filtered samples; and concentrations measured in filtered samples were considered to represent the dissolved fraction (although possibly including a fine colloidal fraction

also). Total N was calculated as TKN (non-filtered sample) plus oxidised N; and dissolved organic N as TKN (filtered) minus ammonium-N.

Calculation of discharge and fluxes

Stream-flow data at SU, NT, FN and TW were obtained from nearby gauging stations. Accurate flow data were not available for NI and SI (non-gauged tidal sites) so estimates were made from discharge at upstream gauged sites, by applying a factor for each site based on relative catchment areas and mean annual rainfall (M Greer pers. comm.); and adding a lag time of 2.5 and 2 hours for NI and SI, respectively. Tidal influences were considered to have been insignificant during a major flood. Discharge data for NI and SI were calculated as follows:

Discharge at NI = 1.15 x discharge at NT;

Discharge at SI = 1.35 x discharge at SU.

Flood-waters had largely subsided by 3 February and nutrient and SS fluxes for the Sadie event were therefore calculated for the four day period from 30 January to 2 February, inclusive. Software packages *Datread* and *Datman* (Doherty and Brebber 1992) were used to calculate fluxes by interpolating concentrations to discharge measuring times and integrating the product with respect to time.

Results and Discussion

Nutrient and suspended sediment concentrations

Very high flow rates were recorded in the lower catchment during cyclone Sadie, with peak flow rates of 1756 m^3/s recorded at SU and 3932 m^3/s at NT (compared with typical wet season base flows at these sites of 45 and 68 m^3/s, respectively). Suspended sediment concentrations increased markedly with increasing flow rates (Fig. 2), the SS presumed to be predominantly soil particles mobilised upstream due to soil erosion in the catchment, stream bank collapse and/or entrainment of stream-bed sediments. At all sites, SS concentrations decreased quickly as flood waters subsided.

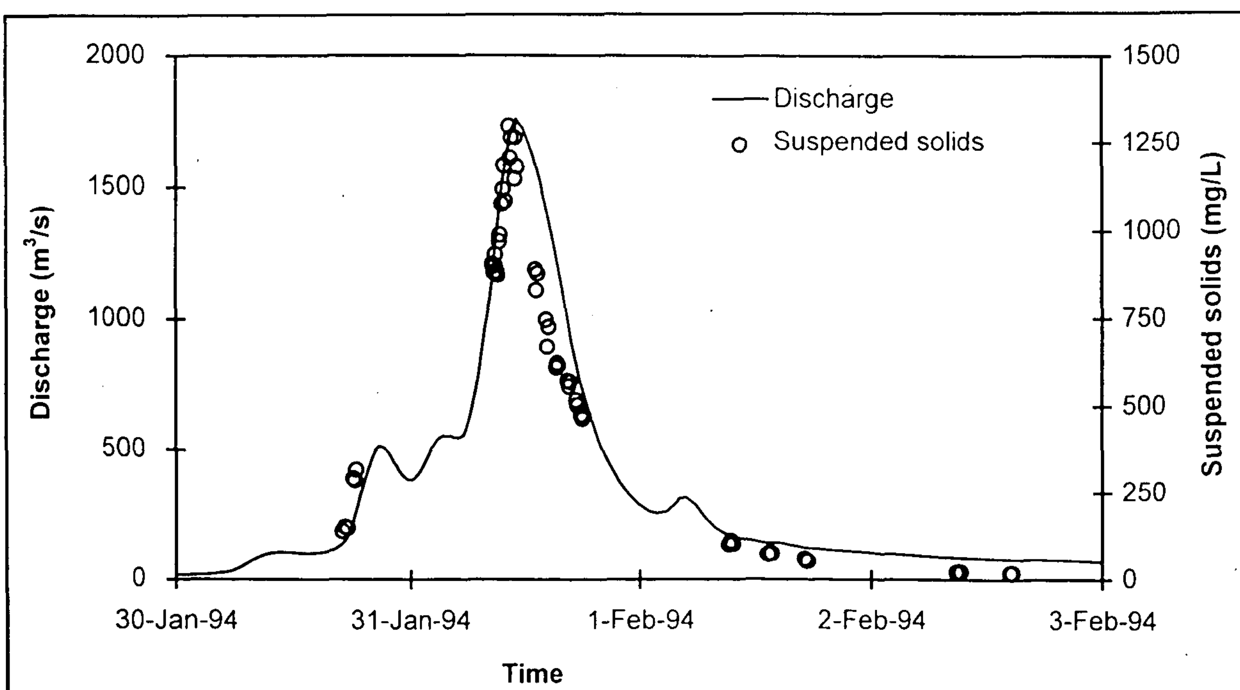

Fig. 2. River discharge and suspended sediment concentrations measured in the South Johnstone River upstream of S. Johnstone Mill during cyclone Sadie.

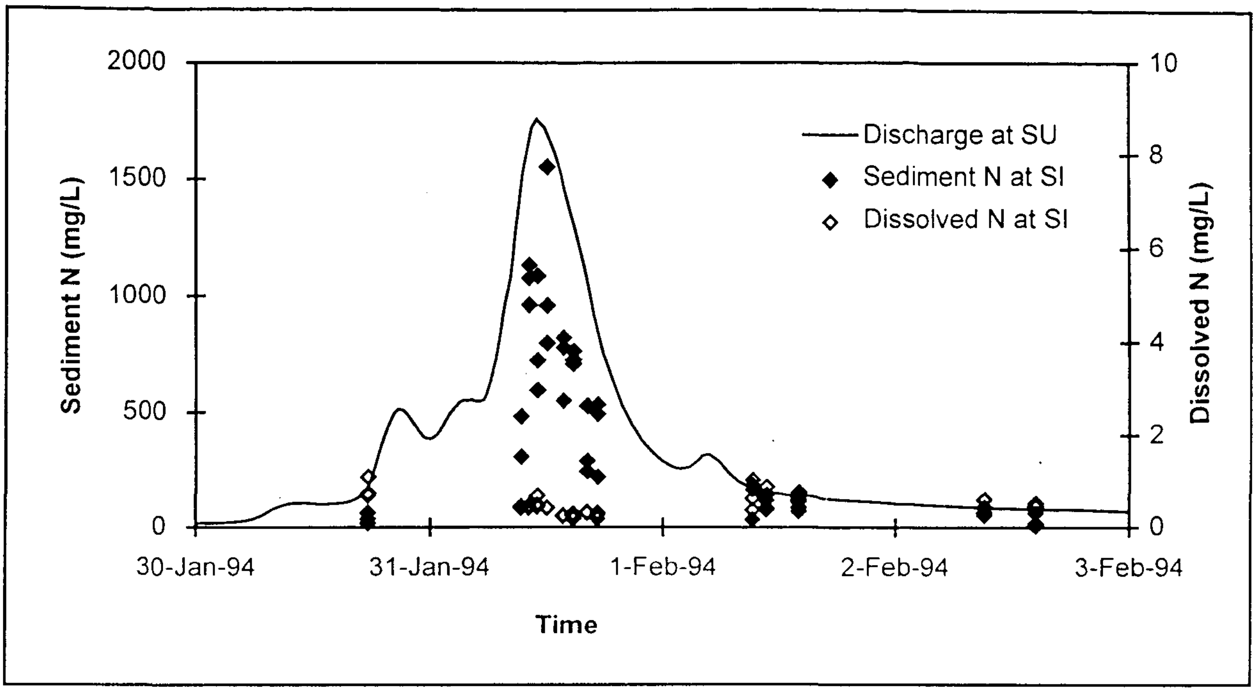

Fig. 3. Concentrations of sediment-bound N and dissolved N in the South Johnstone River at Innisfail during cyclone Sadie.

Nutrient concentrations similarly increased markedly with increasing flow rate, most of the nutrients being associated with the SS fraction. This is illustrated (Fig. 3) for N concentrations at SI; with similar trends occurring at the other sites and for P.

Median concentrations of total N, P and OC during the event were higher in the South Johnstone River at SU and SI than in the Johnstone River at NI (Table 1); possibly because relatively more of the discharge from the latter river system is derived from the Atherton Tableland, where only minor runoff and flooding occurred. Median concentrations of these parameters were very much higher during the Sadie flood event than corresponding median concentrations over a preceding two-year period of well-below-average rainfall and discharge.

Table 1. Median nutrient concentrations (mg/L) at three sites[1] in the Johnstone catchment during cyclone Sadie and comparison with concentrations during low flow conditions in 1991–1993[2].

	Cyclone Sadie			1991–1993
	NI (n=44)	SI (n=44)	SU (n=59)	NI (n~220)
Suspended sediment	218	551	557	6
Total Kjeldahl N	1.06	1.36	2.23	0.18
Total P	0.40	0.54	0.74	0.02
Total OC	4.8	6.5	6.3	–
Filterable Kjeldahl N	0.20	0.22	0.29	0.12
Filterable total P	0.03	0.02	0.03	0.01
Filterable total OC	3.4	3.6	3.6	–
Ammonium-N	0.035	0.044	0.040	0.021
Oxidised N	0.140	0.139	0.126	0.080
Filterable reactive P	0.007	0.006	0.007	0.004

[1] NI (Johnstone R., Innisfail); SI (Sth. Johnstone R., Innisfail); SU (Sth. Johnstone R. upstr. Sth. Johnstone Mill)

[2] Median concentrations at NI for 1991–1993 are given as an example. There were minor differences in median concentrations of some parameters at SI and/or SU.

By contrast, there were only small increases in median concentrations of dissolved (filterable) N and P fractions during the Sadie event, including the inorganic fractions of ammonium-N, oxidised N and filterable reactive P (Table 1). Median concentrations of dissolved N and P in both rivers during cyclone Sadie were low in terms of the potential to cause eutrophication in freshwaters, but oxidised N and ammonium-N concentrations exceeded proposed indicative guideline limits for estuarine and coastal waters (ANZECC 1992).

The median ammonium-N concentration in rain-water collected during cyclone Sadie was considerably lower than was measured in rain-water during much smaller events in 1991–1993 (Table 2). This may have reflected the much more widespread nature of the Sadie event, compared with the earlier rainfall, which may have absorbed ammonia from local sources, (e.g. volatilised from surface applications of urea fertiliser). Moreover, concentrations of N and P in rain-water during cyclone Sadie (Table 2) were very much lower than respective dissolved concentrations in river water during the flood event (Table 1).

Table 2. Comparison between median concentrations of N and P (mg/L) in rain-water during cyclone Sadie[1] and during much smaller events in 1991–1993[2].

	Sadie	1991–1993
Total Kjeldahl N	$\leq$0.06	<0.06
Total P	$\leq$0.02	<0.02
Ammonium-N	0.005	0.034
Oxidised N	0.008	0.018
Filterable reactive P	<0.001	0.002

[1] Includes samples taken at Johnstone R. at Innisfail (NI); South Johnstone R. at Innisfail (SI); and Sth. Johnstone R. upstream of South Johnstone Mill (SU); n=10

[2] Most samples taken at Johnstone R. at Tung Oil (NT)); n=20

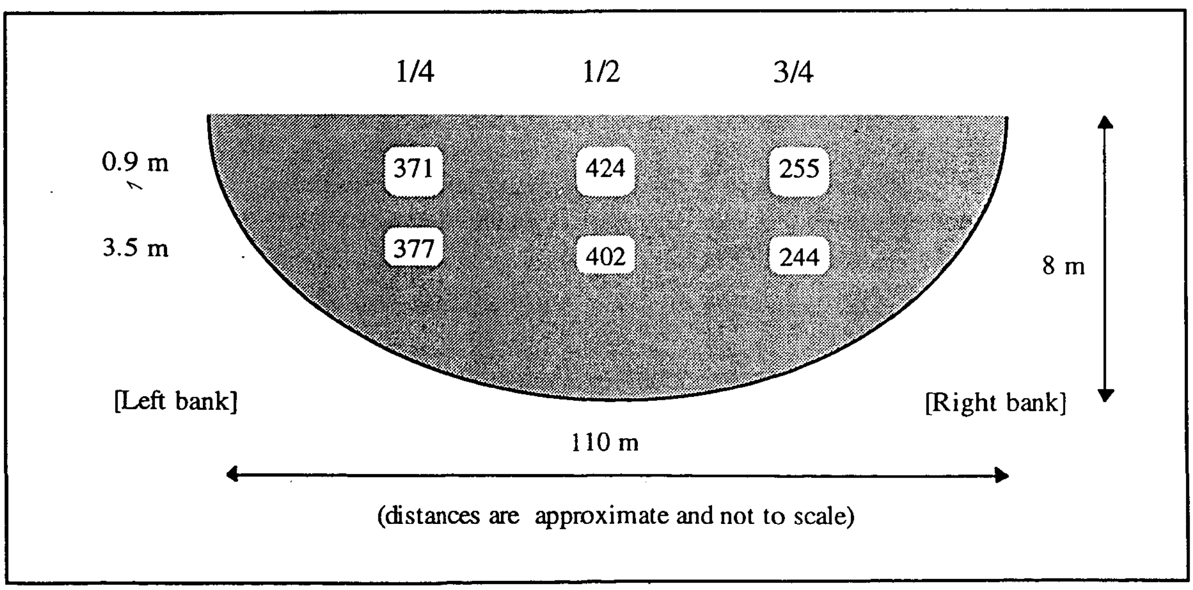

Fig. 4. Distribution of suspended sediment (mg/L) in discharge at Tung Oil on 30 January, 1994 (1637–1807 h) at three points on the stream transect.

Distribution of suspended sediment in flood waters

During the early stages of the flood event, SS concentrations at NT were higher mid-stream and towards the left bank than near the right bank, but there was little difference between respective concentrations at depths of 0.9 and 3.5 m (Fig. 4). Under near peak-flow conditions on 31 January,

depth-integrated samples taken at NI, SI and SU showed river waters to be well mixed across the stream (particularly at SI and SU), with relatively small differences only in SS concentrations between samples taken at three points on the transect at each site (Table 3). This was in contrast to some previous smaller events (when for example, SS concentrations near the left bank at SI were approximately double those near the right bank) and probably reflected the relatively intense, uniform and widespread nature of the rainfall in the lower catchment during cyclone Sadie.

Table 3. Cross-sectional variation in concentrations of suspended sediment (mg/L) under near peak-flow conditions during cyclone Sadie.

Site	**Point on stream transect**		
	1/4	1/2	3/4
Johnstone R. at Innisfail	1298	1207	1265
South Johnstone R. at Innisfail	1109	1118	1065
South Johnstone R. upstr. S. Johnstone mill	1301	1181	1113

Fluxes of suspended sediment and nutrients

Almost 200 000 tonnes of SS were discharged in flood waters of the Johnstone River system over the four day period of the Sadie flood event (Table 4); most of the discharge occurring on 31 January (Fig. 2). More of the total SS, N and P flux came from the Johnstone River (58%, 57% and 60%, respectively), while more (57%) of the OC came from the South Johnstone River.

Table 4. Fluxes of suspended sediment and nutrients from the Johnstone River system during the cyclone Sadie flood event[1]

	Flux (tonnes)		**Total flux**
	NI	**SI**	**(NI + SI)**
Suspended sediment	111 206	81 346	192 552
Nitrogen	492	366	858
Phosphorus	189	125	314
Organic C	958	1256	2214

[1] Fluxes calculated for the four day period from 30 January to 2 February 1994, inclusive.

Of the total nutrient flux from the Johnstone River system, 97% of the total P and 85% of the total N were associated with the SS load (Table 5). In contrast, much less of the OC (45%) was associated with the SS load, particularly in the Johnstone River. Averaged across the two rivers, the soluble N fraction (15% of the total N flux) contained oxidised N (46%), organic N (42%) and ammonium-N (12%).

Table 5. Relative amounts of nutrients associated with the suspended sediments in river discharges during cyclone Sadie

	Sediment-bound nutrients (%)[1]		
	NI	**SI**	**NI + SI**
Nitrogen	87	81	85
Phosphorus	97	97	97
Organic carbon	34	54	45

[1] (sediment-bound nutrient flux / total nutrient flux) x 100

Conclusions

Cyclone Sadie provided an ideal opportunity to measure nutrient and SS fluxes in the lower Johnstone River system during a major flood event and provide quantitative information on loads discharged to the GBR. Nutrient and SS concentrations were very much higher than measured under baseflow conditions, but concentrations fell quickly as flow rates decreased. Since the cyclone followed a period of prolonged dry weather the levels of soil and nutrient loss in the catchment may have been higher than would occur during a flood event following more typical weather conditions. The nutrient loads in flood waters were predominantly associated with the SS load. Thus management options for reducing fluxes of both sediment and nutrients should focus on minimising soil movement in the catchment. Sources of the SS/nutrients during the flood event were not determined but probably included soil erosion (e.g. from farm paddocks, road-side verges and urban runoff); stream bank erosion and mobilised stream-bed sediments.

Acknowledgements

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References

ANZECC (1992) Australian Water Quality Guidelines for Fresh and Marine Waters, Australian and New Zealand Environment Council draft document, November 1992

APHA (1989) Standard Methods for the Examination of Water and Wastewater, 17th edition, Clesceri LS, Greenberg AE, Trussell RR (eds), American Public Health Association, Washington, USA

Cosser PR (1989) Nutrient concentration-flow relationships and loads in the South Pine River, south-eastern Queensland, I, Phosphorus loads. Aust. J. Mar. Freshwater Res. 40: 613-630

Cullen P, Rosich R, Bek P (1978) A Phosphorus Budget for Lake Burley Griffin and Management Implications for Urban Lakes, Aust. Water Res. Council Tech. Paper No. 31, Aust. Gov. Publ. Serv., Canberra, ACT, Australia

Doherty JE, Brebber LJ (1992) Datman and Login: software for data editing, processing and display, Queensland Department of Primary Industries unpublished draft manual

Hunter HM (1993) Fluxes of Nitrogen, Phosphorus and Suspended Solids in the Johnstone River System: April 1991 – March 1993, Queensland Department of Primary Industries Agricultural Chemistry unpublished report ACU 93.19

Wong WT, Alexander D, Eades G (1992) Proc. Workshop, Sediment Sampling, Brisbane, Oct. 1992, Queensland Department of Primary Industries, Report No. 000830. PR/1