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Hydrology and suspended sediment transport in the Gulungul Creek catchment, Northern Territory: 2005–2006 wet season monitoring

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Hydrological and Geomorphic Processes Program

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Executive summary

Gulungul Creek is a small left bank tributary of Magela Creek. The Gulungul Creek catchment contains part of the Energy Resources of Australia Ranger Mine tailings dam and will receive sediment generated as a result of the removal and rehabilitation of the tailings area. It is important that the hydrology and sediment transport characteristics in the Gulungul Creek catchment are investigated before rehabilitation at the mine site occurs. Continuous rainfall, runoff and mud (<63 µm and >0.45 µm fraction) concentration data collected at gauging stations on Gulungul Creek during 2005–06 are presented in this report. The mud concentration data collected upstream and downstream of the mine during 2005–06 were used to establish preliminary trigger values for an event-based Before-After-Control-Impact, paired difference design (BACIP). This comparison of event mud loads observed upstream and downstream of the mine will be used to provide the basis for future impact assessment.

Acknowledgements

Grant Staben, Gary Fox and Anthony Sullivan assisted in the field with several of the velocity-area gaugings conducted at high flows. Jeff Klein, Klein Electronics Pty Ltd, helped with the installation and the maintenance of the gauging station equipment. Dr David Jones, ***eriss***, constructively and comprehensively reviewed the draft report.

Hydrology and suspended sediment transport in the Gulungul Creek catchment, Northern Territory: 2005–2006 wet season monitoring

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1 Introduction

As part of the data required to assess the success of rehabilitation of the Energy Resources of Australia (ERA) Ranger mine, it is proposed to determine the baseline loads of stream suspended sediment in the catchment of Magela Creek. The first stage of this work will involve the measurement of suspended sediment loads in Gulungul Creek. Gulungul Creek is a small left bank tributary of Magela Creek (Fig 1.1) and is one of the tributaries that will be the first to receive sediment generated from the rehabilitated mine site (Erskine & Saynor 2000). Given the location of Gulungul creek and the potential for erosion and transport of sediment into Magela Creek, the hydrology and sediment transport characteristics in Gulungul Creek are being investigated before rehabilitation at the mine site occurs.

Two gauging stations have been installed within the Gulungul Creek catchment, one station upstream (GCUS) and one downstream (GCDS) of the Ranger mine (Fig 1.1). The upstream station was installed in November 2003 and the downstream station was installed in February/March 2005 (Moliere et al 2005a). Stream suspended sediment is monitored at the stations using field-calibrated turbidimeters. Mud (fine suspended sediment) concentration data, derived from *in situ* continuous turbidity measured over several years, will be used to assess mine impact through the derivation of trigger values in accordance with The Australian and New Zealand water quality guidelines (WQG) (ANZECC & ARMCANZ 2000) using a BACIP approach. Flow data collected at the two stations will be used to determine long-term trends and assess flood risk both upstream and downstream of the Ranger mine. The long-term runoff record at station G8210012 (Fig 1.1) (a station operated between 1971 and 1993 along Gulungul Creek that is neither entirely upstream nor downstream of the Ranger mine site influence and now re-instumented) will be used to extrapolate the record at the relatively new station locations.

This report presents hydrology and mud concentration data collected from the stream gauging stations within the Gulungul Creek catchment during the 200506 wet season.

1.1 Study area

Gulungul Creek lies within the Alligator Rivers Region (ARR) and is approximately 160 km east of Darwin. Located in the monsoon tropics climatic zone, the Alligator Rivers Region 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 general flow period for Gulungul Creek is approximately six months (December to May) (Moliere 2005). The average annual rainfall for the region is approximately 1480 mm (Bureau of Meteorology 1999).

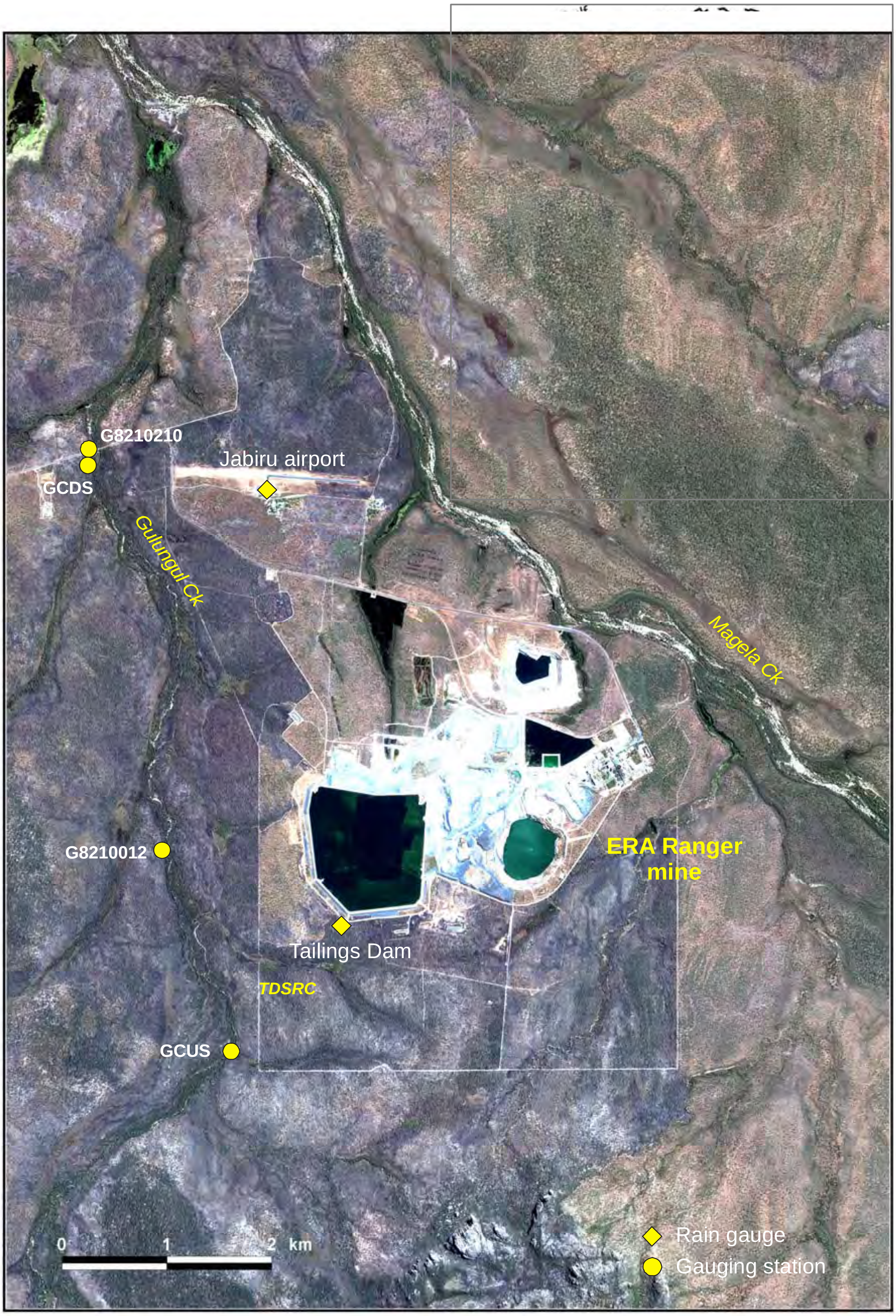

Figure 1.1 Location of Gulungul Creek and the ERA Ranger mine within the Alligator Rivers Region. The gauging stations and rain gauges in the area of interest are also shown. The image is an Ikonos satellite image taken June 2001.

Ranger mine lies partly within the catchment of Gulungul Creek (Fig 1.1). Current infrastructure in the catchment includes part of the tailings dam, part of the Arnhem Highway, mine access roads and minor tracks (Fig 1.1). It is very likely that part of the final rehabilitated landform will lie within the catchment (Crossing 2002). The total area of the Gulungul Creek catchment upstream of GCDS is approximately 66 km^2.

As stated above, a gauging station was operated on Gulungul Creek (G8210012) (Fig 1.1) between November 1971 and December 1993, a period of 22 years, by Natural Resources, Environment and the Arts (NRETA). Flow data were also collected by Duggan (1991) approximately 100 m upstream of the Arnhem Highway along Gulungul Creek between 1984 and 1987. Duggan's (1991) study site is a registered gauging station of NRETA (G8210210) (Fig 1.1). However, the flow data collected at G8210210 are unavailable as the data are stored within an obsolete spreadsheet package and cannot be read (Moliere 2005).

2 Rainfall data

A 0.2 mm tipping bucket rain gauge was installed at each of the three gauging stations along Gulungul Creek (GCUS, GCDS and G8210012) and readings were taken at 6-minute intervals. Daily rainfall data were also collected at Jabiru Airport (Fig 1.1) by the Bureau of Meteorology, which lies just outside the boundary of the Gulungul Creek catchment (Moliere 2005). Both daily and continuous rainfall data were collected at the Tailings Dam (Fig 1.1) by ERA, which lies within the Gulungul Creek catchment. However, the data collected at the Tailings Dam are not discussed in this report because the daily rainfall record since 2003 is relatively poor (Moliere et al 2005a). The total annual rainfall (September to August) at the three gauging stations and at Jabiru Airport during 2005–06 are shown in Table 2.1.

Table 2.1 Total annual rainfall over the Gulungul Creek region during 2005–06

Station	Rainfall (mm)
GCUS	2137(1)
G8210012	2172
GCDS	1803(2)
Jabiru airport	2107(3)

(1) Data partly infilled using G8210012 (see Section 2.1)
(2) No rainfall data collected until 17 November 2005
(3) Data obtained from Bureau of Meteorology website

To determine an annual recurrence interval (ARI) of the total annual rainfall volume observed at Gulungul Creek catchment, it was necessary to compare the observed data to long-term rainfall data collected in the region. Moliere et al (2005a) showed that rainfall in the Gulungul Creek catchment is not significantly different to that at Jabiru airport, which lies just outside the boundary of the Gulungul Creek catchment and has a period of record of 35 years.

The total annual rainfall over the Gulungul Creek catchment during 2005–06 of 2155 mm, determined simply as the average of the annual rainfall at GCUS and G8210012 (Table 2.1), compared to the Jabiru airport rainfall distribution, corresponds to a 1:38 rainfall year (Fig 2.1). That is, the annual rainfall over the catchment during 2005–06 is well above average for the region.

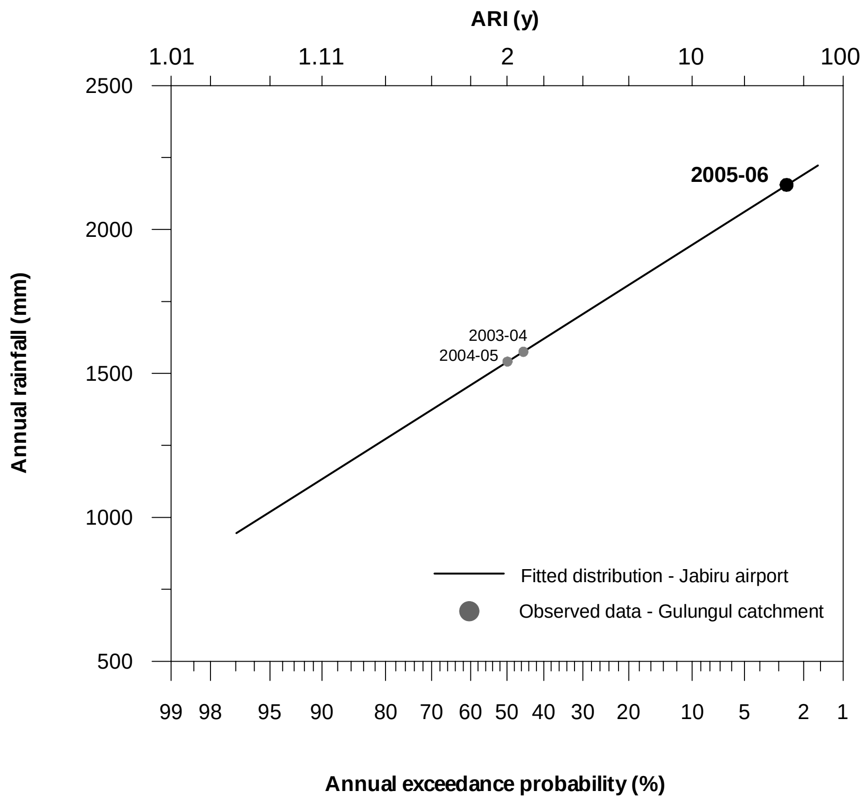

Figure 2.1 Annual rainfall frequency curve for Jabiru airport. The 2005–06 rainfall, along with the previous two years of rainfall, for the Gulungul Creek catchment are also shown.

2.1 Missing data

Periods where missing data occurred during the 2005–06 wet season at each rain gauge are given in Table 2.2. The reason for a gap, and whether the gap was infilled, is also documented. It should be noted that rainfall data collected at G8210012 were used to infill gaps in the rainfall record at GCUS (and *vice versa*) as Moliere et al (2005a) showed that rainfall data at these two stations are statistically similar.

Table 2.2 Missing data during 2005–06 at Gulungul Creek rain gauges

Station	Missing period	Comments
GCUS	19–21 Nov	Problem with the datataker. However, no rainfall was recorded during this period at G8210012
	22 Dec	Error in downloading data remotely. However, no rainfall was recorded during the 21 hour gap at G8210012.
	27 Dec – 11 Jan	Fuse blown at the station. Rainfall record at G8210012 was used to infill the gap (~ 240 mm).
	7–13 Mar	Problem with the datataker. Rainfall record at G8210012 was used to infill the gap (~ 230 mm).
G8210012	4–5 May	Error in downloading data remotely. However, no rainfall was recorded during the gap at GCUS.
GCDS	1 Sept – 17 Nov	Problem with the datataker. Rainfall data recorded at other stations during this period were not used to infill the gap (although approximately 110 mm fell at Jabiru airport, the closest station).
	12 Dec	Four hour gap due to station maintenance. No rainfall occurred during this period.
Jabiru airport	na	

3 Runoff data

Stage height (m) at GCUS and GCDS was measured at 6-minute intervals by both a pressure transducer and a shaft encoder. During the 2005–06 wet season, the shaft encoder was the primary instrument for data collection, while the data collected by the pressure transducer were used as back-up. (During the previous two years of monitoring, stage height data were only collected by pressure transducer at GCUS and GCDS.) Stage height at G8210012 was measured at 6-minute intervals by a pressure transducer. The stage data were checked against the stream gauge board at regular intervals throughout the period of flow (approximately fortnightly). These checks showed that the instrument readings were generally similar to that at the gauge board for each station.

3.1 Rating curves

A rating curve used to convert stage data to discharge data is required for each station. These rating curves are derived using velocity-area gaugings taken along a reasonably stable cross section at each station at various times over a range of flows.

GCUS

Velocity-area gaugings taken at GCUS throughout 2003–04 and 2004–05 were used to derive a rating curve for the site. However, no gaugings were taken at overbank flow during these two wet seasons and, therefore, the rating curve was not considered reliable for flood events. Moliere et al (2005a) recommended that several high flow velocity-area gaugings be taken during the 2005–06 wet season to further refine the 'top end' of the rating curve. Three gaugings were taken during overbank flow during the 2005–06 wet season at approximately 0.1 m, 0.2 m and 0.32 m above the floodplain level (Fig 3.1). (Furthermore, using Figure 3.1 we were able to estimate the bankfull stage at GCUS as approximately 1.6 m on the gauge board.) These three gauging points, when plotted on the rating curve previously fitted by Moliere et al (2005a) for GCUS (Fig 3.2), demonstrate that the high end of the rating curve extrapolated from the 2003–05 dataset is not appropriate. Consequently, a revised rating curve was fitted for GCUS (Fig 3.2) that is considered more reliable for high flow conditions than that fitted previously. The highest recorded stage height at GCUS during 2005–06 of 2.33 m, which occurred on 4 April 2006, is approximately 0.40 m above the highest velocity-area gauging and 1.93 m above cease-to-flow (Fig 3.3). Therefore, we have gauged to approximately 80% of the maximum flow for the 2005–06 wet season, which is a relatively high level of quantitation compared to most gauging stations throughout the tropical rivers region (Moliere 2007).

G8210012

A series of rating curves were previously fitted for G8210012 by NRETA using 107 velocity-area gaugings taken between 1971 and 1993. Moliere et al (2005a) used the most recent of these rating curves to derive the annual hydrograph for 2003–04 and 2004–05 at G8210012, as it was considered that velocity-area gaugings taken during 2003–04 and 2004–05 by ***eriss*** fit reasonably well on the rating curve. However, closer inspection of the gauging data, including several points taken during 2005–06, indicates that the rating curve fitted by NRETA is not entirely appropriate for the low to medium flow range for the 2005–06 wet season. Consequently, the rating curve was revised between cease-to-flow and approximately 2.3 m on the gauge board to better fit the velocity gaugings taken since 2003 (Fig 3.4). The rating curve for G8210012 is considered to be reliable for not only within-channel flows, but also for overbank flow conditions (to approximately 3.3 m stage height) as velocity-area gaugings were taken by NRETA at high flows well above bankfull stage (Fig 3.5).

Figure 3.5 also shows the level of the bottom of the rain gauge at G8210012. As discussed in Moliere et al (2005a), a major storm event occurred within the Gulungul Creek during the previous wet season on 2–3 February 2005 in which the resultant floodwaters rose above the bottom of the rain gauge (indicated as 'old RG' in Figure 3.5) and affected the tipping bucket mechanism. Before the 2005–06 wet season the rain gauge was elevated approximately 300 mm in order to prevent this happening again for most flood conditions. The highest peak flow for the 2005–06 wet season of 3.67 m, which occurred on 4 April 2006, was only just below the bottom of the rain gauge. It was recommended by Moliere et al (2005a) that the rain gauge needed to be elevated 500 mm above the old position (old RG in Figure 3.5) to ensure that a 1:30 y flood would not rise above the base of the rain gauge. Therefore, it is recommended that, prior to the 2006-07 wet season, the rain gauge is elevated a further 200 mm above its current position (RG in Figure 3.5).

GCDS

Velocity-area gaugings taken during 2005–06, combined with those taken during 2004–05, have been used to derive a rating curve for GCDS (Fig 3.6). Gaugings taken at medium to high flows during 2005–06 (ie above 1.2 m on the gauge board) were conducted at the road culvert approximately 100 m downstream of the station. It is considered that the discharge at the culvert would not be significantly different to that at the station, given that the catchment areas upstream of these two points are almost identical. The highest recorded stage height at GCDS during 2005–06 of 2.57 m, which occurred on 5 April 2006, is approximately 0.40 m above the highest velocity-area gauging and approximately 2 m above cease-to-flow (Fig 3.7). Therefore, we have gauged to approximately 80% of the maximum flow for the 2005–06 wet season, which, similar to GCUS, is relatively high compared to gauging stations throughout the tropical rivers region (Moliere 2006 in prep). It is considered that the rating curve for GCDS is reliable for most flow conditions.

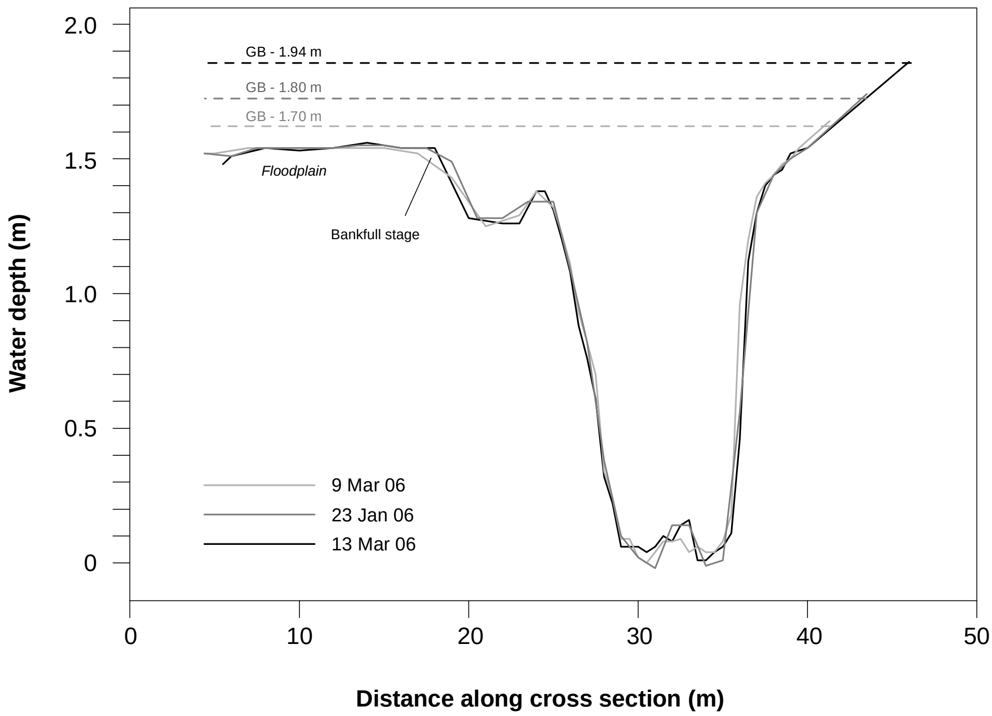

Figure 3.1 Cross sections at GCUS taken during three overbank flow gaugings during the 2005–06 wet season

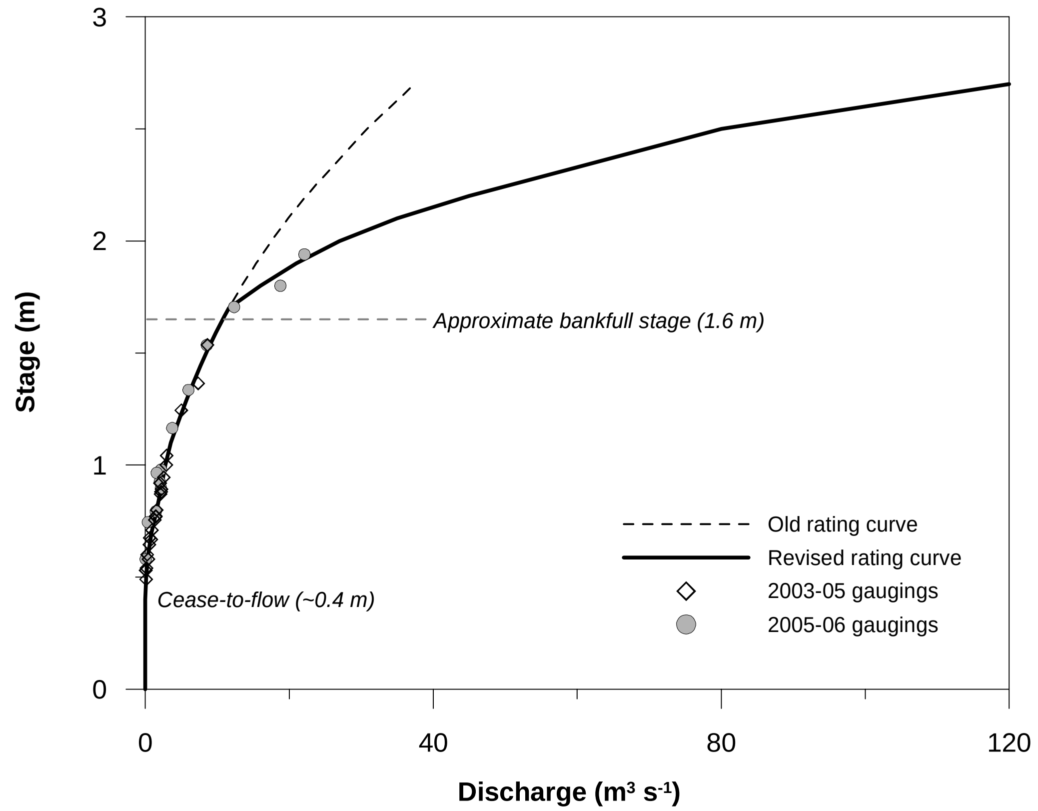

Figure 3.2 Revised rating curve for GCUS with the gauging points shown. Old rating curve for GCUS is also shown.

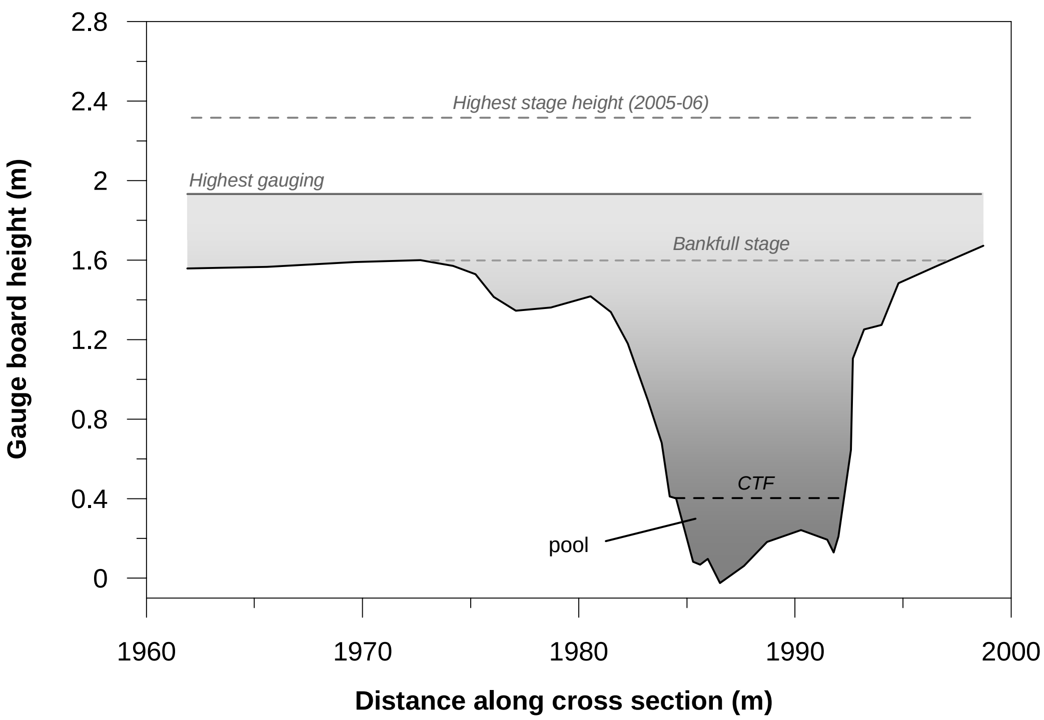

Figure 3.3 Cross section at GCUS taken during August 2005. CTF = cease-to-flow.

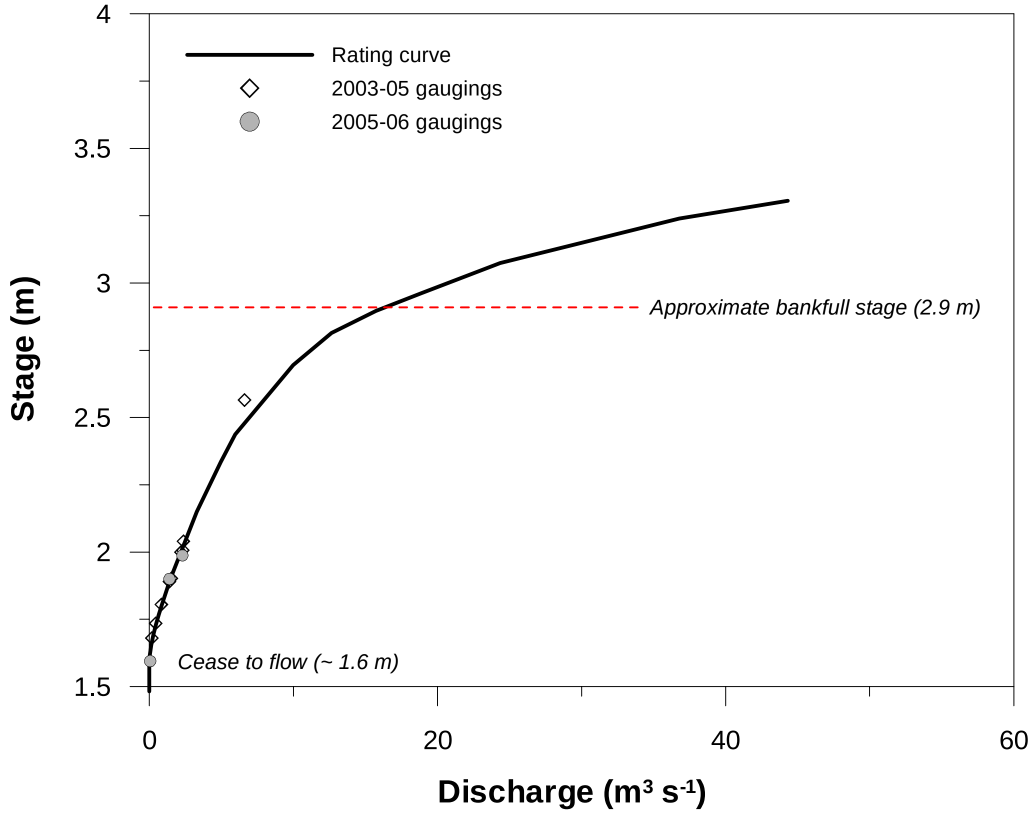

Figure 3.4 Rating curve for G8210012 with the gauging points shown

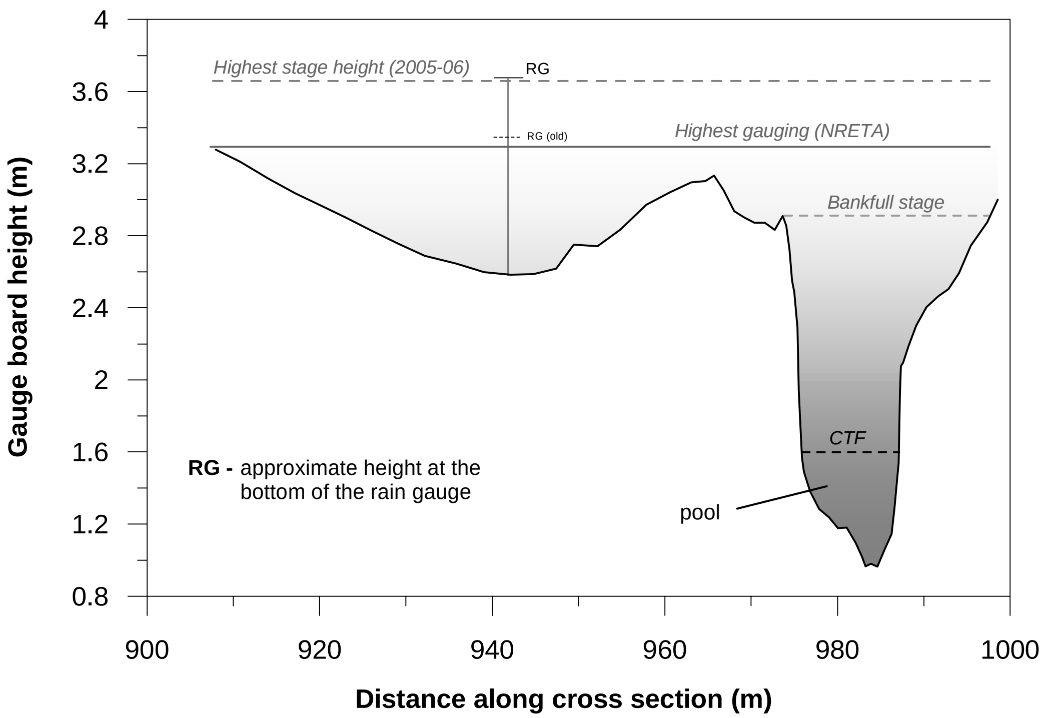

Figure 3.5 Cross section at G8210012 taken during August 2005. CTF = cease-to-flow.

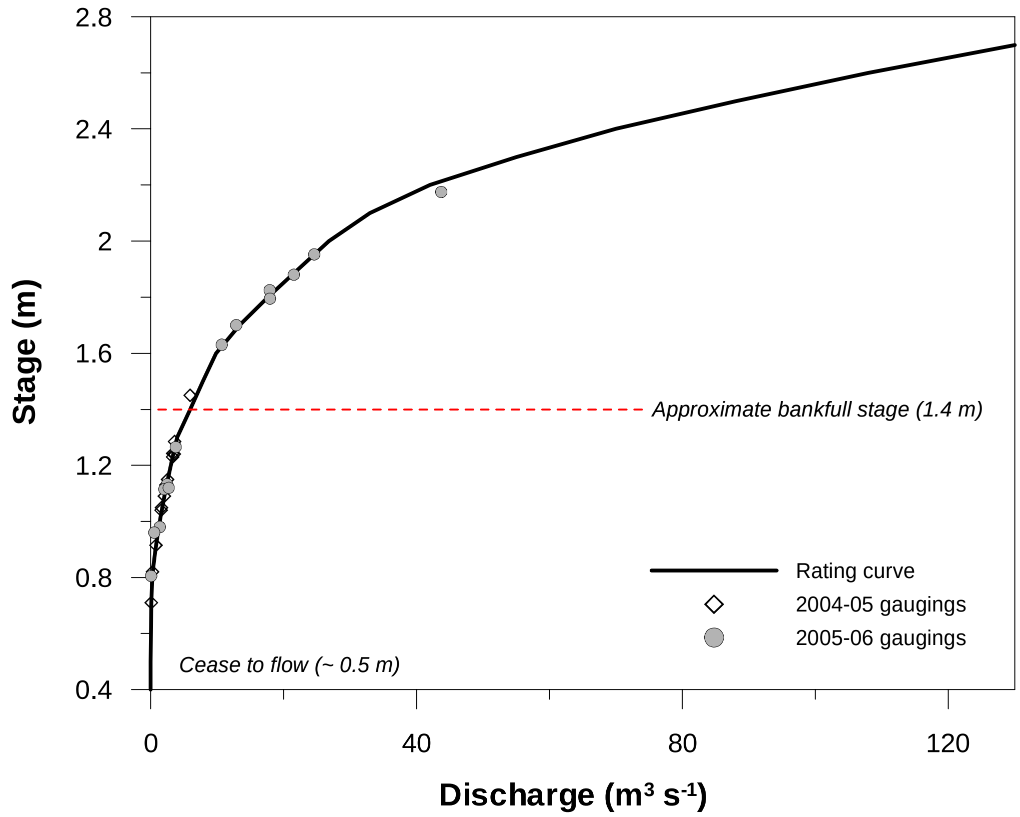

Figure 3.6 Rating curve for GCDS with the gauging points shown

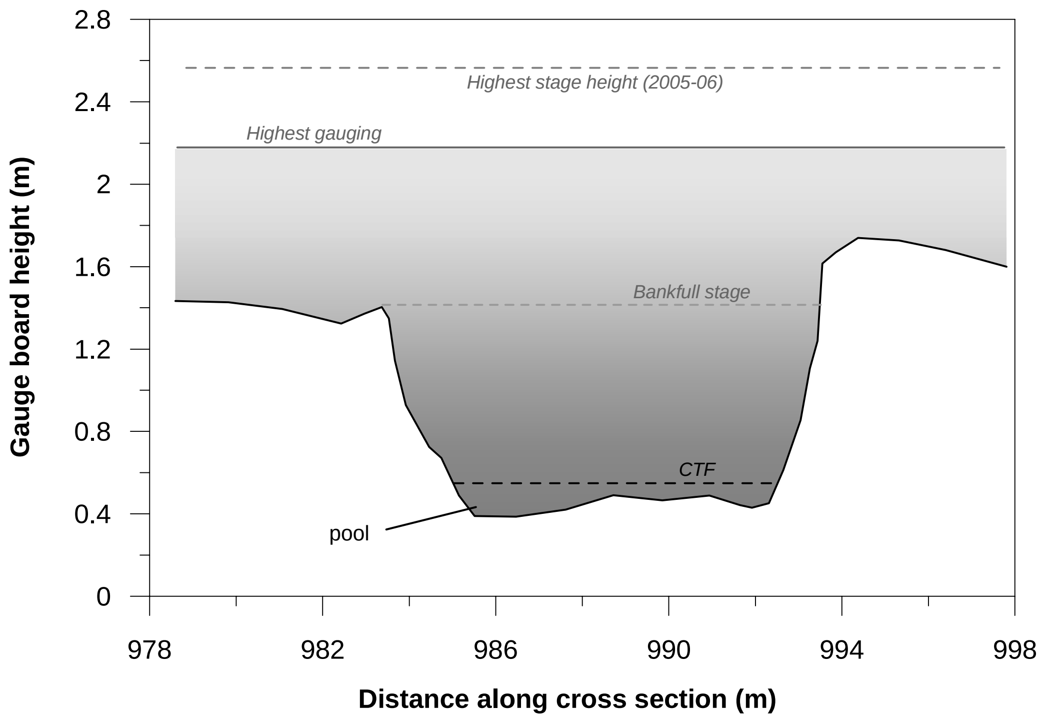

Figure 3.7 Cross section at GCDS taken during September 2005. CTF = cease-to-flow.

3.2 Annual hydrograph

The complete hydrographs for GCUS, G8210012 and GCDS for the 2005–06 wet season are shown in Figure 3.8. The total runoff at each station, determined by the area under the hydrograph, is given in Table 3.1. The total annual runoff at G8210012 during 2005–06 (Table 3.1) is twice the average annual runoff volume of 25 548 ML, derived by Moliere (2005) using the historical runoff record. The total runoff at G8210012 during 2005–06 is the second highest recorded at the station (the highest occurred during 1975–76), which is an expected result given that the total annual rainfall recorded within the Gulungul Creek catchment corresponded to a 1:38 rainfall year. The total runoff at GCDS is incomplete (Table 3.1). Flow data collected between the start of flow (25 November 2005) and 12 December 2005 is unreliable due to problems with the datalogger. The faulty datalogger was replaced and consequently flow data collected from 12 December is considered reliable. According to the flow data collected at GCUS and G8210012, approximately 1% of the total annual runoff occurred during this period (25 November to 12 December 2005). Therefore, the total annual runoff value given in Table 3.1 is likely to be only slightly underestimated.

Velocity-area gauging data taken across the cross section at GCUS during overbank flow indicate that the channel bankfull stage is approximately 1.6 m (Fig 3.1). Survey data taken across the cross sections at G8210012 and GCDS indicate that the bankfull stage is approximately 2.9 m and 1.4 m at the two sites, respectively. Using the rating curves derived for these stations (Figs 3.2, 3.4 and 3.6), the bankfull discharges for GCUS, G8210012 and GCDS are 10.0 m^3 s^{-1}, 14.3 m^3 s^{-1} and 6.0 m^3 s^{-1} respectively (indicated on the annual hydrographs in Figure 3.8). It is worth noting that the total duration of overbank flow at GCUS and G8210012 during 2005–06 is 9.7 days and 7.4 days respectively, whereas the total duration of overbank flow at GCDS is 42.2 days.

Figure 3.8 also shows that the annual hydrographs for the three stations are similar, particularly the flow observed at GCUS and G8210012, which are almost identical. This indicates that very little flow enters the Gulungul Creek main channel between GCUS and G8210012 along the TDSRC (Tailings Dam southern road culvert) flow path (Fig 1.1).

Antecedent rainfall

The antecedent rainfall, which is defined as the amount of rainfall between the start of rainfall and the start of streamflow, during 2005–06 at GCUS and G8210012 (Table 3.1) is similar to the mean antecedent rainfall derived for the Gulungul Creek catchment of 295 mm (Moliere 2005).

Table 3.1 Total annual rainfall and runoff at each gauging station for the 2005–06 wet season

Station	Total rainfall (mm) (from Table 2)	Antecedent rainfall (mm)	Runoff period	Total runoff (ML) [Peak discharge (m^3s^{-1})]
GCUS	2137	232	25 Nov – 20 Aug	49105 [59.1]
G8210012	2172	277	25 Nov – 20 Aug	52010 [92.4]
GCDS	1803(1)	na	25 Nov – 10 Aug	71561(2) [101]

(1) Incomplete (see Section 2 – Rainfall)

(2) Slightly underestimated - unreliable flow data collected between 25 Nov and 12 Dec 2005

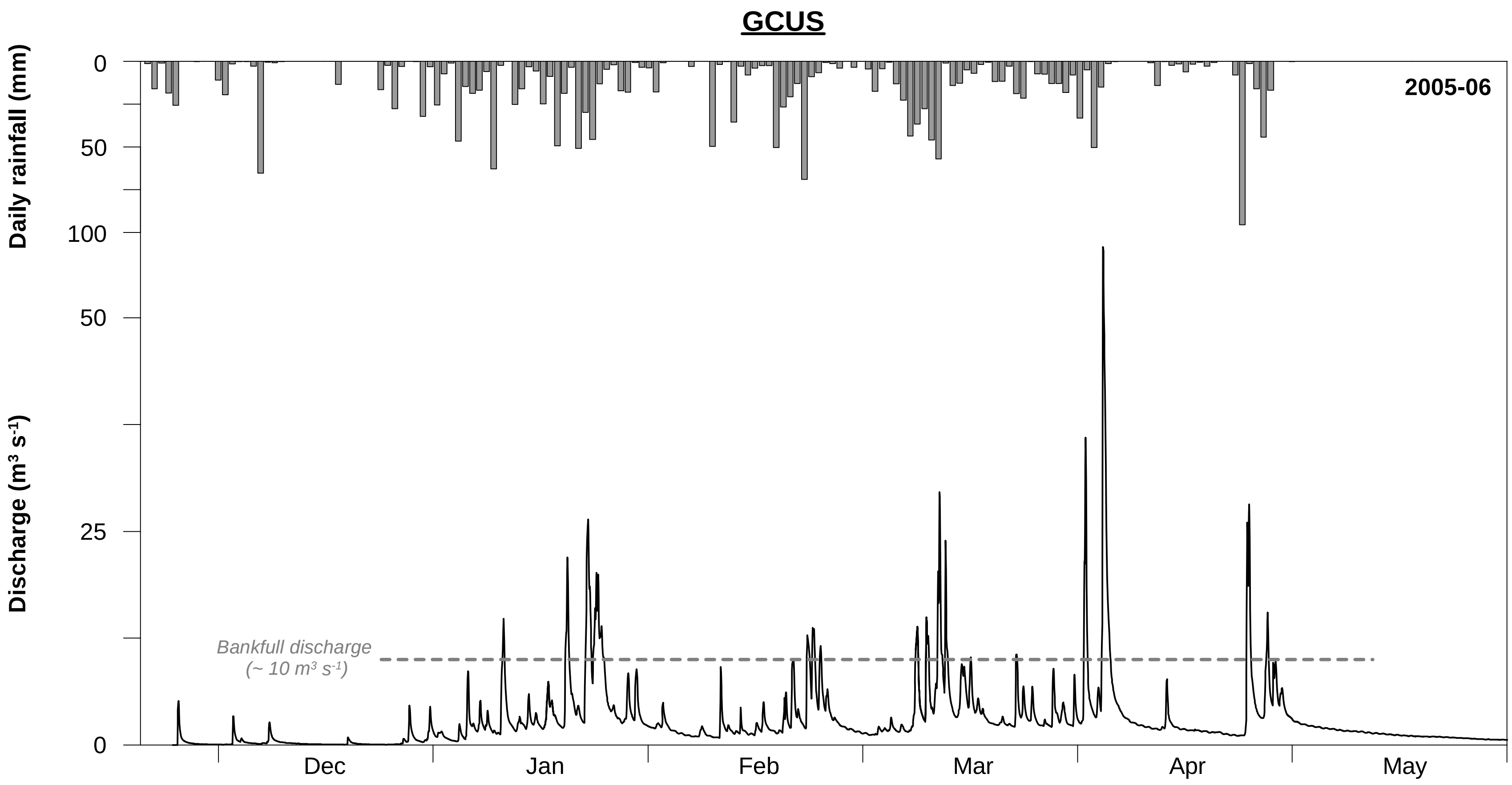

Figure 3.8a Daily rainfall and the hydrograph for GCUS during the 2005–06 wet season

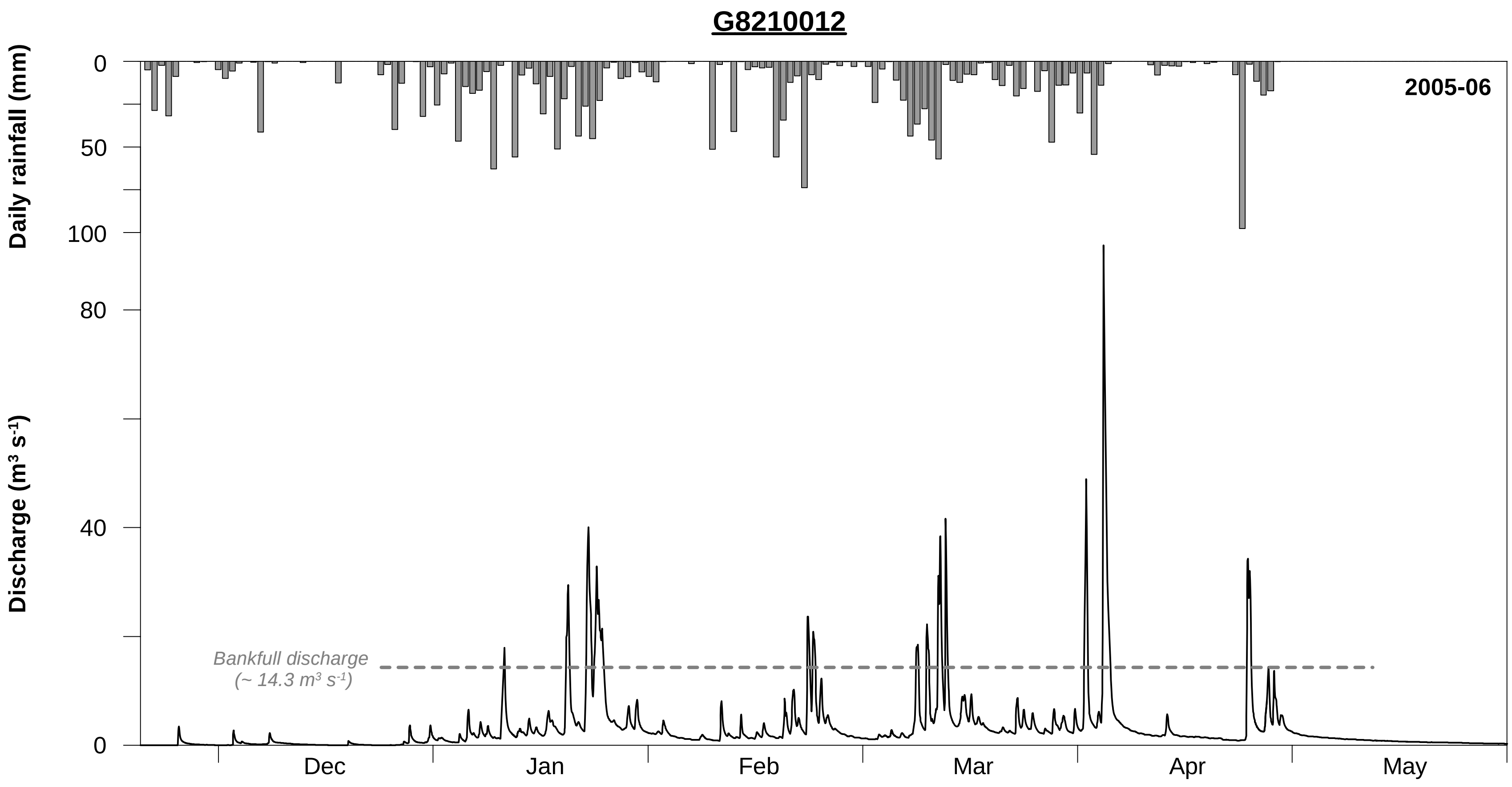

Figure 3.8b Daily rainfall and the hydrograph for G8210012 during the 2005–06 wet season

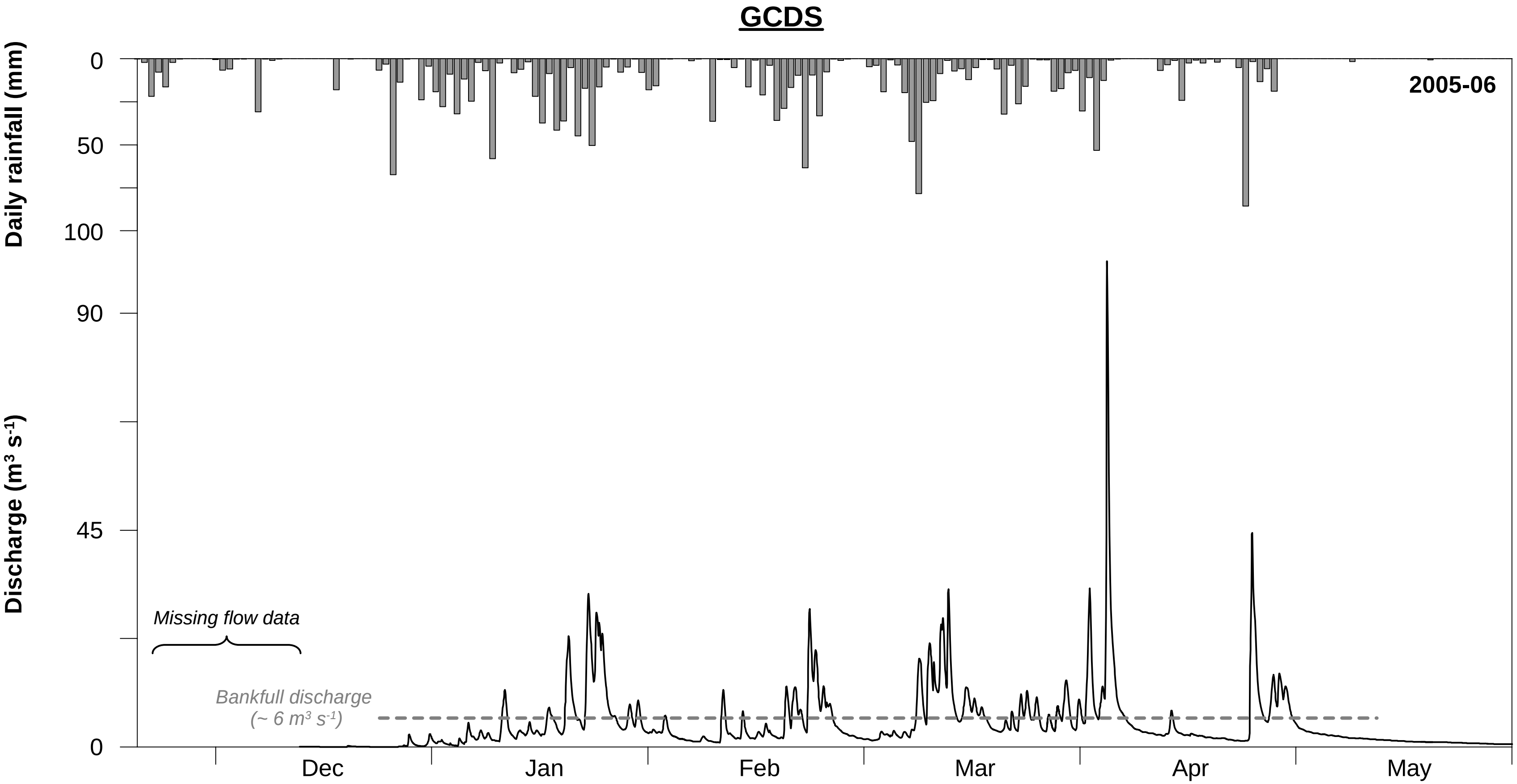

Figure 3.8c Daily rainfall and the hydrograph for GCDS during the 2005–06 wet season

3.3 Flood frequency analysis

Flood frequency curves for GCUS and GCDS will be used to investigate the long-term trends and carry out a flood risk assessment both upstream and downstream of the Ranger mine (Moliere 2005). It is particularly important to develop these relationships before rehabilitation at the mine site commences. However, because it is unlikely that these two new stations will have a sufficient runoff record (at least 10 to 15 years of data are required for a flood frequency analysis (Pilgrim 2001)) by the time rehabilitation commences, it is important to investigate whether or not the long-term runoff record at station G8210012 (1971 to 1993) can be used to extrapolate the record at GCUS and GCDS. If a significant regression relationship between observed peak discharges at the two new stations and corresponding peak discharges at G8210012 can be established using several years of runoff data, the relationship could be used to estimate values at the two new stations for the period of record available at G8210012 (1971 to 1993).

Regression analysis was conducted for concurrent flow records at GCUS and G8210012 (2003 to 2006) and GCDS and G8210012 (2005 to 2006) to determine the strength of the correlation between the two pairs of stations. Major event peak discharges observed at GCUS (> bankfull discharge of 10 $m^3\ s^{-1}$) were compared to the corresponding peak discharge at G8210012 for the same event. Similarly, major event peak discharges observed at GCDS were also compared to the corresponding peak discharge at G8210012. Figure 3.9 shows that the relationships between floods that occurred in the same storm are statistically significant for both pairs of stations.

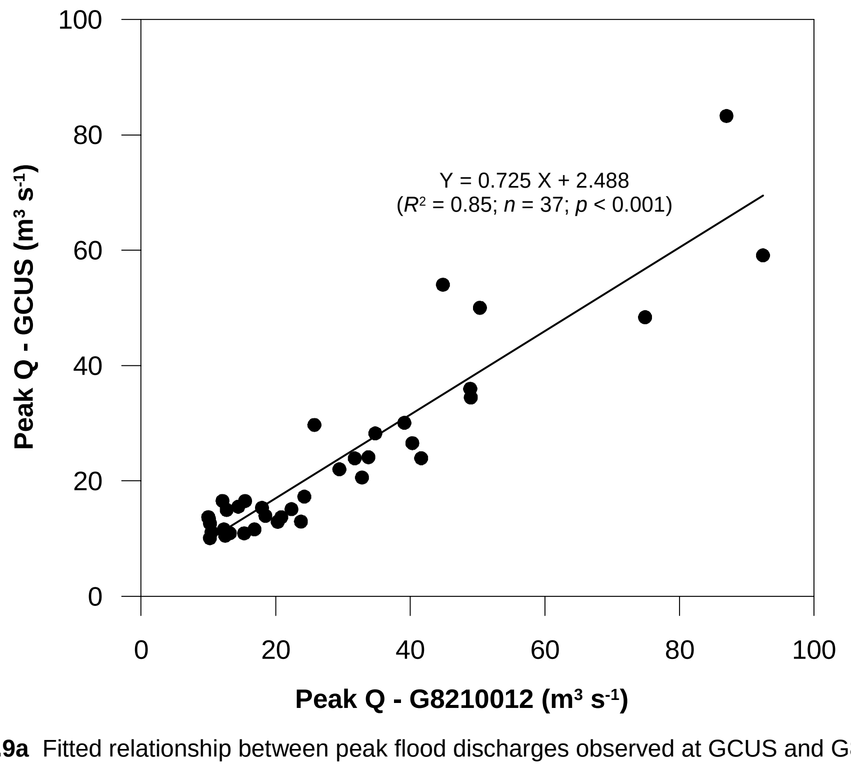

Figure 3.9a Fitted relationship between peak flood discharges observed at GCUS and G8210012

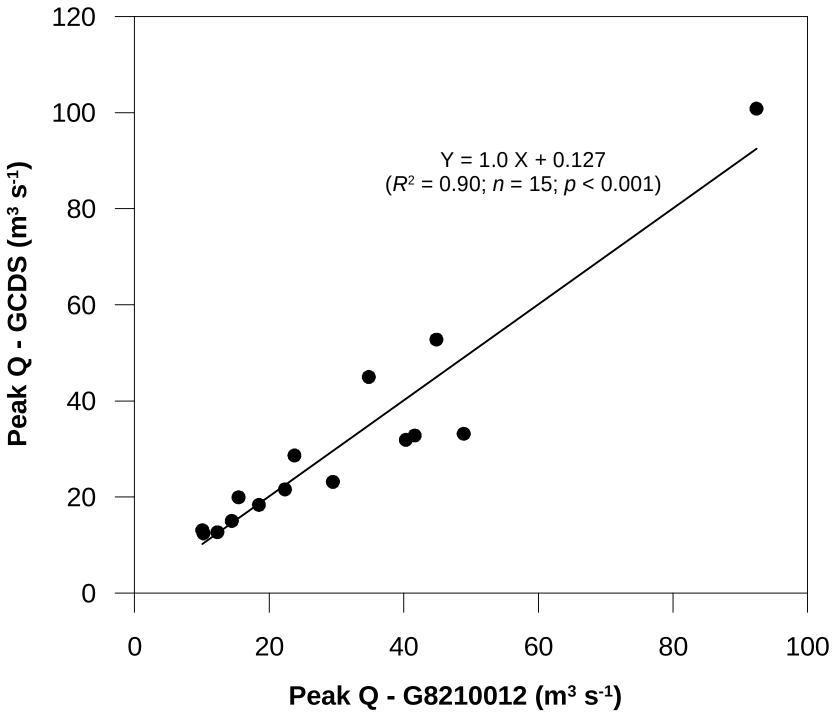

Figure 3.9b Fitted relationships between peak flood discharges observed at GCDS and G8210012

The relationships fitted in Figure 3.9 were used to estimate values at GCUS and GCDS for the period of record available at G8210012 (1971 to 1993). Based on the method outlined in Pilgrim (2001), a log Pearson III distribution was then fitted for the annual peak discharges for both GCUS and GCDS using annual peak discharges for 23 years and 21 years of record respectively.

Initially, while the frequency curves gave an adequate fit to most of the plotted annual floods (ie most of the data fits within the 5% and 95% confidence limits), it diverged from the highest flood event which occurred on 4 February 1980. It appears that the log Pearson III distribution is unable to fit both the lower and higher annual floods and, as a result, the frequency curve is distorted at both ends of the observed range. Therefore, similar to the flood frequency analysis conducted for G8210012 (Moliere 2005), the lowest annual flood was deleted from the datasets and a revised log Pearson III distribution for GCUS and GCDS was fitted to the remaining data (Figs 3.10 and 3.11 respectively). A summary of the annual exceedence probabilities (AEPs) and the corresponding peak discharges for GCUS and GCDS are shown in Table 3.2. Using the flood frequency curves, the annual peak discharge at GCUS and GCDS for 2005–06 corresponds to a 1:4 y and a 1:7 y flood event respectively.

Table 3.2 Summary of the fitted flood frequency distribution for GCUS and GCDS

ARI (y)	AEP (%)	Peak discharge - GCUS (Fig 3.10) ($m^3 s^{-1}$)	Peak discharge - GCDS (Fig 3.11) ($m^3 s^{-1}$)
2	50	40.7	50.7
5	20	66.9	87.2
10	10	91.9	124
20	5	123	171
50	2	178	256
100	1	231	343

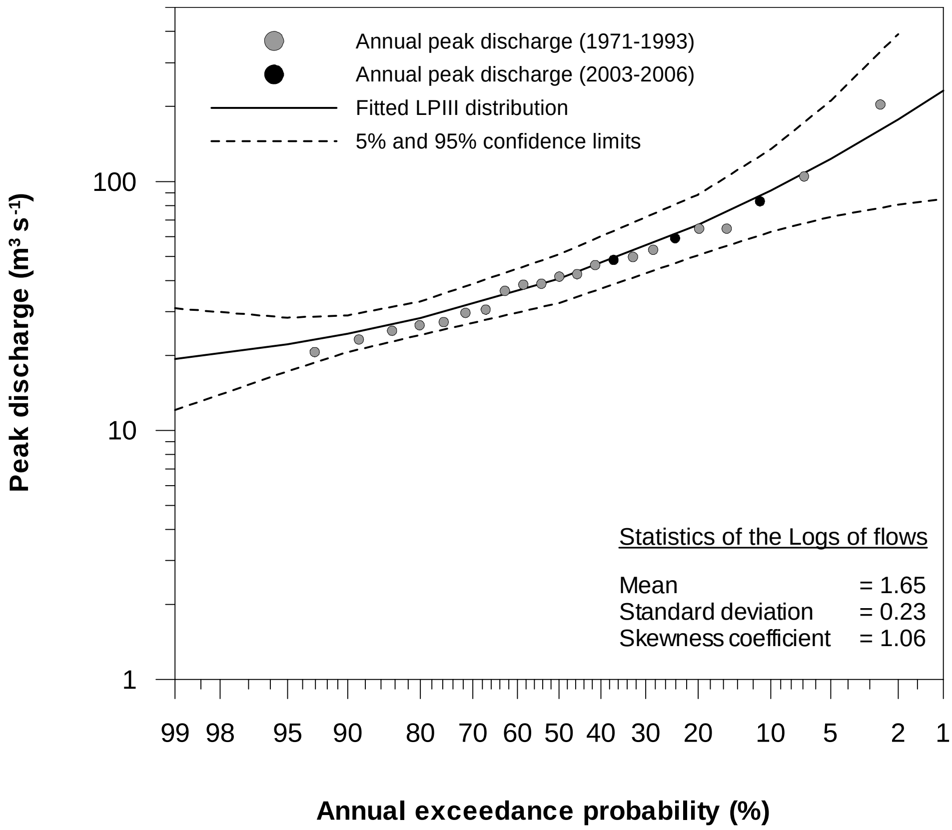

Figure 3.10 Frequency curve of annual peak discharge at GCUS

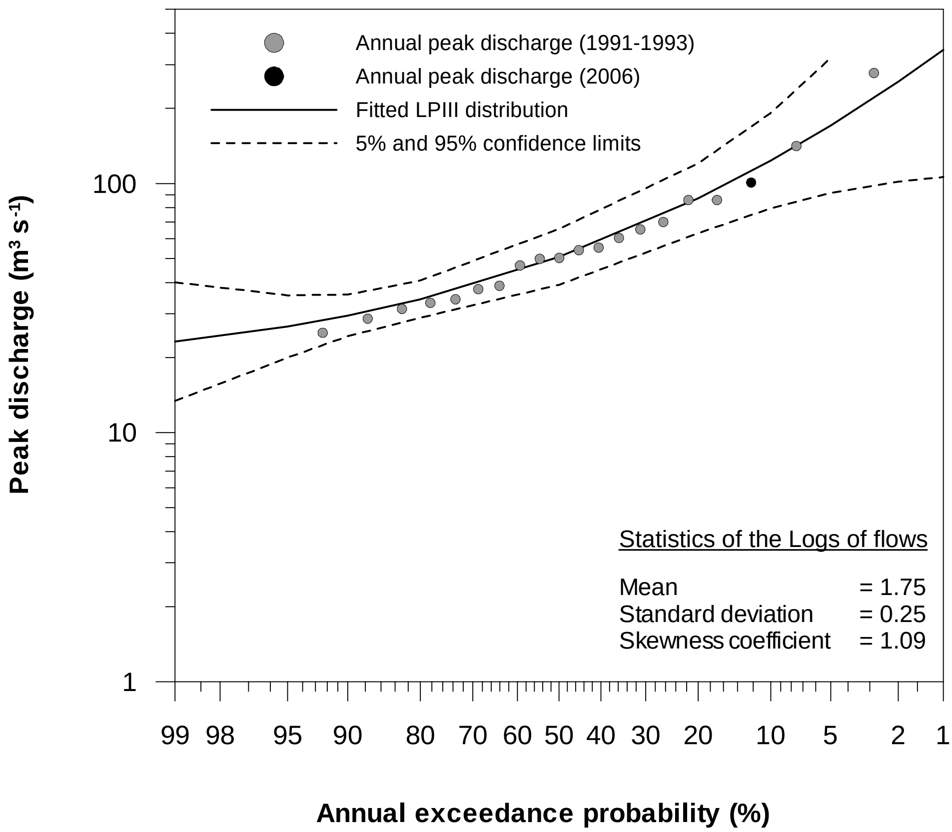

Figure 3.11 Frequency curve of annual peak discharge at GCDS

3.4 Hydrology data summary – 2003–2006

The total annual rainfall and runoff observed at each station within the Gulungul Creek catchment throughout the three-year monitoring period are given in Table 3.3. The Annual Recurrence Interval (ARI) of the total annual rainfall volume observed at the Gulungul Creek catchment, compared to the long-term rainfall data collected at Jabiru airport, is also given in Table 3.3. Using the flood frequency curves fitted for each station, the ARI of the annual peak discharges observed at each station throughout the monitoring period were estimated (Table 3.3). It should be noted that the annual runoff volume for GCUS and G8210012 during 2003–04 and 2004–05 given in Table 3.3 are different to that in Moliere et al (2005a) as a result of refinements made to the rating curves (see Section 3.1 – Rating curves). In particular, the revised annual peak discharge at GCUS for the 2003–04 and 2004–05 wet seasons (Table 3.3) were under-predicted by more than 50% using the old extrapolated rating curves (Moliere et al 2005a).

Table 3.3 Total annual rainfall and runoff at each gauging station within the Gulungul Creek catchment for the 3-year monitoring period (2003 to 2006)

Year	Station	Total rainfall (mm)	Mean rainfall(2) (mm) [ARI (y)]	Rainfall period	Antecedent rainfall (mm)	Total runoff (ML)	Peak discharge (m^3s^{-1}) [ARI (y)]	Runoff period
2003–04	GCUS	1540	1575 [1:2.3]	8 Oct – 31 May	317	28271(3)	48.4 [1:3]	21 Dec – 1 Jul
	G8210012	1611			289	34471(3)	74.9 [1:4]	21 Dec – 1 Jul
	GCDS	-			-	-	-	-
2004–05	GCUS	1591	1541 [1:2.1]	14 Nov – 9 May	281	26888	83.3 [1:8]	18 Dec – 25 Jun
	G8210012	1492			319	27272	87.0 [1:5]	22 Dec – 10 Jun
	GCDS	-			-	-	-	-
2005–06	GCUS	2137	2155 [1:38]	24 Oct – 13 Jul	232	49105	59.1 [1:4]	25 Nov – 20 Aug
	G8210012	2172			277	52010	92.4 [1:6]	25 Nov – 20 Aug
	GCDS	1803(1)			na	71561(4)	101 [1:7]	25 Nov – 10 Aug

(1) Incomplete (see Section 2 – Rainfall)

(2) Mean annual rainfall for the Gulungul Creek catchment – determined as the average of the annual rainfall at GCUS and G8210012

(3) Gap in runoff record (Moliere et al 2005a)

(4) Slightly underestimated - unreliable flow data collected between 25 Nov and 12 Dec 2005

4 Suspended sediment data

During the 2004–06 wet season, turbidity data were collected at GCUS and GCDS at 6 minute intervals throughout the annual hydrograph by an Analite turbidity probe. The probe was calibrated in the laboratory prior to the wet season using polymer-based turbidity standards. A turbidity-mud concentration (mud *C*) relationship was fitted for GCUS by Moliere et al (2005a) using data collected during 2004–05. To validate the turbidity-mud *C* relationship fitted for GCUS, and to derive a turbidity-mud *C* relationship for GCDS, water samples were collected by a stage-activated pump sampler during the 2005–06 wet season. These water samples were downloaded approximately fortnightly and mud *C* in each sample was determined by filtering and oven drying techniques (Erskine et al 2001). The pump samplers were programmed to collect water samples only during the rising stage of the event hydrograph as it has been shown that most of the mud movement in the region generally occurs before the peak of the hydrograph (Duggan 1991). Only one pump sampler was installed at each station (with a capacity of 24 water samples). Therefore, no more than 24 samples were collected from each station per site visit (approximately fortnightly).

The relationship between turbidity and mud *C* at GCUS during 2005–06 is almost identical to that fitted using data collected at GCUS during 2004–05 (Eqns 1 and 2).

2004-05: $Y = 0.60\ X \quad (R^2 = 0.82,\ n = 93)$ (1)

2005-06: $Y = 0.61\ X \quad (R^2 = 0.80,\ n = 62)$ (2)

Therefore, the turbidity-mud *C* relationship fitted using both years of data is considered appropriate for converting the continuous turbidity data to mud concentration (Fig 4.1). (Figure 4.1 also shows that the turbidity-mud *C* relationship fitted using the 2005–06 data only is, as expected, very similar to that fitted using both years of data.) A significant relationship between turbidity and mud *C* was also found for GCDS (Fig 4.2). The continuous stream mud *C* at GCUS and GCDS for the 2005–06 wet season, collected using turbidimeters and converted to concentration using the regression relationships (Figs 4.1 and 4.2), is shown in Figure 4.3.

Figure 4.3 highlights some interesting differences in the mud concentration data between the two stations:

- Baseflow mud concentration is higher at GCDS (~3 mg L^{-1}) than at GCUS (<1 mg L^{-1}) and,
- Spikes in mud concentration associated with runoff events were all higher at GCUS than at GCDS during the wet months of January to March.

Furthermore, only once did a spike in mud concentration at GCUS exceed 30 mg L^{-1} (although it was likely to have exceeded 30 mg L^{-1} during the period immediately after Cyclone Monica, but data were not recorded due to equipment damage as a result of the cyclone). During the previous two wet seasons, mud concentration exceeded 30 mg L^{-1} on at least ten occasions (Moliere et al 2005a).

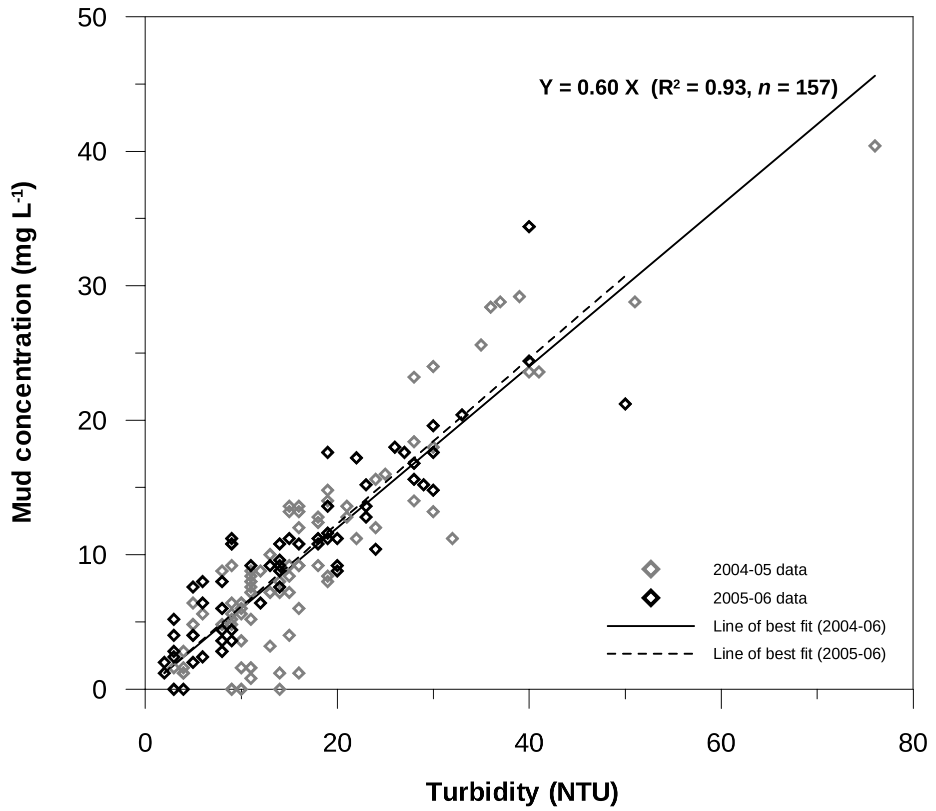

Figure 4.1 Relationship between turbidity and mud concentration for GCUS

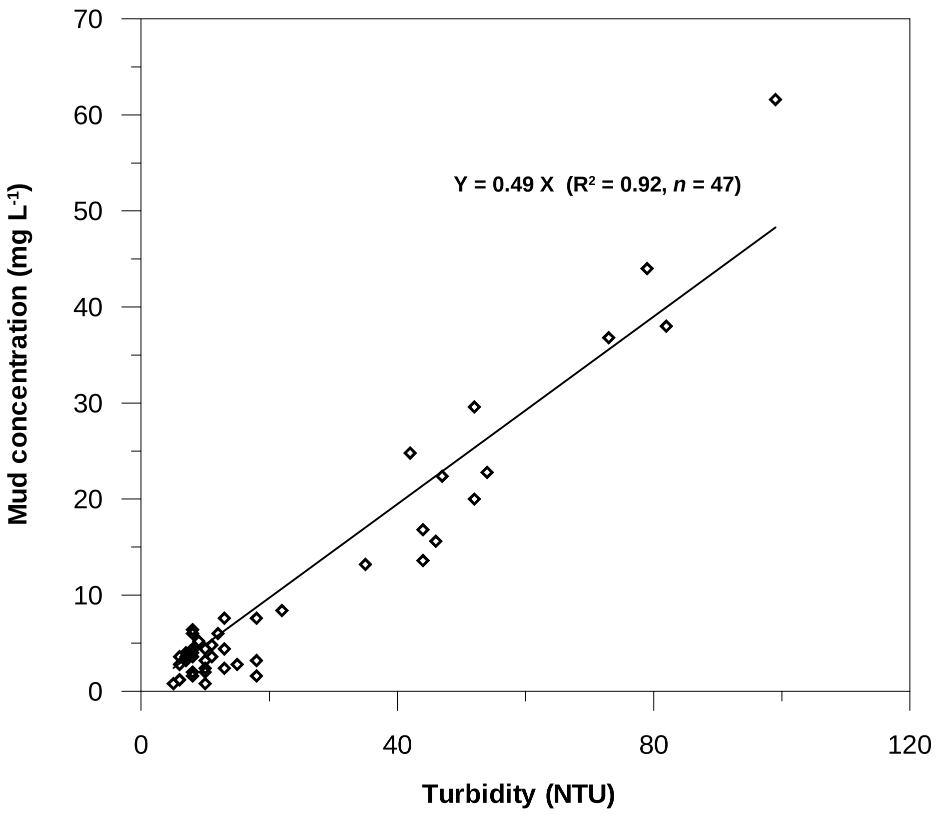

Figure 4.2 Relationship between turbidity and mud concentration for GCDS

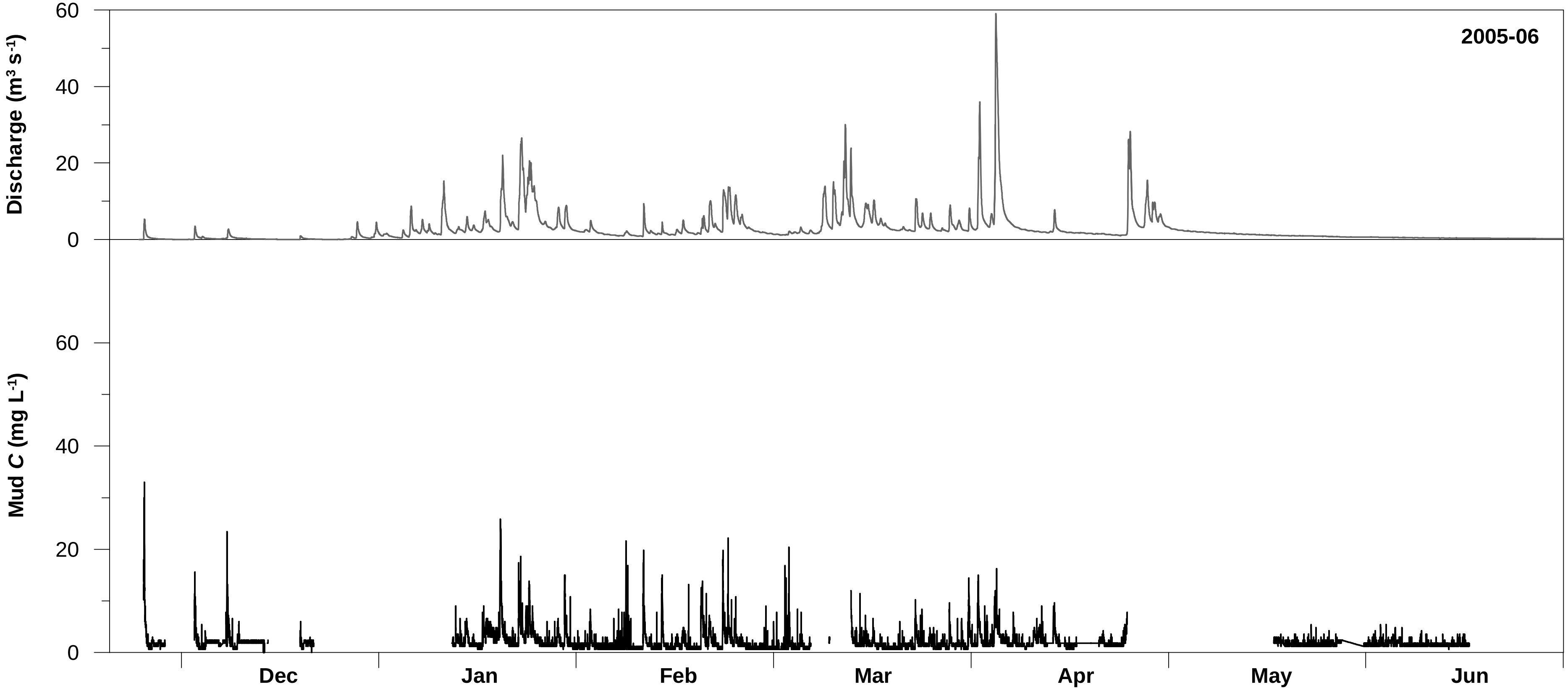

Figure 4.3a Continuous mud *C* data derived from the turbidimeter record for the 2005–06 wet season at GCUS. Discharge data are also shown.

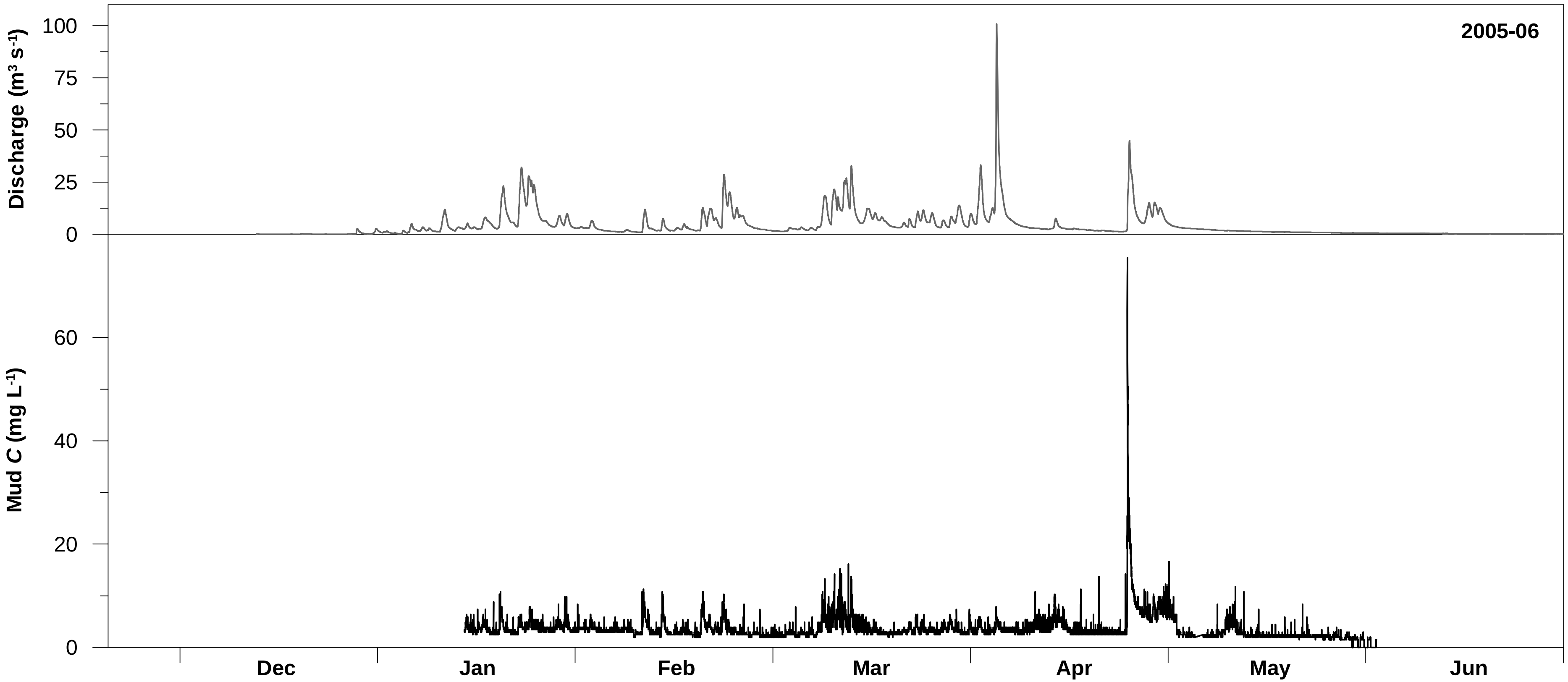

Figure 4.3b Continuous mud *C* data derived from the turbidimeter record for the 2005–06 wet season at GCDS. Discharge data are also shown.

4.1 Missing data

During the 2005–06 wet season there were periods where no turbidity data were recorded at both GCUS and GCDS, which means that the annual sedigraphs are incomplete.

Figure 4.3a shows two periods of missing data at GCUS between late November and mid-December. During these periods the stage height was below the level of the turbidimeter and hence no turbidity data were recorded. It is likely that during these low flow periods, mud *C* was at baseflow concentrations of approximately 1 mg L^{-1}. There are three other distinct gaps in the mud concentration data collected at GCUS:

1) 27 December to 11 January: Fuse blown – no rainfall, stage height (pressure transducer) and turbidity data collected during this period. Fuse replaced on 11 January.

2) 7 March to 13 March: Problem with the datataker – no rainfall, stage height (pressure transducer) and turbidity data collected during this period. Datataker replaced on 13 March.

3) 25 April to 17 May: Damaged cables due to Cyclone Monica – no stage height (pressure transducer) and turbidity data collected during this period. Cables fixed on 17 May.

Turbidity data collection at GCDS did not commence until 13 January 2006 (Fig 4.3b). No gaps in data occurred after this date for the remainder of the wet season.

4.2 Impact assessment

Previous studies by Evans et al (2004) and Moliere et al (2005b) used a Before-After-Control-Impact, paired difference design (BACIP) (Stewart-Oaten et al 1986, 1992, Humphrey et al 1995) to establish trigger levels for mud concentration and mud load respectively for the nearby Ngarradj catchment. These trigger levels were derived in accordance with The Australian and New Zealand water quality guidelines (WQG) (ANZECC & ARMCANZ 2000) and, when exceeded, should inititate a management response. Continuous mud concentration data collected at GCUS and GCDS during 2005–06 were used to establish preliminary trigger values for an event-based BACIP. Using a similar approach to the Ngarradj catchment (Moliere et al 2005b), GCUS and GCDS were treated as paired sites and the comparison of event load ratios used to provide the basis for future impact assessment.

During 2005–06 there were 11 events with complete event load data collected at both GCUS and GCDS. (Event load data for these events observed at the two stations are given in Appendix A.) Figure 4.4 shows that the mean ratio of GCDS mud load to GCUS mud load for the one-year monitoring period is approximately 1.8. The events of ‘interest’ are those that lie greater than one standard deviation above the mean ratio (ie > +1 SD) because these are events where elevated mud loads are measured at GCDS relative to the load at GCUS. During 2005–06 there were three successive events above the +1 SD line (Fig 4.4) that occurred during a 10-day period in February. All three events had a relatively high ratio of peak discharge downstream to peak discharge upstream compared to the other events (Appendix A). It is possible that during these three events the runoff from the smaller tributaries below GCUS was relatively high compared to the runoff at GCUS (perhaps due to localised storm activity on the lower catchment area). Consequently, a higher contribution of mud load from these tributaries compared to the load at GCUS may have occurred during these events. Nevertheless, the event-based BACIP analysis indicates that the ratios of event mud load observed at GCDS to GCUS during these three events are not considered as outliers as they are within the 95% prediction intervals (ie within two standard deviations) of the mean ratio.

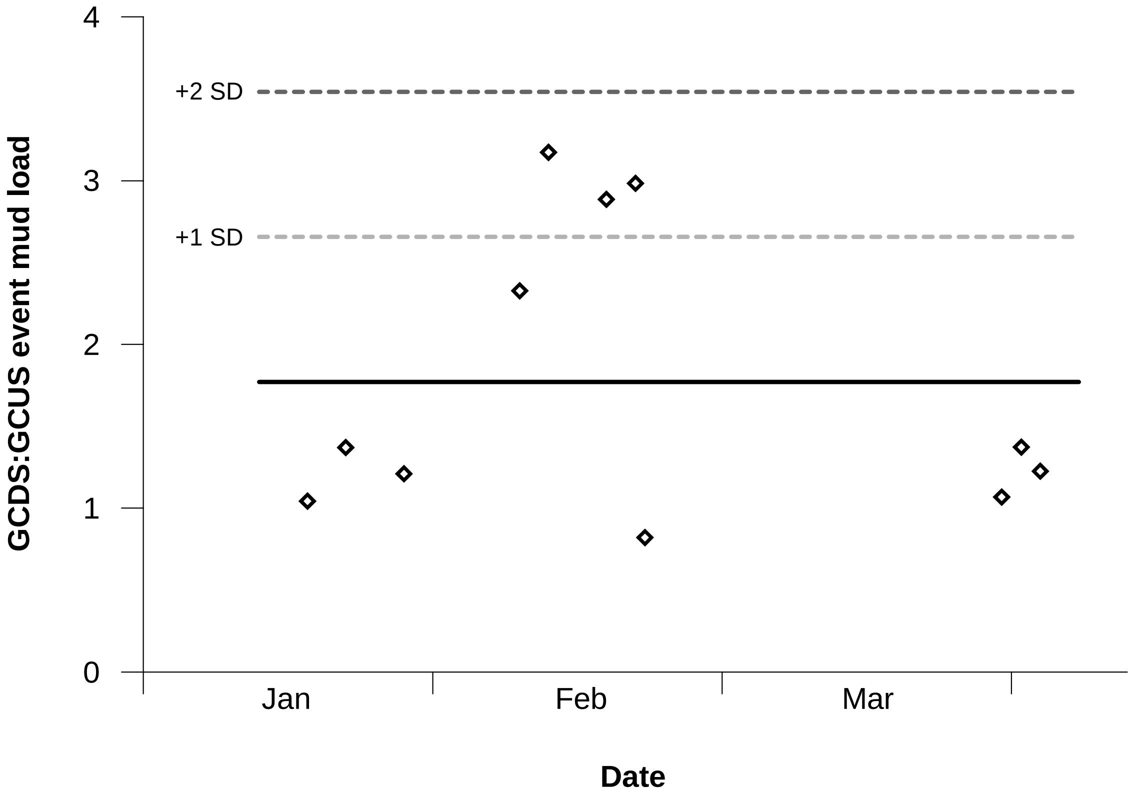

Figure 4.4 Temporal variation of the ratio of event mud loads measured at GCDS to that at GCUS during 2005–06 (indicated as◇). The mean ratio and associated standard deviations are also shown.

5 Conclusions and future work

Continuous rainfall, runoff and mud concentration data collected within the Gulungul Creek catchment during 2005–06 are presented in this report. Water samples were collected at GCUS (upstream of Ranger) to validate the turbidity-mud concentration relationship previously fitted using 2003–2005 data. Water samples collected at GCDS (downstream of Ranger) were used to derive a turbidity-mud concentration relationship for the site.

During the 2005–06 wet season several high flow velocity-area gaugings were taken at GCUS and GCDS to refine the 'higher end' of the rating curve for GCUS and to fit a rating curve for GCDS. Both stations have now been gauged to approximately 80% of the maximum flow for the 2005–06 wet season and, therefore, it is considered that the rating curve for GCUS and GCDS is reliable for most flow conditions. However, it is recommended that during the 2006–07 wet season, more medium to high flow velocity-area gaugings are conducted, particularly to assess any change in the rating curves due to channel form changes within Gulungul Creek as a result of Cyclone Monica (25 April 2006).

Using three years of runoff data at GCUS and one year at GCDS, significant relationships were fitted between observed event peak discharges at the two stations with corresponding peak discharges at G8210012. This indicates that the historical long-term runoff record at station G8210012 (1971 to 1993) can be used to extrapolate the record at GCUS and GCDS.

Using the extended runoff record at the two stations, flood frequency curves were established for GCUS and GCDS. The annual peak discharge at GCUS and GCDS for the 2005–06 wet season (which occurred on 4–5 April 2006) correspond to a 1:4 y and a 1:7 y flood event respectively.

A preliminary event-based before-after-control-impact paired site design (BACIP) was used for impact assessment on mud loads downstream of Ranger. The analysis indicated that there were three successive events during a 10-day period in February with a mud load measured at GCDS that was relatively high compared to the load measured at GCUS. However, the ratio of event mud load measured at GCUS to that measured at GCDS during these three events was not significantly different to the other events at > 2 SD from the mean. It is recommended that event load data are collected for at least two more years within the Gulungul Creek catchment to provide sufficient data for a robust BACIP analysis.

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Appendix A
Mud pulse characteristics

Table A.1 Rainfall, discharge and mud characteristics for each mud pulse event observed at GCUS during 2005–06

Date	**Rain**		**Discharge**		**Mud pulse**			
	Total rainfall (mm)	Start of rainfall[1]	Peak discharge (m^3)	Time of Q_p	Peak mud *C* (mg L^{-1})	Time of mud C_p	Duration	Mud load (kg)
18 Jan	45	20:30	22.00	06:54	25.8	22:24	18 Jan 20:30 – 19 Jan 08:54	4925
21 Jan	67	15:48	26.54	04:48	18.6	00:42	21 Jan 16:12 – 22 Jan 09:24	6042
28 Jan	18	18:00	8.87	01:00	15.0	19:54	28 Jan 18:00 – 29 Jan 05:00	1536
09 Feb	50	18:54	9.31	22:24	19.8	21:00	09 Feb 18:54 – 10 Feb 08:06	1681
12 Feb	35	15:30	4.53	18:18	15.0	17:36	12 Feb 15:30 – 13 Feb 00:42	641
18 Feb	24	19:06	6.24	03:24	13.8	22:24	18 Feb 16:06 – 19 Feb 08:30	1508
21 Feb	56	23:36	12.95	03:54	19.8	01:42	21 Feb 23:36 – 22 Feb 08:30	2497
22 Feb	24	17:18	13.70	22:00	22.2	19:48	22 Feb 17:54 – 23 Feb 02:06	2089
31 Mar	15	17:00	8.24	20:42	14.4	18:42	31 Mar 15:36 – 01 Apr 02:12	1201
02 Apr	33	01:48	35.95	11:00	15.0	05:18	02 Apr 02:00 – 02 Apr 13:18	5083
04 Apr	51	15:06	59.10	22:18	16.2	17:36	04 Apr 15:06 – 05 Apr 12:00	13048
25 Apr[2]							No turbidity data	

1 Start of effective rainfall (ie rainfall that produces runoff)

2 Cyclone Monica

Table A.2 Rainfall, discharge and mud characteristics for each mud pulse event observed at GCDS during 2005–06

Date	**Rain**		**Discharge**		**Mud pulse**			
	Total rainfall (mm)	Start of rainfall[1]	Peak discharge (m^3)	Time of Q_p	Peak mud C (mg L^{-1})	Time of mud C_p	Duration	Mud load (kg)
18 Jan	34	20:24	23.14	13:24	10.8	02:48	18 Jan 22:30 – 19 Jan 14:24	5137
21 Jan	45	16:00	31.87	07:48	6.4	02:42	21 Jan 16:12 – 22 Jan 09:24	8277
28 Jan	0	-	9.72	07:42	9.8	23:12	28 Jan 21:18 – 29 Jan 10:00	1859
09 Feb	37	19:30	11.88	06:12	11.3	00:54	09 Feb 19:30 – 10 Feb 23:36	3911
12 Feb	5	14:42	7.49	00:18	10.8	21:48	12 Feb 17:42 – 13 Feb 11:12	2034
18 Feb	29	19:06	12.62	02:42	10.8	02:12	18 Feb 18:36 – 19 Feb 13:42	4349
21 Feb	63	23:48	28.63	08:42	10.3	07:42	22 Feb 00:36 – 22 Feb 16:24	7452
22 Feb	10	18:00	20.20	05:06	5.4	02:18	22 Feb 23:00 – 23 Feb 05:42	1714
31 Mar	8	17:12	9.95	04:12	7.4	22:30	31 Mar 20:48 – 01 Apr 06:06	1283
02 Apr	30	01:18	33.15	16:18	5.9	09:36	02 Apr 02:36 – 02 Apr 22:06	6971
04 Apr	54	15:18	100.83	03:00	7.8	01:00	04 Apr 22:42 – 05 Apr 11:48	16011
25 Apr[2]	81	01:00	44.96	11:30	75.5	04:30	25 Apr 00:54 – 26 Apr 10:30	52099

(1) Start of effective rainfall (ie rainfall that produces runoff)

(2) Cyclone Monica