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Hydrology and suspended sediment of the Ngarradj catchment, Northern Territory: 2004–2005 wet season monitoring

DR Moliere, MJ Saynor, KG Evans & BL Smith

August 2005

(Release status – unrestricted)

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Hydrology and suspended sediment of the Ngarradj catchment, Northern Territory: 2004–2005 wet season monitoring

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1 Introduction

The Jabiluka uranium deposit is located in the catchment of Ngarradj in the wet-dry tropics of the Northern Territory, Australia (fig 1). Ngarradj is a major downstream right-bank tributary of Magela Creek, which flows directly into the Magela Creek floodplain. The Magela Creek and floodplain are listed as Wetlands of International Importance under the Ramsar Convention and recognised under the World Heritage Convention.

The Ngarradj catchment will be the first to be affected should any impact occur as a result of mining operations at Jabiluka. In 1998 the Environmental Research Institute of the Supervising Scientist (***eriss***) established a stream gauging network to determine the pre-mining hydrological and suspended sediment transport characteristics of the Ngarradj catchment. Stream gauging stations were installed upstream (Upper Main – UM; East Tributary – ET) and downstream (Swift Creek – SC) (fig 1) of Jabiluka (Erskine et al 2001). Gauging stations were also operated at tributaries North, Central and South (TN, TC and TS respectively) (fig 1) by Energy Resources of Australia (ERA), however, data collected from these stations are not discussed in this report. A site description of the three ***eriss*** gauging stations is given in Appendix A.

The purpose of this report is to present the hydrology and mud concentration data collected from the three stream gauging stations within the Ngarradj catchment during the 2004-05 Wet season. These data were collected as part of the long-term study on the impact of mining at Jabiluka on the Ngarradj catchment.

1.1 Study area

The Ngarradj catchment is located approximately 230 km east of Darwin and 20 km north-east of Jabiru (fig 1). Oenpelli, Arnhem Land, is a further 20 km north-east of the Ngarradj catchment. Located in the monsoon tropics climatic zone, the catchment experiences a distinct wet season from October to April, and a dry season for the remainder of the year. Stream flow, as a consequence, is highly seasonal. The average annual rainfall for the region is approximately 1410 mm (Moliere et al 2002).

Ngarradj main channel flows in a well-defined valley in a northwesterly direction from the Arnhem Land sandstone plateau to the Magela Creek floodplain with one major right bank tributary (East Tributary) (fig 1). Both the upper reaches of the Ngarradj main channel and East Tributary flow in essentially a bedrock confined channel on the plateau (fig 1). There are several left bank tributaries that drain predominantly wooded lowland areas and have significantly smaller areas of bedrock and escarpment than the main channel and East Tributary. The total catchment area of the Ngarradj catchment (upstream of SC) is approximately 43.6 km^2.

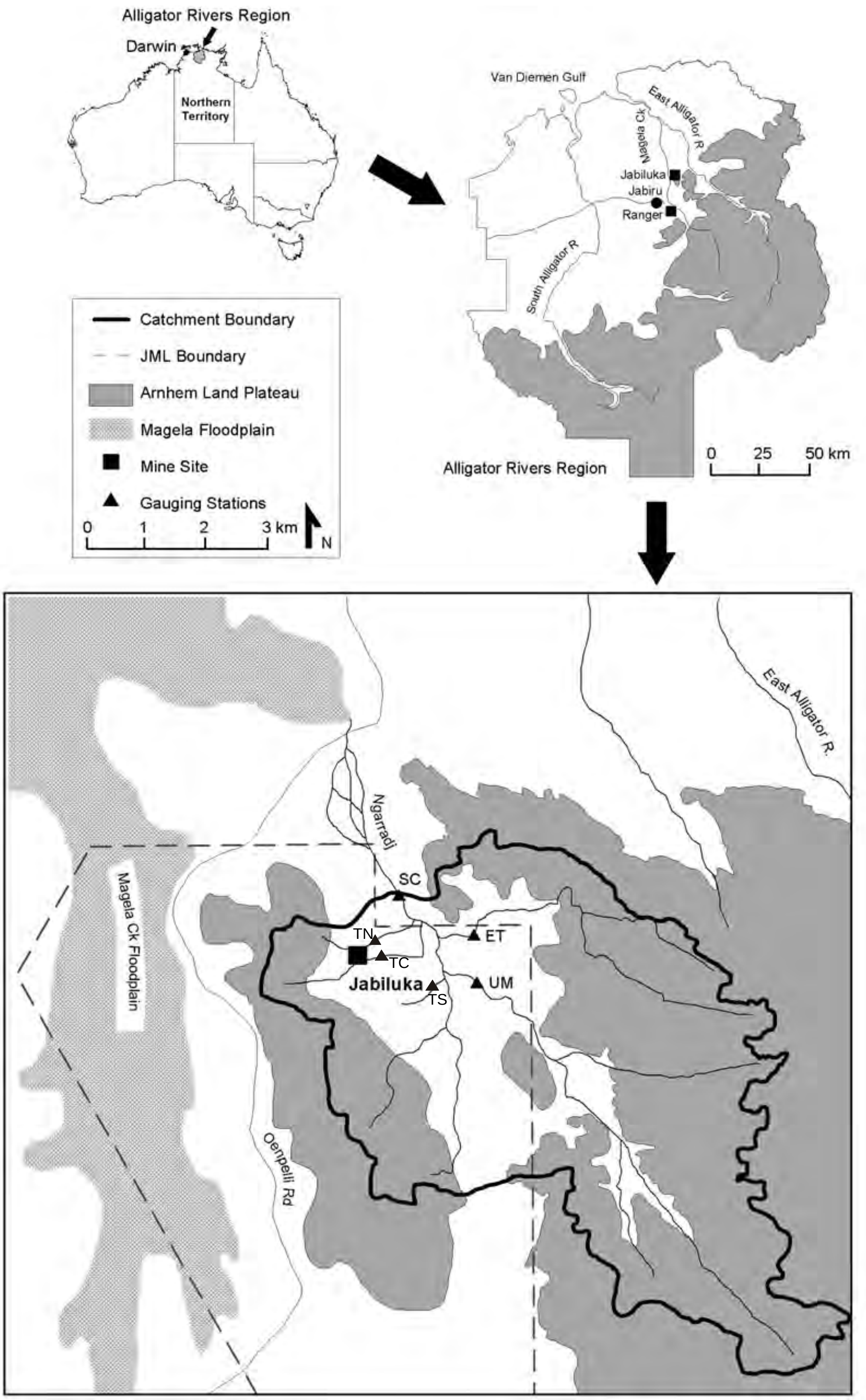


Figure 1 The Ngarradj catchment showing the location of Jabiluka and the gauging station sites

2 Rainfall data

A 0.2 mm tipping bucket rain gauge was installed at each ***eriss*** gauging station within Ngarradj catchment and readings were taken at 6-minute intervals (Saynor et al 2001). Continuous rainfall data were also collected at Jabiluka (fig 1) by Energy Resources of Australia. The total rainfall (September to June) at each gauging station (SC, UM and ET) and at Jabiluka during the 2004-05 wet season is shown in table 1. The total annual rainfall over the Ngarradj catchment, determined using the Thiessen Polygon method (Thiessen 1911) to spatially average the total rainfall measured at the three gauging stations and Jabiluka during the year, was 1356 mm (table 1).

Table 1 Total rainfall over the Ngarradj catchment during 2004–05 derived using the Thiessen Polygon method

Station	Rainfall (mm)	Polygon area (% of total area)
SC	1356	0.324
UM	1358	0.482
ET	1353	0.105
Jabiluka	1351	0.089
Total [ARI]	1356 [1:1.7]	1.00

To determine an annual recurrence interval (ARI) of the total annual rainfall volume observed at the Ngarradj catchment, it was necessary to compare the observed data to long-term rainfall data collected in the region. Moliere et al (2002) showed that rainfall at the Ngarradj catchment is not significantly different to that at Oenpelli, which has a period of record of approximately 90 years. The annual rainfall at the Ngarradj catchment during 2004–05 of 1356 mm, compared to the Oenpelli rainfall distribution, corresponds to a 1:1.7 rainfall year (fig 2), which is below average for the catchment.

Figure 3 shows the monthly rainfall distribution for the Njarradj catchment during 2004–05. Except for December, every monthly rainfall at Ngarradj was below the mean monthly rainfall for Oenpelli (fig 3).

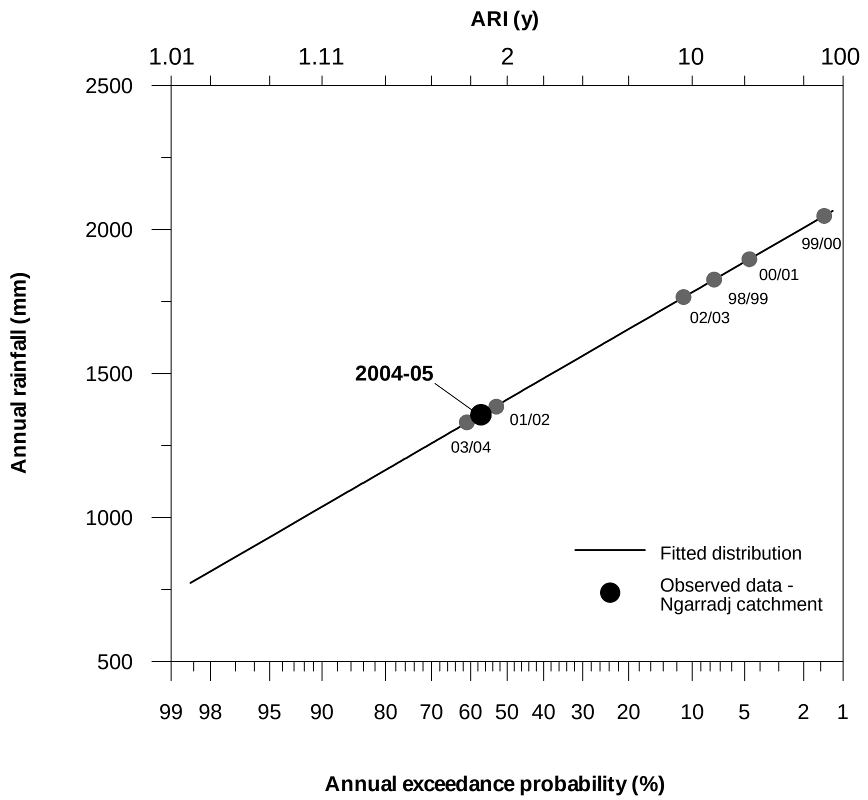


Figure 2 Annual rainfall frequency curve for Oenpelli. The 2004-05 rainfall, along with the previous six years of rainfall, for the Ngarradj catchment are also shown.

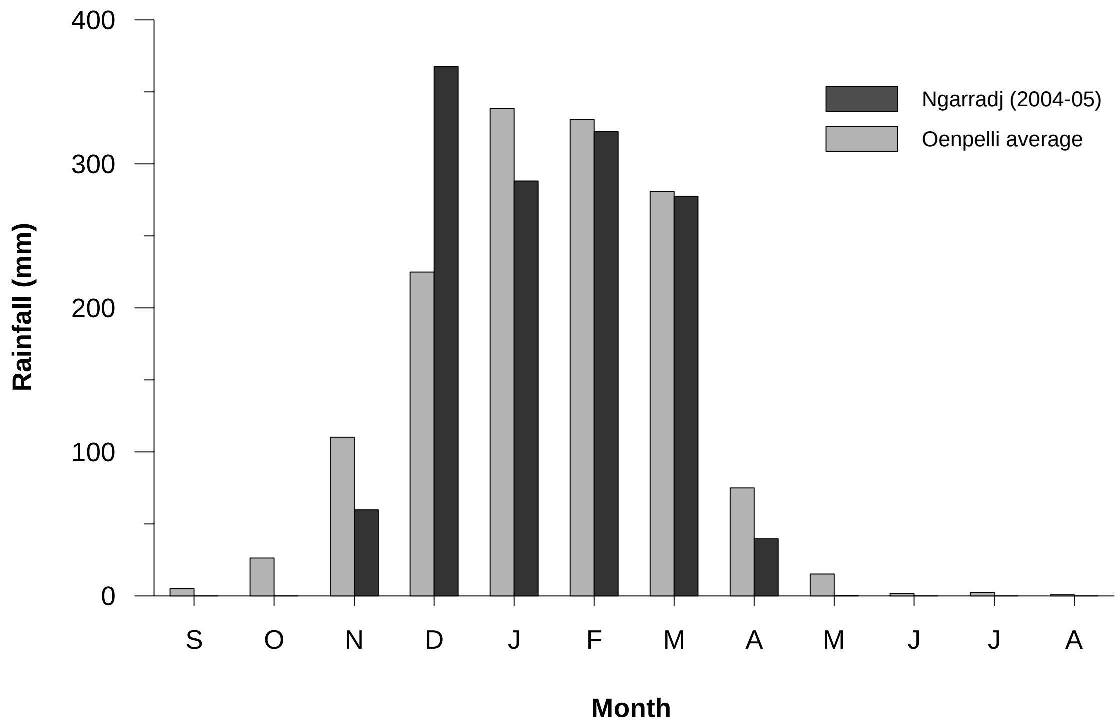


Figure 3 Monthly rainfall distribution for the Ngarradj catchment during 2004–05. Average monthly rainfall for Oenpelli is also shown.

3 Runoff data

Stage height (m) at each gauging station was measured at 6-minute intervals by both a pressure transducer and a shaft encoder (Saynor et al 2001). During the 2004–05 wet season, the shaft encoder was the primary instrument for stage data collection, while the data collected by the pressure transducer were used as back-up.

The stage data measured by either the shaft encoder or the pressure transducer were checked against the true stage of the stream (gauge board) at regular intervals throughout the period of flow (approximately monthly). These checks showed that the instrument readings were generally similar to that at the gauge board. Table 2 shows the similarity between stage measured at the gauge board and that measured by the shaft encoder, the primary instrument for continuous stage collection, at each site during 2004–05.

Table 2 Stage measured at the gauge board and by the shaft encoder at each site during 2004–05

	Stage height (m)					
	SC		**UM**		**ET**	
Date	Gauge board	Shaft encoder	Gauge board	Shaft encoder	Gauge board	Shaft encoder
29-Dec-04	0.43	0.43	No flow	-	0.35	0.31
06-Jan-05	0.72	0.73	0.45	0.45	0.38	0.39
24-Jan-05	0.48	0.48	0.24	0.24	0.28	0.29
24-Feb-05	0.46	0.46	0.26	0.27	0.29	0.29
23-Mar-05	0.97	0.95	0.61	0.61	0.47	0.47
19-Apr-05	0.27	0.27	0.13	0.12	0.20	0.18
16-May-05	0.17	0.17	0.04	0.03	NF	NF
Average Difference		<0.01 m		<0.01 m		<0.01 m

Two low-flow velocity-area gaugings were taken at each station throughout the 2004–05 wet season. These gaugings fit on the rating curves (fig 4) (Moliere et al 2001) and, therefore, it is considered that the previously-derived rating curves were appropriate for the 2004–05 wet season at each site.

In summary, the fact that (1) stage data collected by the shaft encoder at each site is aligned with the gauge board (table 2), and (2) the velocity-area gaugings fit well along the previously fitted rating curves (fig 4), suggests that the hydrograph for each station during 2004-05 should be considered reliable. The complete hydrograph for each gauging station for the 2004-05 wet season is shown in figure 5. The total runoff for each wet season at the gauging stations, determined as the area under the hydrograph, is given in table 3. Total rainfall, the runoff period and antecedent rainfall (defined as the amount of rainfall before the start of streamflow) at each gauging station are also given in table 3.

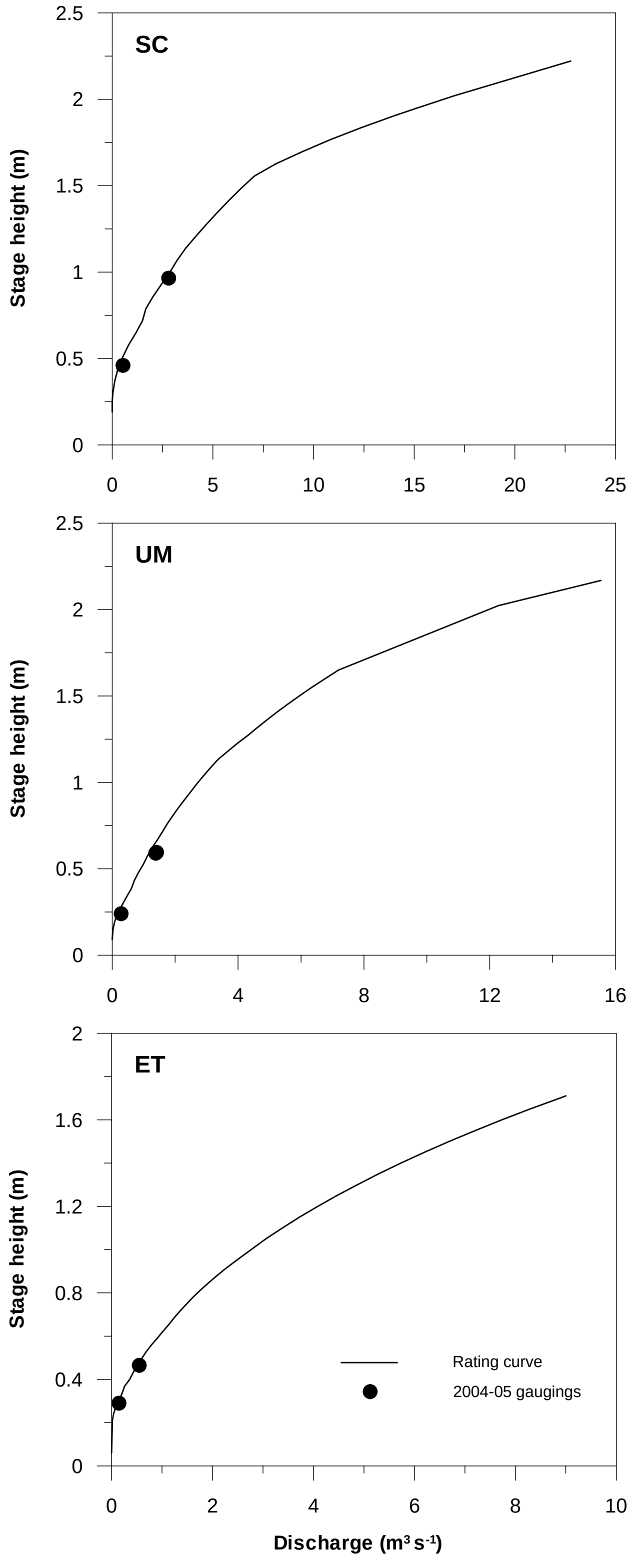


Figure 4 Rating curves for SC, UM and ET with the gauging points taken during 2004–05 shown

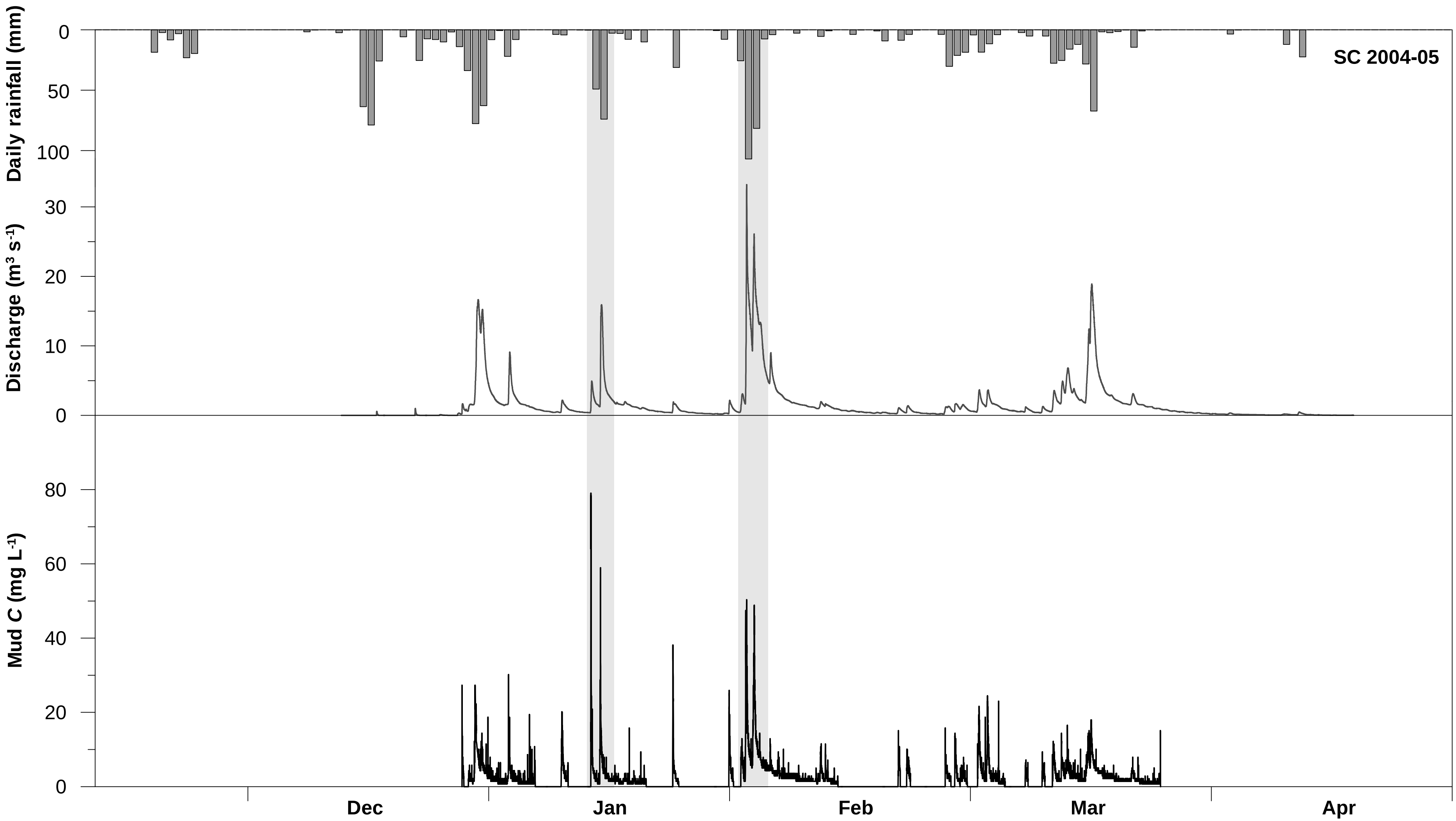


Figure 5a Discharge, mud *C* and daily rainfall for the 2004-05 wet season at SC. Two periods of high mud transport are indicated by the shaded regions.

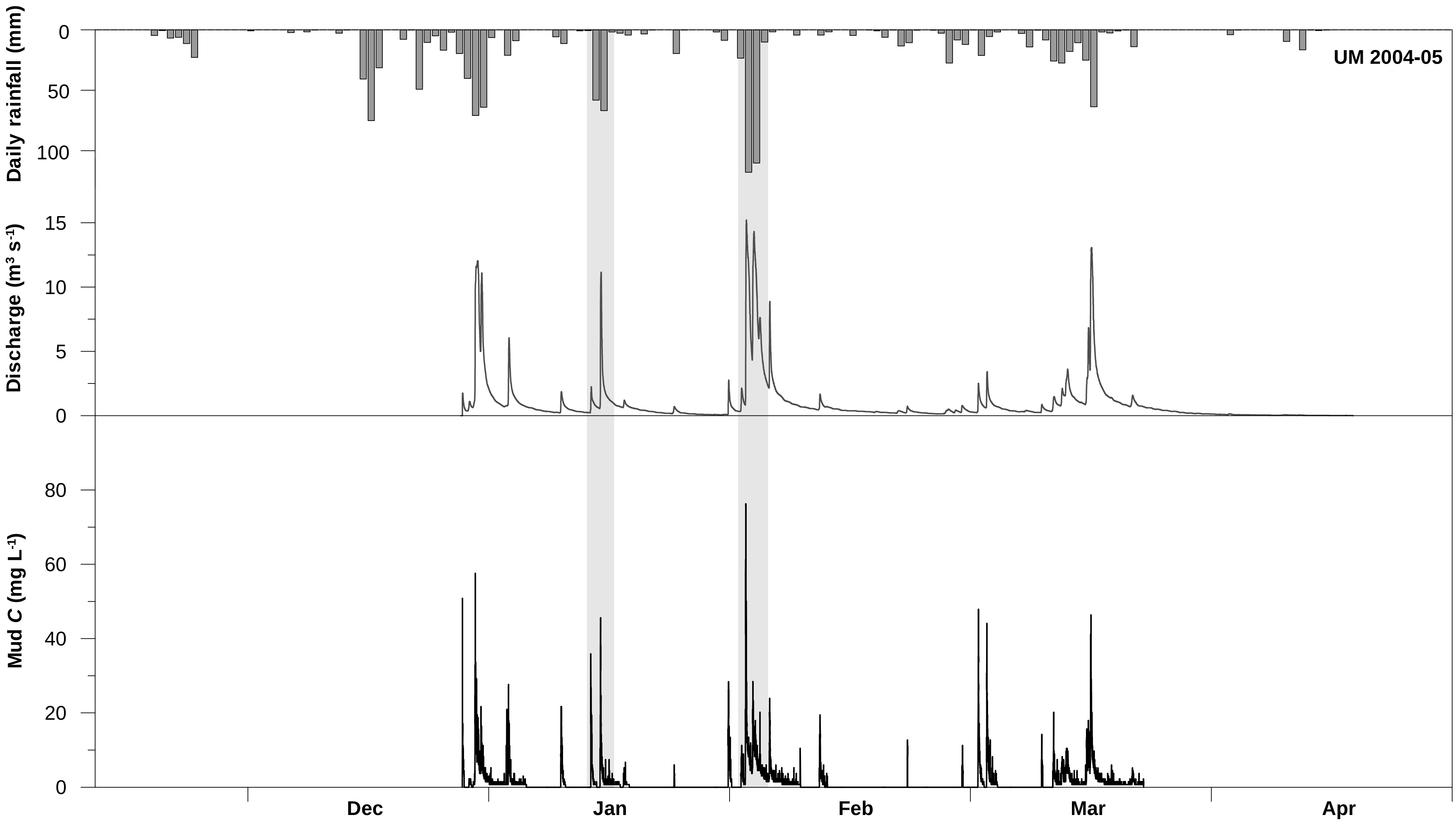


Figure 5b Discharge, mud *C* and daily rainfall for the 2004-05 wet season at UM. Two periods of high mud transport are indicated by the shaded regions.

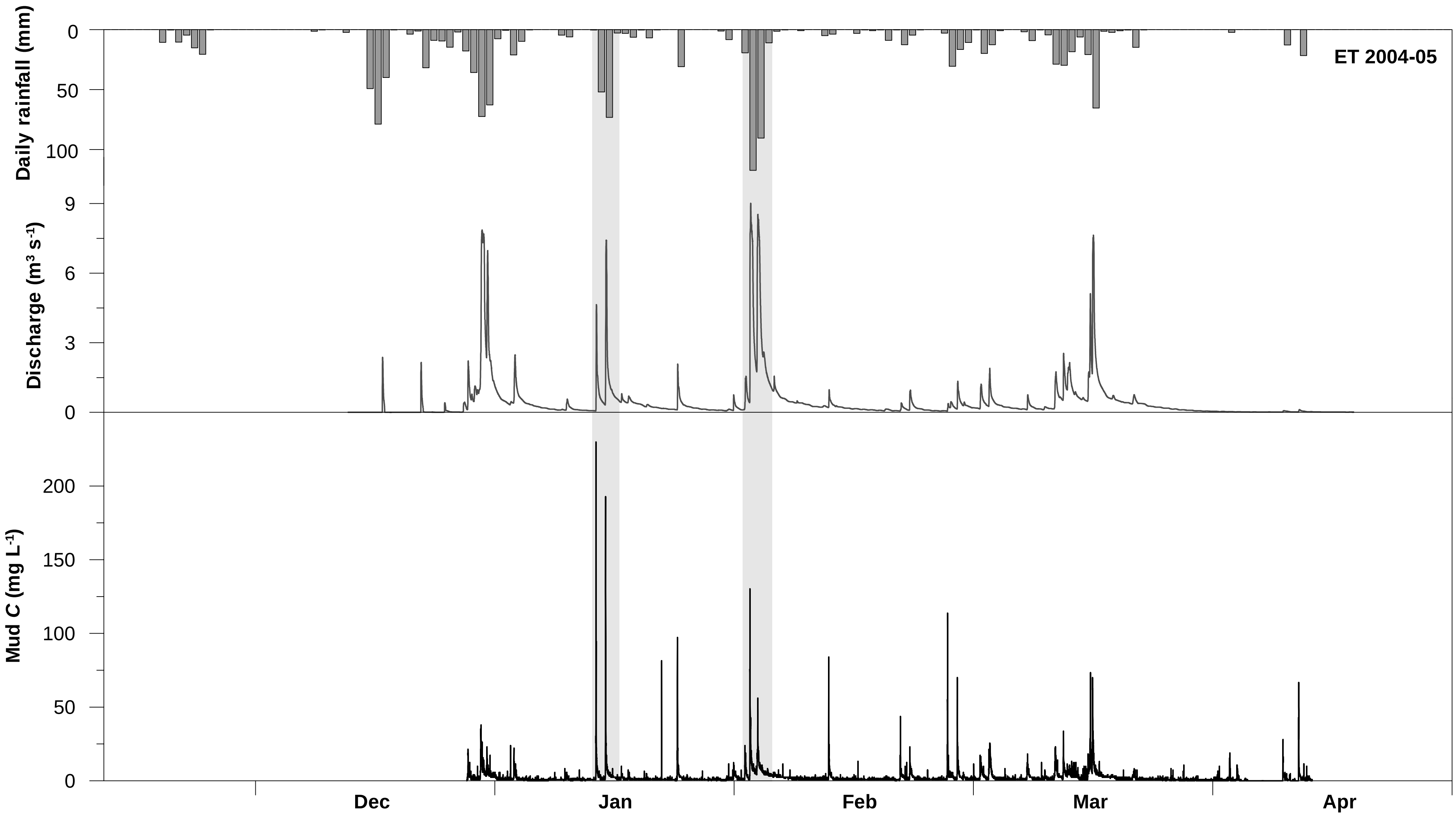


Figure 5c Discharge, mud *C* and daily rainfall for the 2004-05 wet season at ET. Two periods of high mud transport are indicated by the shaded regions.

Table 3 Total annual rainfall, runoff and mud load at each gauging station for the 2004–05 wet season

Station	Total rainfall (mm)	Antecedent rainfall (mm)	Runoff period	Total runoff (ML) [Peak discharge (m^3s^{-1})]	Total mud load (kg) [Peak mud *C* (mg L^{-1})]
SC	1356	254	23 Dec* – 20 May	16755 [33.2]	106 [79.1]
UM	1358	318	29 Dec – 20 May	8839 [15.2]	51.8 [76.3]
ET	1353	239	23 Dec* – 10 May	4712 [9.0]	34.3 [230]

* Pulse of flow occurred late on 18 December 2004 and then flow ceased less than 12 hours later

4 Suspended sediment data

During five years of monitoring at Ngarradj between 1998 and 2003, stream suspended sediment concentration was determined by collecting water samples during the annual hydrograph and filtering and drying the samples in the laboratory (Erskine et al 2001, Evans et al 2004). The collection of water samples and the subsequent laboratory process was very labour intensive and expensive, particularly for monitoring suspended sediment movement over the long-term (ie an entire wet season). A common alternative to suspended sediment sample collection is the continuous monitoring of turbidity in streams as an indirect measure of suspended sediment concentration (ie Walling 1977, Gippel 1989, Glysson & Gray 2002). Turbidity and mud concentration (mud *C*) data collected at SC, UM and ET during the 2003-04 wet season showed that the use of turbidimeters is a robust and efficient technique to monitor mud movement within the Ngarradj catchment (Moliere et al 2005a,b). Moliere et al (2005b) fitted significant relationships to convert the turbidity data to mud *C* data for each station.

During the 2004–05 wet season, turbidity data were collected at each station at 6-minute intervals throughout the annual hydrograph by Analite turbidity probes. The probes were calibrated in the laboratory before installation using polymer-based turbidity standards. To validate the previously fitted turbidity-mud *C* relationships (and support any elevated readings), water samples were collected by a stage-activated pump sampler. These water samples were downloaded approximately monthly and mud *C* in each sample were determined by filtering and oven drying techniques (Erskine et al 2001). The pump samplers were programmed to only collect water samples during the rising stage of the event hydrograph as it has been shown that most of the mud movement generally occurs before the peak of the hydrograph. Only one pump sampler (with a capacity of 24 water samples) was installed at each site and, therefore, no more than 24 samples were collected per site visit. (To avoid the issue of leaving water samples in the sampler for long periods of time, the pump sampler was also programmed to commence the collection of samples two weeks before the next site visit.)

Figure 6 shows that the turbidity-mud *C* data collected during 2004–05 lie above the previously fitted turbidity-mud *C* relationships (Moliere et al 2005b). There is no obvious explanation for this behaviour. However, it does highlight the importance of the continued collection of water samples over several wet seasons to validate or, in this case, revise the turbidity-mud *C* relationship. Nevertheless, the correlation between turbidity and mud *C* data collected during 2004–05 is strong. The new turbidity-mud *C* relationships fitted for each site are given in figure 6.

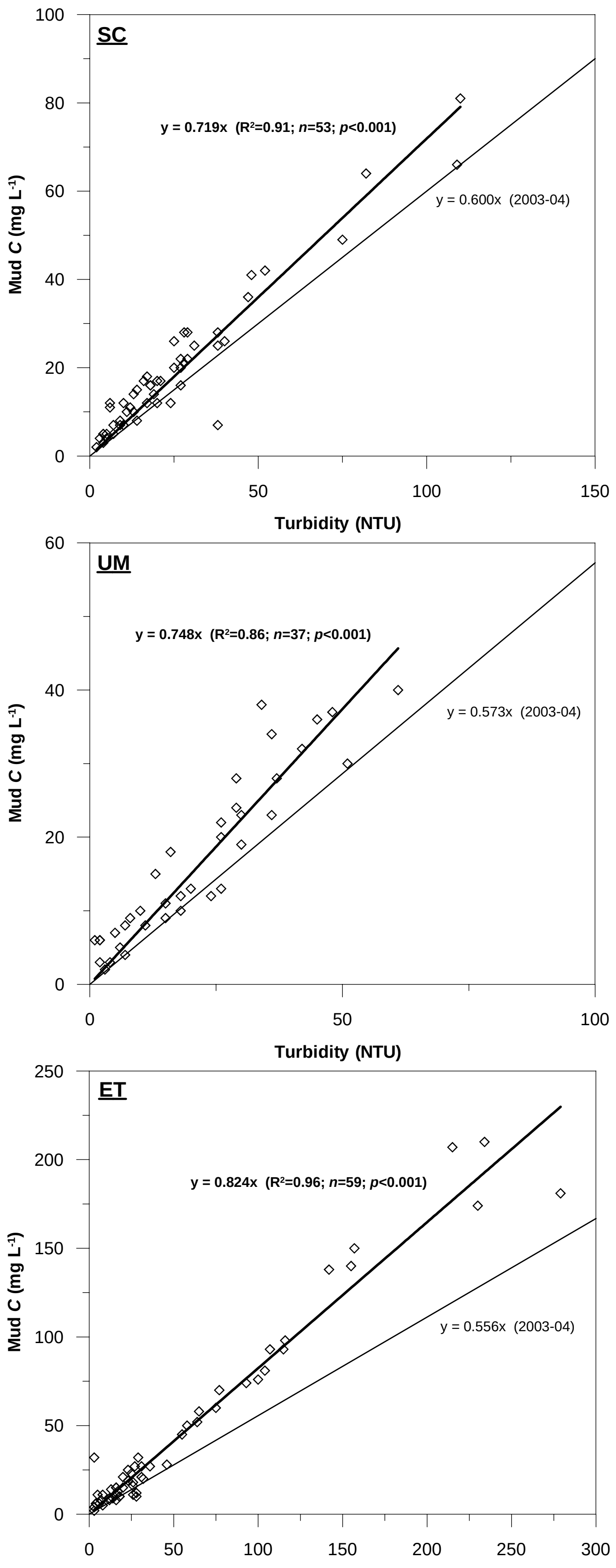


Figure 6 Relationships between turbidity and mud concentration for each gauging station. The previously fitted relationships derived using 2003-04 data (Moliere et al 2005b) are also shown.

The continuous stream mud *C* at SC, UM and ET for the 2004–05 wet season, collected using turbidimeters and converted to concentration using the revised regression relationships (fig 6), is shown in figure 5. Total annual mud load at each station, defined as the area under the sedigraph, is given in table 3.

4.1 High magnitude events

During 2004–05 there were two periods of high sediment transport within the Ngarradj catchment (highlighted in figure 5 as shaded regions) and these occurred during 14-16 January and 2–4 February 2005. The hydrograph and sedigraph for these periods at SC, UM and ET are shown in figures 7, 8 and 9 respectively. Total rainfall, peak discharge and maximum rainfall intensities over several durations for these events are given in table 4.

14–16 January 2005

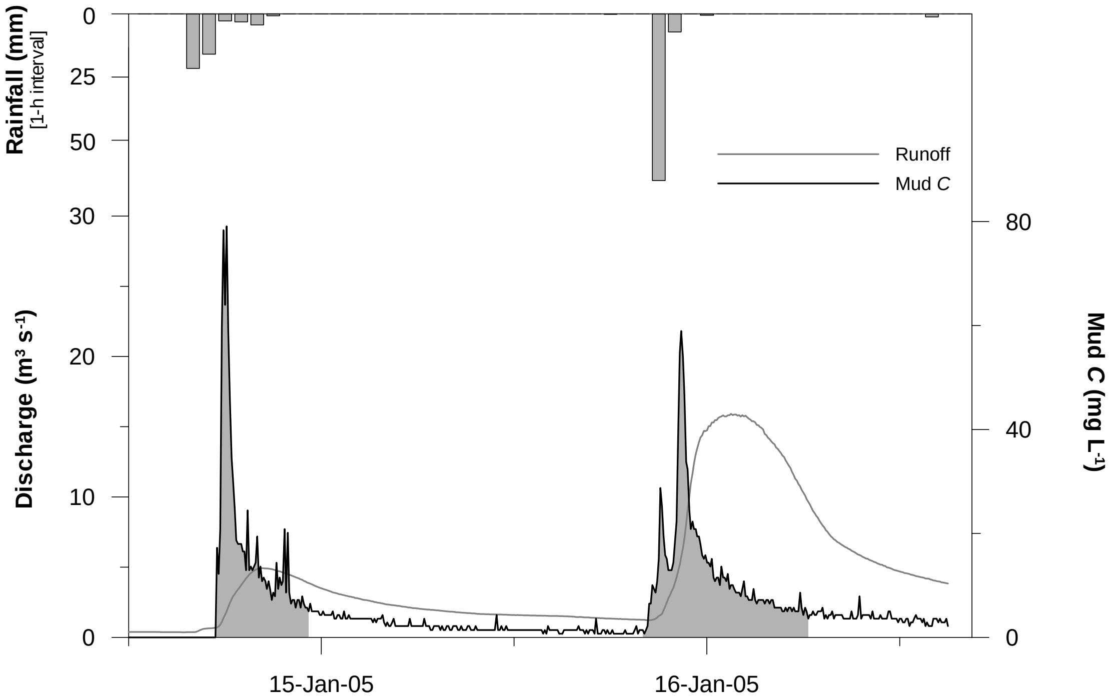
Peak mud *C* associated with these two mud pulses were the highest and second highest peaks of the year at both SC and ET (fig 5). However, the intensity of the rainfall (table 4) does not seem to reflect the high magnitude of the peak in mud *C* at both stations, particularly that associated with the first storm event. Given that the corresponding peaks in mud *C* at UM are relatively low, it can be assumed that the large mud pulses observed at SC are primarily attributed to the very high mud concentrations observed at ET. Particularly in the case of the first storm event, it is likely that the centre of the storm was located over the upper catchment area of East Tributary on the Arnhem Land plateau, where rainfall intensity would have been significantly greater than that recorded at the rain gauges. This is supported by the fact that rainfall over the western part of the Ngarradj catchment (recorded at Jabiluka) during this first event was very minor (24 mm with a maximum rainfall intensity of <15 mm h^{-1} over a one hour duration), compared to that recorded at the three gauging stations (table 4).

2–4 February 2005

During this period, two succesive, significant storm events occurred within one 24 h period. The combined rainfall total for the Ngarradj catchment within the 24 h period was 194 mm, equivalent to a 1 in 12 y rainfall event (table 4). This is the largest 24 h rainfall total recorded at the Ngarradj catchment since monitoring commenced in 1998 (the previous highest was approximately 155 mm which occurred on 6–7 January 2003). At UM, the total rainfall recorded was 212 mm, greater than a 1:20 y event for a 24 h duration.

Rainfall intensity associated with the first storm event was relatively high over the 30 min, 60 min and 2 h durations (table 4). At UM, the rainfall was more intense with 61 mm recorded within the first half hour of rainfall (ie 122 mm h^{-1} rainfall intensity – equivalent to a greater than 1:13 y event). Peak runoff associated with the first storm event was the highest ever observed during the 7 y monitoring period at all three sites. (Peak runoff of the second event was the second highest ever recorded at SC and ET, and the third highest at UM.) At SC, peak discharge of this first event was higher than that observed by ERA during January 1998 – a flood event associated with rainfall generated from a rain depression over the Northern Territory (tropical cyclone ‘Les’) (Moliere et al 2002).

Peak mud *C* of the first mud pulse was the third highest for the year at SC and ET (behind the two mud pulses which occurred on 14–16 January 2005) and the highest for the year at UM. Total load for these two pulses were the highest and second highest for the year at all three sites (Appendix B). The combined mud load for these two events was greater than 40% of the total annual load at SC and more than 20% of the total annual load at UM and ET. Interestingly, the second pulse peaked at about the same time as the hydrograph at both SC and ET. It has been well documented that the peak of the sedigraph generally peaks before the hydrograph. As a result of this 'shift' in the timing of the mud C peak, the mud load measured at SC and ET is larger than the relatively low mud concentration observed during the event would indicate.



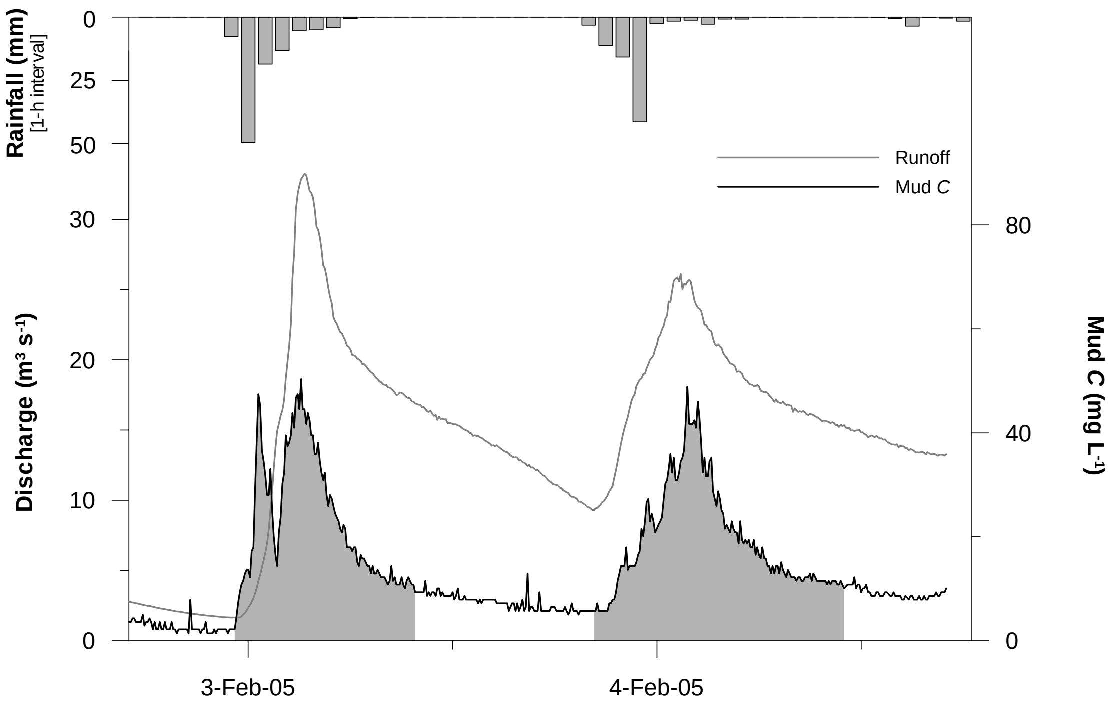


Figure 7 Hydrograph and sedigraph at SC during 14–16 January 2005 (Top) and 2–4 February 2005 (Bottom). The mud pulses associated with the storm events are indicated as shaded regions of the sedigraph.

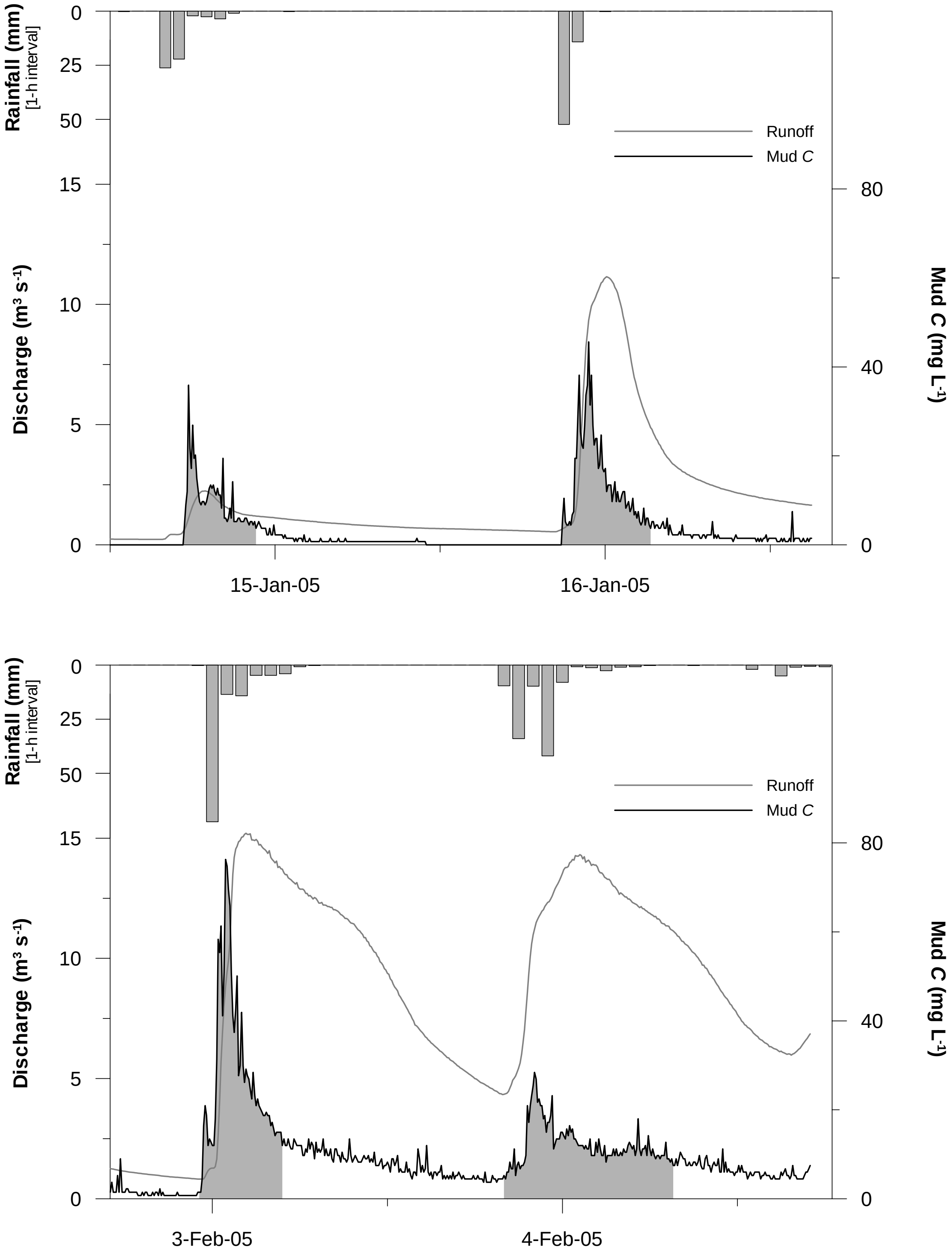


Figure 8 Hydrograph and sedigraph at UM during 14–16 January 2005 (Top) and 2–4 February 2005 (Bottom). The mud pulses associated with the storm events are indicated as shaded regions of the sedigraph.

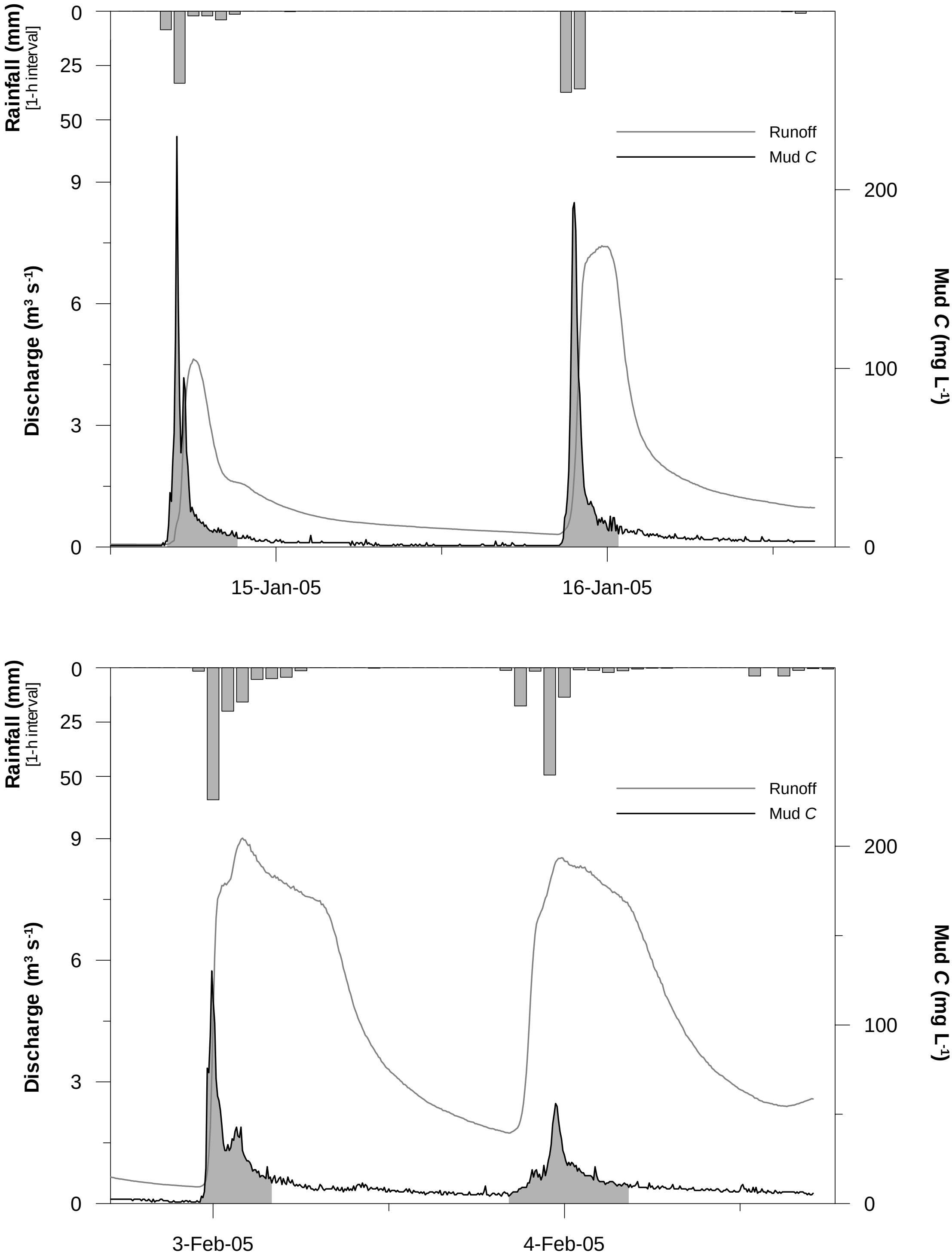


Figure 9 Hydrograph and sedigraph at ET during 14–16 January 2005 (Top) and 2–4 February 2005 (Bottom). The mud pulses associated with the storm events are indicated as shaded regions of the sedigraph.

Table 4 Description of the rainfall and runoff which contributed to the two periods of high sediment transport at each gauging station during 2004-05. Approximate annual recurrence intervals (ARI) for peak discharge and maximum rainfall intensity are also shown (if greater than 1:1 y).

Date	**Total rainfall (mm)**[(1)]	**Peak discharge ($m^3 s^{-1}$) [ARI (y)]**[(2)]			**Maximum rainfall intensity ($mm h^{-1}$) [ARI (y)]**[(3)]				
		SC	**UM**	**ET**	**Duration**				
					30 min	60 min	120 min	24 h	48 h
14 Jan	54	4.9	2.2	4.6 [1.3]	69.1 [1.1]	42.2	21.8		
15 Jan	70	15.9 [1.9]	11.2 [2.0]	7.4 [2.5]	84.3 [2.3]	64.5 [3.9]	34.9 [2.2]		
							Combined	-	2.6
02 Feb	111	33.2 [6.8]	15.2 [3.6]	9.0 [3.9]	102 [5.2]	63.2 [3.6]	39.4 [3.9]		
03 Feb	96	26.1 [4.2]	14.3 [3.1]	8.5 [3.4]	58.5	46.7 [1.1]	29.5 [1.2]		
							Combined	8.1 [12.1]	4.8 [6.3]

(1) Total rainfall and corresponding rainfall intensities were assumed to occur over the whole Ngarradj catchment and were determined using the Thiessen Ploygon method to spatially average the rainfall measured at the three stations

(2) ARI for peak discharge was estimated from frequency curves derived in Moliere et al (2002)

(3) ARI for maximum rainfall intensities were estimated from intensity-frequency-duration (IFD) curves for the Ngarradj catchment derived by the Bureau of Meteorology (pers comm. 2000)

5 Impact assessment

Evans et al (2004) derived mud (defined in the report as 'fine suspended-sediment') concentration values for the Ngarradj catchment, which when exceeded, should trigger a management response. These concentration values were derived in accordance with The Australian and New Zealand water quality guidelines (WQG) (ANZECC & ARMCANZ 2000). Evans et al (2004) used a Before-After-Control-Impact, paired difference design (BACIP) (Stewart-Oaten et al 1986, 1992, Humphrey et al 1995) where the upstream sites UM and ET are before impact in a spatial sense and the downstream site SC is after impact in a spatial sense. If elevated values observed at SC are not observed at UM or ET it is assumed that the source is from the mine-site catchment and investigations are required to identify the source.

Evans et al (2004) derived these numerical trigger values using mud *C* data determined by collecting water samples throughout the event hydrograph and filtering and drying the samples in the laboratory. The parameter used to assess impact was the monthly median mud *C* value at each site. During the 2004–05 wet season, relatively few water samples were collected compared to previous years and these were primarily used to validate the turbidity-mud *C* relationship. It is considered that the water samples collected this year are too few to assess against the trigger values derived by Evans et al (2004). In addition, these trigger values cannot be simply applied to the continuous mud *C* data collected by the turbidimeter. This is because the mud *C* data used to derive the trigger values were collected almost entirely during runoff events and only very few data were collected during baseflow conditions. The continuous turbidity data were collected throughout the entire annual hydrograph (ie during both runoff events and baseflow conditions). Therefore, the monthly median mud *C* values for the two datasets cannot be compared. As a result, a variation of the BACIP analysis previously done by Evans et al (2004) was used this year for impact assessment using event mud loads derived from mud *C* data collected by the turbidimeter.

5.1 BACIP

This assessment uses an event-based BACIP design where SC and the combination of UM and ET are treated as paired sites and the comparison of ratios is used to assess impact. Therefore, only events where event loads were determined for all three stations were used in the analysis. Event load data collected during 2003–04 using the turbidimeter were also included. During 2003–04 and 2004–05 there were 18 events (nine in both years) with complete event load data collected at all three stations. (Event load data for all events observed at each station during 2004–05 are given in Appendix B.)

Figure 10 shows that the mean ratio of UM + ET mud load to SC mud load for the two-year monitoring period is approximately one. The events of 'interest' are those that lie greater than one standard deviation below the mean ratio (ie <-1 SD) because these are events where elevated mud loads are measured at SC relative to the combined load at UM and ET. During 2004-05 there were two events below the –1 SD line (fig 10) and these were associated with the high magnitude events on 2–4 February discussed in Section 4.1 above. As a result of the unusually high discharges that occurred during these events, it is possible that the contribution of mud load from the small tributaries within the western part of the catchment area (ie TN, TC and TS – fig 1), which are generally minor, may have been relatively high at these intense flow conditions. Nevertheless, the event-based BACIP analysis indicates that the ratios of event mud load observed at UM and ET to SC during these two events are not considered as outliers as they are within the 95% prediction intervals (ie within two standard deviations) of the mean ratio.

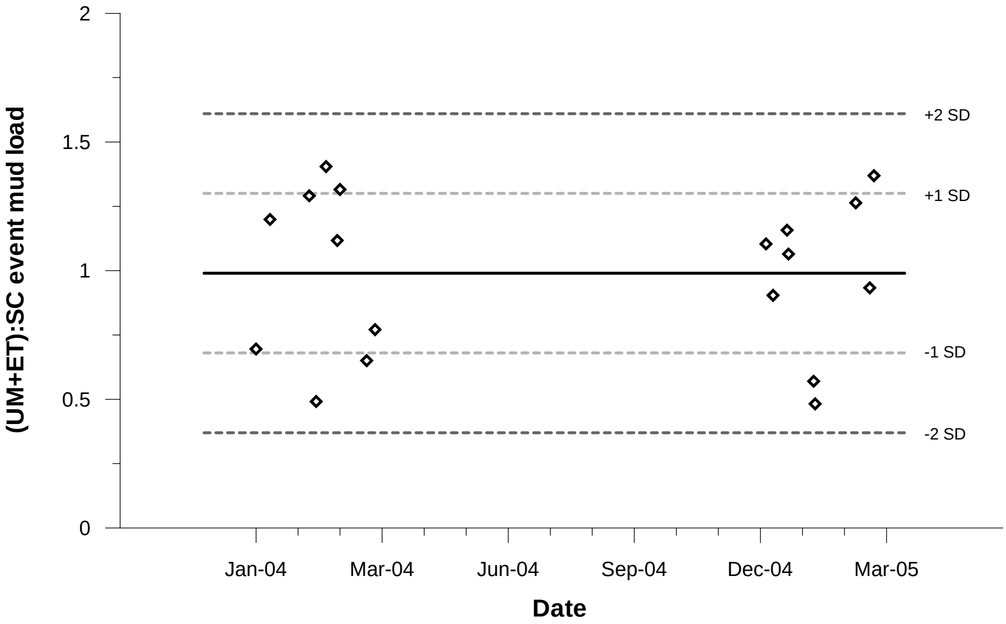


Figure 10 Temporal variation of the ratio of event mud loads measured at UM and ET to that at SC during 2003-04 and 2004-05 (indicated as ◇). The mean ratio and associated standard deviations are also shown.

6 Conclusions

Continuous rainfall, runoff and mud concentration data were collected within the Ngarradj catchment at SC, UM and ET. Approxiately 40-60 water samples were collected at each site to validate the turbidity-mud concentration relationships previously fitted using 2003–04 data. The data indicated that the turbidity-mud concentration relationship changed at all three sites from the previous year. There is no obvious explanation for this behaviour. However, it does highlight the importance of the collection of water samples over several wet seasons to validate or, in this case, revise the turbidity-mud concentration relationship.

An event-based before-after-control-impact paired site design (BACIP) was used for impact assessment on mud loads downstream of Jabiluka. The analysis indicated that there were two events with a mud load measured at SC that was relatively high compared to the combined load measured at UM and ET. These events were associated with two of the largest runoff events ever observed within the Ngarradj catchment throughout the seven-year monitoring period. However, the ratio of event mud load measured at UM and ET to that measured at SC during these two events was not significantly different to the other events.

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Appendix A Gauging station details

Date installed: November 1998

Custodian: Environmental Research Institute of the Supervising Scientist

Data collected: Rainfall, stage and turbidity at 6-minute intervals and water samples collected during the rising stage of some runoff events (to determine suspended sediment concentration for the calibration of the turbidimeter)

Equipment: Rainfall – Hydrological Services 0.2 mm tipping bucket rain gauge

Stage – Unidata starlogger with optical shaft encoder (primary) and Hawk water level pressure transducer (secondary)

Turbidity – Analite turbidimeter

Water samples – Gamet automatic pump sampler (capacity of 24 samples)

Data storage: Hydstra database (maintained by D Moliere, HEP)

Download frequency: Approximately monthly

Station location:

Site	Area (km^2)	Decimal degrees [WGS84]		AMG [Zone 53]	
		Lat	Long	Lat	Long
SC	43.6	12.491467	132.92257	274228.928	8618214.04
UM	18.8	12.503583	132.93395	275478.828	8616883.80
ET	8.5	12.495117	132.93317	275384.543	8617819.20

Staff post:

At all three stations the staff post in the creek channel has an assumed datum with 2 x 1.0 m gauge plates (assumed datum is 0.0 – 1.0 m and 1.0 – 2.0 m) (figs A1 to A3). At SC and UM there is a third staff post located on the bank with a 1 x 1.0 m gauge plate (assumed datum is 2.0 – 3.0 m) (figs A1 and A2).

Figure A1 Staff posts and gauge plates at SC

Figure A2 Staff posts and gauge plates at UM

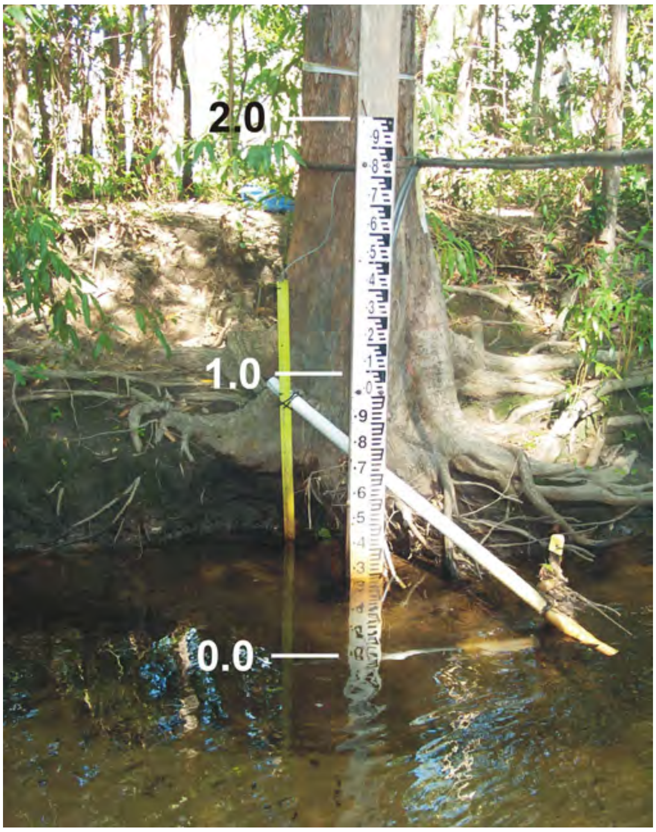

Figure A3 Staff post and gauge plates at ET

Appendix B Mud pulse characteristics

Table B.1 Rainfall, discharge and mud characteristics for each mud pulse event observed at SC during 2004–05. Shaded events indicate the periods of high sediment transport discussed in Section 4.1.

Date	Rain		Discharge		Mud pulse				
	Total rainfall (mm)	Start of rainfall	Peak discharge (m^3)	Time of Q_p	Peak mud C ($mg\ L^{-1}$)	Time of mud C_p	Duration	Mud load (g)	Mean mud C ($mg\ L^{-1}$)
30 Dec	93	21:54	16.64	16:24	27.3	07:18	31 Dec 04:36 – 31 Dec 18:42	5545	12.1
04 Jan	18	08:12	9.10	15:18	30.2	11:42	04 Jan 09:00 – 04 Jan 17:00	1142	6.8
10 Jan	4	21:06	2.17	04:06	20.1	02:48	11 Jan 00:54 – 11 Jan 08:30	494	9.3
14 Jan	49	15:18	4.93	20:12	79.1	18:06	14 Jan 17:24 – 14 Jan 23:12	1190	18.0
15 Jan	74	20:00	15.91	01:30	59.0	22:24	15 Jan 20:00 – 16 Jan 06:18	4640	12.7
24 Jan	31	20:24	1.94	24:00	38.1	23:00	24 Jan 22:24 – 25 Jan 02:42	293	11.7
31 Jan	0	-	2.17	00:42	25.9	23:12	31 Jan 22:00 – 01 Feb 03:54	435	11.8
02 Feb	104	22:36	33.22	03:18	50.3	03:06	02 Feb 23:12 – 03 Feb 09:48	18007	23.1
03 Feb	81	19:30	26.11	01:24	48.9	01:48	03 Feb 20:18 – 04 Feb 11:00	20897	19.5
05 Feb	4	20:36	9.01	03:24	12.9	01:30	05 Feb 23:48 – 06 Feb 04:30	970	7.7
12 Feb	5	00:06	1.97	09:30	10.8	08:36	12 Feb 01:54 – 12 Feb 13:48	311	4.2
12 Feb	1	19:48	1.66	23:24	11.5	22:42	12 Feb 21:12 – 13 Feb 01:30	124	5.0
28 Feb	21	22:36	1.69	05:00	14.4	02:12	01 Mar 01:06 – 01 Mar 08:12	280	6.9
03 Mar	18	19:18	3.65	02:48	21.6	01:54	03 Mar 21:30 – 04 Mar 07:42	1105	10.0
04 Mar	11	21:24	3.64	04:48	24.4	03:12	04 Mar 23:18 – 05 Mar 08:48	1103	10.0
14 Mar	17	04:48	4.93	11:36	14.4	08:12	14 Mar 06:00 – 14 Mar 14:42	745	5.9
17 Mar	48	21:12	18.91	03:00	18.0	00:06	17 Mar 21:18 – 18 Mar 08:12	6477	9.9

Table B.2 Rainfall, discharge and mud characteristics for each mud pulse event observed at UM during 2004-05. Shaded events indicate the periods of high sediment transport discussed in Section 4.1.

Date	Rain		Discharge		Mud pulse				
	Total rainfall (mm)	Start of rainfall	Peak discharge (m^3)	Time of Q_p	Peak mud C ($mg\ L^{-1}$)	Time of mud C_p	Duration	Mud load (g)	Mean mud C ($mg\ L^{-1}$)
30 Dec	93	21:54	11.63	11:06	57.6	08:18	31 Dec 05:42 – 31 Dec 12:36	3915	16.3
04 Jan	22	08:18	6.04	13:00	27.7	11:24	04 Jan 09:30 – 04 Jan 15:48	809	7.9
10 Jan	11	20:54	1.86	01:30	21.7	00:30	10 Jan 23:30 – 11 Jan 06:24	370	9.3
14 Jan	58	15:24	2.24	18:54	35.9	17:42	14 Jan 17:18 – 14 Jan 22:36	320	10.0
15 Jan	67	20:06	11.16	00:06	45.6	22:48	15 Jan 20:48 – 16 Jan 03:18	2636	14.3
31 Jan	0	-	2.77	21:42	28.4	21:12	31 Jan 20:00 – 01 Feb 01:18	480	12.2
02 Feb	115	22:54	15.21	02:18	76.3	00:54	02 Feb 23:06 – 03 Feb 04:48	6216	28.0
03 Feb	110	19:42	14.32	01:12	28.4	22:06	03 Feb 20:00 – 04 Feb 07:36	6168	12.3
05 Feb	1	20:42	8.88	00:30	23.9	00:06	05 Feb 22:06 – 06 Feb 02:48	1293	10.4
12 Feb	4	00:18	1.67	06:42	19.4	06:54	12 Feb 04:36 – 12 Feb 10:18	226	7.5
03 Mar	21	19:30	2.51	00:12	47.9	00:18	03 Mar 22:42 – 04 Mar 04:54	707	15.1
04 Mar	6	21:30	3.42	02:00	44.1	01:18	05 Mar 00:00 – 05 Mar 06:18	876	13.9
14 Mar	21	05:00	2.12	10:48	8.2	10:12	14 Mar 05:36 – 14 Mar 13:36	199	3.9
17 Mar	45	21:18	13.07	02:12	46.4	00:24	17 Mar 22:00 – 18 Mar 06:00	5727	17.3

Table B.3 Rainfall, discharge and mud characteristics for each mud pulse event observed at ET during 2004-05. Shaded events indicate the periods of high sediment transport discussed in Section 4.1.

Date	**Rain**		**Discharge**		**Mud pulse**				
	Total rainfall (mm)	Start of rainfall	Peak discharge (m^3)	Time of Q_p	Peak mud C ($mg\ L^{-1}$)	Time of mud C_p	Duration	Mud load (g)	Mean mud C ($mg\ L^{-1}$)
30 Dec	92	22:12	7.87	09:42	37.9	06:48	31 Dec 03:12 – 31 Dec 11:24	2208	13.5
04 Jan	19	08:24	2.48	13:06	22.2	09:42	04 Jan 08:42 – 04 Jan 14:54	223	6.5
14 Jan	52	15:36	4.64	18:00	229.9	16:48	14 Jan 16:06 – 14 Jan 21:12	1057	30.0
15 Jan	73	20:18	7.43	23:36	192.8	21:36	15 Jan 20:30 – 16 Jan 00:48	2305	39.8
24 Jan	31	20:36	2.08	22:30	97.2	21:36	24 Jan 20:42 – 24 Jan 23:48	331	28.8
02 Feb	115	22:54	9.01	02:00	130.2	23:54	02 Feb 23:06 – 03 Feb 04:00	4056	35.4
03 Feb	89	19:48	8.53	23:48	56.0	23:24	03 Feb 20:12 – 04 Feb 04:24	3913	17.5
12 Feb	4	19:48	0.97	22:18	84.0	20:42	12 Feb 20:18 – 12 Feb 23:18	134	21.1
21 Feb	13	19:30	0.40	22:54	43.7	20:30	21 Feb 19:30 – 21 Feb 22:54	16	11.9
27 Feb	26	17:12	0.38	20:18	113.7	18:18	27 Feb 17:30 – 27 Feb 21:30	67	25.1
28 Feb	16	22:36	1.34	01:06	70.0	23:36	28 Feb 22:54 – 01 Mar 03:48	220	15.6
04 Mar	13	21:24	1.90	01:18	25.5	01:00	04 Mar 21:30 – 05 Mar 07:06	517	12.5
14 Mar	21	04:48	2.54	07:36	33.8	07:12	14 Mar 05:36 – 14 Mar 12:42	496	10.2
17 Mar	46	21:12	7.64	01:18	70.0	22:36	17 Mar 21:18 – 18 Mar 04:06	3139	22.2