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Hydrology and suspended sediment of the Gulungul Creek catchment, Northern Territory: 2003–2004 and 2004–2005 wet season monitoring

DR Moliere, MJ Saynor, KG Evans & BL Smith

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Contents

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 concentration data collected at gauging stations on Gulungul Creek during 2003-04 and 2004-05 are presented in this report. Due to the brevity of the current record period, it is recommended that several more years of data collection should occur at each station to establish the long-term runoff and mud transport characteristics of the stream.

Acknowledgments

Jeff Klein, Klein Electronics Pty Ltd, helped with the installation and the maintenance of the gauging station equipment. Bob Masters, Energy Resources of Australia Ltd, supplied rainfall data from the rain gauge at the Tailings Dam. Dr David Jones, Director of ***eriss***, constructively and comprehensively reviewed the draft report.

Hydrology and suspended sediment of the Gulungul Creek catchment, Northern Territory: 2003–2004 and 2004–2005 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) 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. This study can be divided into two primary tasks.

Task 1 – Characterise suspended sediment movement within the stream

There have been earlier studies of sediment movement in Gulungul Creek (East et al 1987; Duggan 1991, 1994; East 1996; Skeat et al 1996). However, there is a need for further research on suspended sediment transport within the Gulungul Creek catchment because (Moliere 2005):

- only a relatively small number of the samples collected as part of these previous studies were used to determine the mud (silt and clay) component of the samples. It is well documented that nutrients and contaminants, including heavy metals and radionuclides, are transported in association with fine sediment (Walling & Owens 2002). Therefore, it is important to determine the mud transport characteristics within the Gulungul Creek catchment to quantify the potential for contaminant transport in this fine sediment fraction (Walling 1983; Walling et al 1992).
- suspended sediment concentration data were only collected downstream of the mine with no upstream reference site. Hence it is essential that unimpacted reference site data be acquired for a location upstream of any possible mining-related disturbance against which downstream impacts can be assessed (Erskine & Saynor 2000).

A gauging station was installed upstream of Ranger mine (Gulungul Creek upstream – GCUS) (fig 1) in November 2003. A second gauging station was installed downstream of Ranger mine (Gulungul Creek downstream – GCDS) (fig 1) in February/March 2005. Detailed turbidity data will be collected both upstream and downstream of the mine using turbidimeters installed at the two stations. Erskine et al (2001) considered that turbidity is an important water quality parameter in its own right and, therefore, should be measured. However, in order to calibrate the turbidimeters to measure mud concentration, automatic pump samplers were installed at the two stations to collect water samples for a range of flow conditions. It is planned that mud concentration data will be collected using *in situ* turbidimeters over the next few years to develop an understanding of the fine sediment movement characteristics within the catchment before rehabilitation at the mine site occurs.

These data will be used to develop a framework for assessing mine impact through the derivation of trigger values in accordance with The Australian and New Zealand water quality guidelines (WQG) (ANZECC & ARMCANZ 2000) using upstream percentiles and Before-After-Control-Impact, paired difference design (BACIP) as described by Evans et al (2004).

Task 2 – Derive hydrological characteristics of the catchment

Long-term runoff characteristics have been derived for Gulungul Creek based on flow data collected at G8210012 (fig 1) between 1971 and 1993 (Moliere 2005). However, this station is neither entirely upstream nor downstream of the Ranger mine site influence (fig 1). Therefore, rainfall and runoff data will be collected at all three stations within the Gulungul Creek catchment to determine the long-term runoff behaviour both upstream and downstream of the Ranger mine. It is particularly important to develop an understanding of the dynamic range of behaviour before rehabilitation at the mine site commences. However, it is unlikely that the two new stations (GCUS and GCDS) will have a sufficient runoff record for risk analysis by the time rehabilitation at Ranger mine is initiated. It is recommended that at least 10 to 15 years of data are required to determine long-term characteristics such as flood frequency (Pilgrim 2001). Therefore, it is important to investigate whether or not the long-term runoff record at station G8210012 can be used to extrapolate the record at the new station locations. If a significant regression relationship between observed peak discharges at the two new stations with corresponding peak discharges at G8210012 can be established using the next few 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 (1971–1993).

The hydrology data collected at GCUS and GCDS will also be used to: (1) aid the interpretation of water quality parameter values that will be collected during future wet seasons at these station locations, and (2) trigger the collection of suspended sediment samples using the automatic pump sampler (related to Task 1 above).

This report presents hydrology and mud concentration data collected from the stream gauging stations within the Gulungul Creek catchment during the 2003–04 and 2004–05 Wet seasons. Due to the brevity of the record period, the derivation of the suspended sediment movement and hydrological characteristics of the catchment (ie Tasks 1 and 2 above) will not be implicitly addressed within this report.

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).

Ranger mine lies partly within the catchment of Gulungul Creek (fig 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). 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.

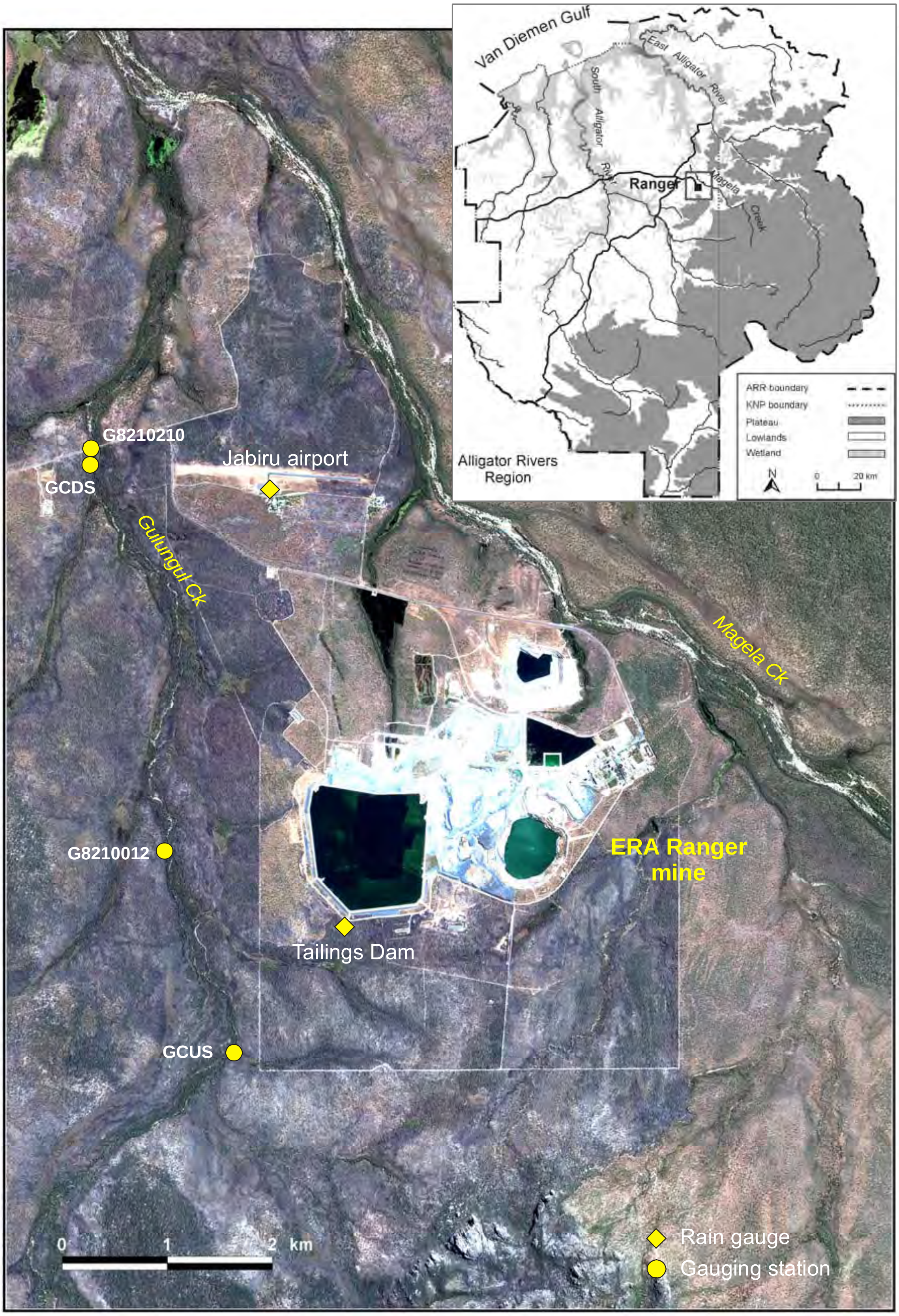

Figure 1 Location of Gulungul Creek and the ERA Ranger mine within the Alligator Rivers Region. The gauging stations and rain gauges in the area of interest are also shown. The image is an Ikonos satellite image taken June 2001.

As stated above, a gauging station was operated on Gulungul Creek (G8210012) (fig 1) between November 1971 and December 1993, a period of 22 years, by the Department of Infrastructure, Planning and Environment (DIPE). 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 DIPE (G8210210) (fig 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).

A site description of the three gauging stations operated by ***eriss*** since 2003 along Gulungul Creek (GCUS, GCDS and G8210012) is given in Appendix A.

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) 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) by ERA, which lies within the Gulungul Creek catchment. It should be noted that the daily rainfall record since 2003 for the Tailings Dam is relatively poor. Of the two years of daily rainfall data collected at the site since September 2003, only 22% of the data are 24-hour totals, 67% of the data are cumulative totals over at least two days and the remaining 10% of the data are missing (of the 73 days where no rainfall data were recorded, 72 occurred during 2004–05).

A description of the rainfall data collected in the region during 2003–04 and 2004–05 is given in table 1. A time line of data collection for these rain gauges is shown in figure 2. The total annual rainfall (September to August) at the three gauging stations and at Jabiru Airport and the Tailings Dam during 2003–04 and 2004–05 are shown in table 2.

Table 1 A description of the rainfall data collected in the region

Location	Data type	Interval	Period of record	Source of data
GCUS	Rainfall Intensity	6-minute	04 Dec 2003 – Aug 2005	*eriss*
GCDS	Rainfall Intensity	6-minute	09 Feb 2004 – Aug 2005	*eriss*
G8210012	Rainfall Intensity	6-minute	04 Dec 2003 – Aug 2005	*eriss*
Jabiru airport	Daily	–	01 Sept 2003 – Jun 2005	Bureau of Meteorology
Tailings Dam	Daily	–	01 Oct 2003 – Aug 2005	ERA
	Rainfall Intensity	continuous(1)	10 Sept 2004 – Apr 2005	ERA

(1) Continuous data during rainfall events (ie datalogger records a pulse signal for each tip of the tipping bucket rain gauge)

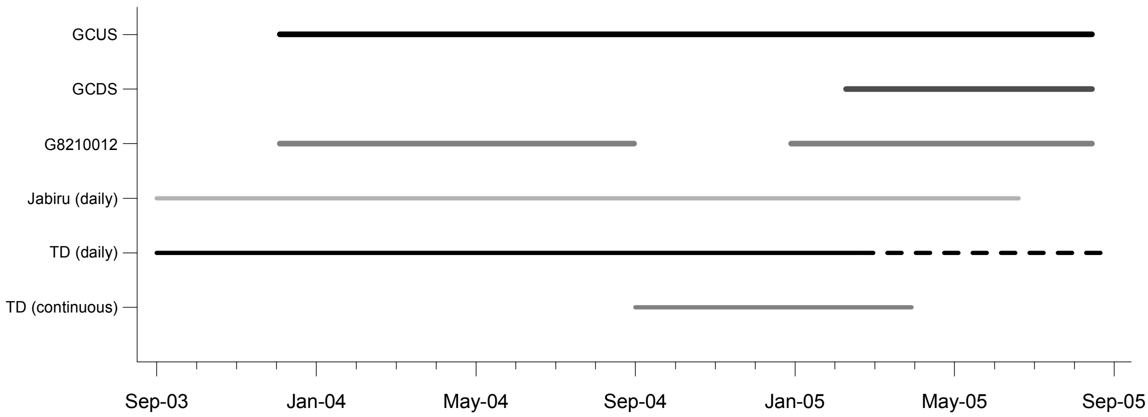

Figure 2 Time lines of data collection for the Gulungul Creek region since September 2003. The dashed line for the daily rainfall record at the Tailings Dam indicates numerous periods of missing data.

Table 2 Total annual rainfall over the Gulungul Creek region during 2003–04 and 2004–05

	Rainfall (mm)	
Station 2003–04		2004–05
GCUS 1540	(1) 1591	
G8210012 1611	(1) 1492	(2)(3)
GCDS -		-
Jabiru airport	1819	1437
Tailings Dam	1315	-

(1) Data partly provided by ERA (see Section 2.1)

(2) Data partly infilled using GCUS (see Section 2.1)

(3) Poor data recorded on 3 February 2005 was omitted from the total (see Section 2.2)

2.1 Missing data

Rain gauges were not installed at GCUS and G8210012 until 4 December 2003 and, as a consequence, early wet season rainfall data (Sept – Nov) for 2003 were not recorded at these sites. In order to estimate the total annual rainfall recorded at GCUS and G8210012, it is important to determine if the rainfall observed at the nearby Tailings Dam gauge is not statistically different to that at GCUS and G8210012 and, therefore, can be used to infill the missing record at these two stations.

Daily rainfall totals, determined using rainfall intensity data, were derived for GCUS, G8210012 and the Tailings Dam for the concurrent rainfall record (2004–05 wet season) (fig 2). The daily rainfall data collected at the Tailings Dam were not used in this analysis because, as discussed above, there were very few data where rainfall was observed over a single 24-hour period during 2003-04 and 2004-05.

Regression analysis showed that the rainfall data collected at GCUS and G8210012 are not significantly different to that at the Tailings Dam on a daily basis. The 1:1 line is within the 95% confidence intervals for the lines of best fit between rainfall at G8210012 and GCUS, and rainfall at the Tailings Dam (fig 3). As a result, the total rainfall recorded at the Tailings Dam from 1 September to 4 December 2003 of 150 mm (using the daily rainfall record) was simply transposed to the GCUS and G8210012 rainfall record to establish the annual rainfall at GCUS and G8210012 during 2003–04 (table 2). (The amount of rainfall recorded at Jabiru airport for that same time period was 146 mm.)

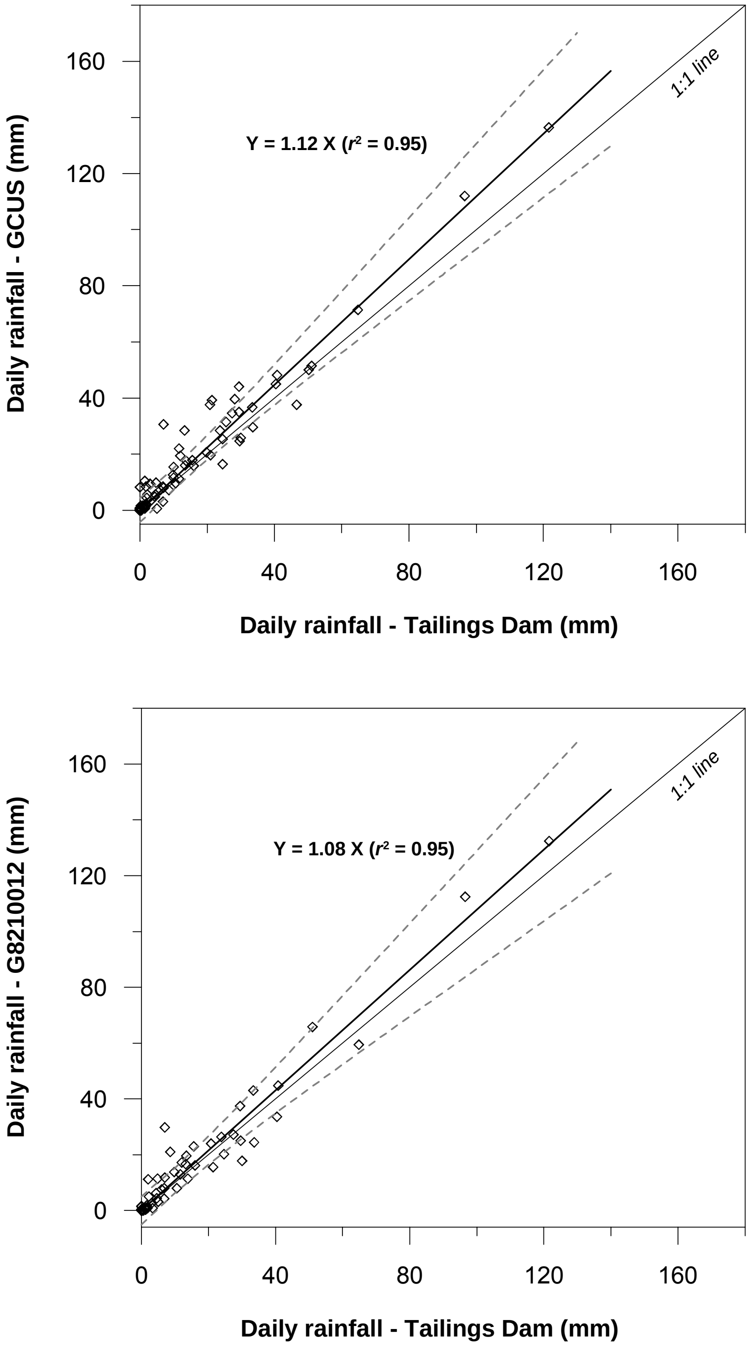

Figure 3 Comparison between rainfall data recorded at GCUS and the Tailings Dam (Top) and G8210012 and the Tailings Dam (Bottom) during the concurrent period (2004–05 wet season). Dashed lines indicate 95% confidence intervals.

Prior to the 2004–05 wet season, a Dry season fire occurred within the Gulungul Creek catchment and destroyed the cables connecting the rain gauge to the datalogger at G8210012. These cables were not re-installed until 29 December 2004. As a result, the early wet season rainfall data (Sept – Dec) for the 2004–05 wet season were not recorded at G8210012. Regression analysis between rainfall data collected at GCUS and that at G8210012 on a daily basis showed that rainfall at these two stations is very similar (fig 4). Rainfall data collected at

G8210012 seem to correlate better with rainfall at GCUS (fig 4) than with rainfall observed at the Tailings Dam (fig 3). Therefore, the total rainfall recorded at GCUS from 1 September to 29 December 2004 of 446 mm was transposed to the G8210012 rainfall record to establish the annual rainfall at G8210012 during 2004–05 (table 2).

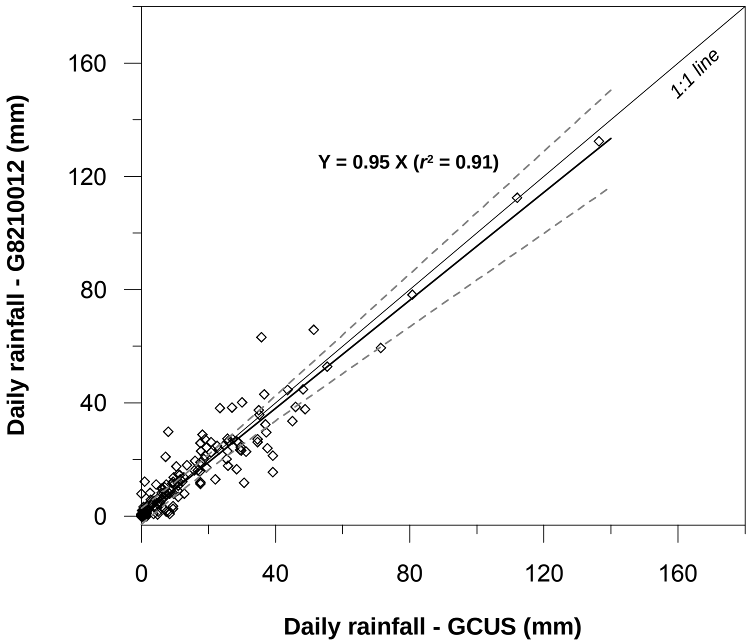

Figure 4 Comparison between rainfall data recorded at GCUS and G8210012 during the concurrent period (2003–2005). Dashed lines indicate 95% confidence intervals.

The rain gauge at GCDS was not installed until 9 February 2005. Given the proximity of the rain gauge at Jabiru airport to GCDS, it is likely that the rainfall data collected at these two sites will be similar. However, due to the brevity of the rainfall record at GCDS, linear regression analysis could not be conducted to determine the relationship between rainfall data collected at the two sites. As a result, the rainfall record during 2004–05 at GCDS was not infilled between September 2004 and February 2005 by the data from Jabiru airport.

2.2 Flood rainfall data – G8210012

A major storm event occurred within the Gulungul Creek catchment on 2–3 February 2005. The resultant flood hydrograph at GCUS and G8210012 had the largest peak discharge over the two year monitoring period (see figures 11 and 12 in Section 3.2 – Annual hydrograph). The peak discharge at G8210012 of 79 $m^3 s^{-1}$ was equivalent to a 1:5 y discharge event (using the flood frequency curve fitted by Moliere (2005)). Figure 5 shows that rainfall at G8210012 during 2–5 February 2005 was very similar to that at GCUS except for a 6-hour period on 3 February where approximately 60 mm of rainfall recorded at G8210012 was not observed at GCUS. (Furthermore, there was no corresponding rise in the hydrograph as a result of this rainfall.) This 6-hour period seemed to coincide closely with the peak of the event hydrograph.

Survey data across the cross section at G8210012 taken during August 2005 (see figure 10 in Section 3.1 – Rating curve) showed that the peak stage of this event was actually above the bottom of the rain gauge. It is likely that floodwaters during the peak of the runoff event affected the tipping bucket mechanism within the rain gauge. As a consequence, the rainfall data recorded during this 6-hour period were removed from the dataset. The adjusted rainfall for the 60-hour period between 2–5 February at G8210012 is now 217 mm, similar to that observed at GCUS of 232 mm (fig 5).

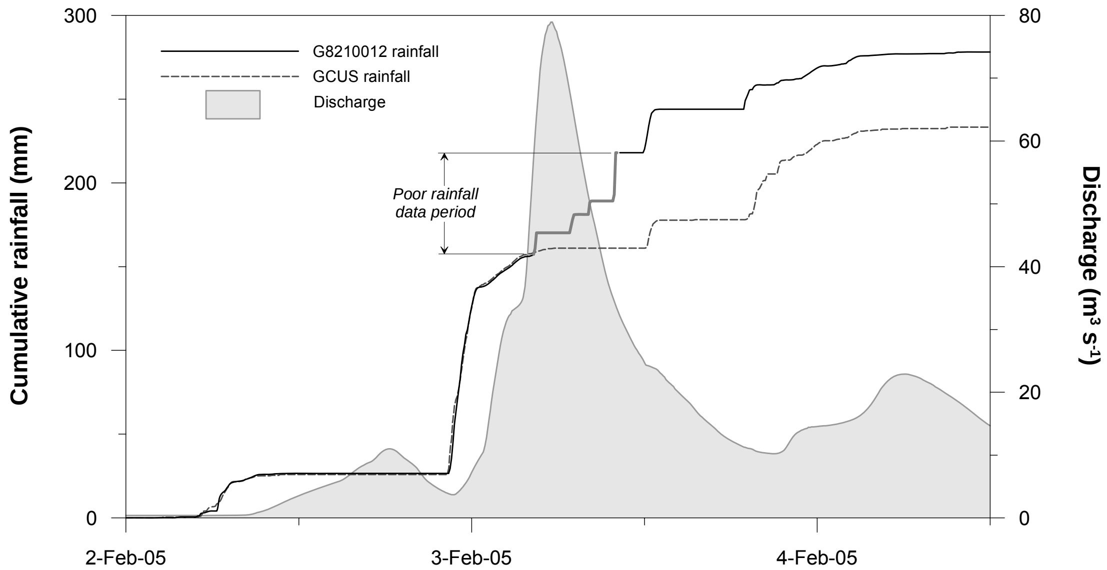

Figure 5 Rainfall data recorded at GCUS and G8210012 associated with the largest discharge event recorded during the two-year monitoring period

It is recommended that, prior to the 2005–06 wet season, the rain gauge should be placed on a higher stand to ensure that streamflow will not rise above the rain gauge for most flood conditions. The highest peak discharge recorded at G8210012, which occurred on 4 February 1980, was approximately 700 mm higher than that observed during the event on 2–3 February 2005 (fig 5). However, the flood event on 4 February 1980 is considered to be a statistically rare event (Moliere 2005). The second highest peak discharge recorded at G8210012, which occurred on 23 February 1984 and corresponded to a 1:14 y event, was only approximately 300 mm higher than that observed during the event on 2–3 February 2005. Therefore, it is considered that the rain gauge needs to be elevated approximately 500 mm above its current position before the 2005–06 wet season. This would ensure that a flood with a peak discharge corresponding to a 1:30 y runoff event would not rise above the base of the rain gauge.

2.3 Annual rainfall distribution

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 (2005) showed that rainfall at Jabiru airport, which lies just outside the boundary of the Gulungul Creek catchment and has a period of record of 34 years, is similar to that at the Tailings Dam, which lies within the boundary of the catchment area. Therefore, it was considered that the long term rainfall characteristics for Jabiru airport can be used to describe the rainfall over the Gulungul Creek catchment.

In this case, the total annual rainfall over the Gulungul Creek catchment was determined simply as the average of the annual rainfall at GCUS and G8210012 (table 2). The annual rainfall for the Gulungul Creek catchment during 2003–04 and 2004–05, compared to the Jabiru airport rainfall distribution, corresponds to a 1:2.3 and 1:2.1 rainfall year respectively (fig 6). That is, the annual rainfall over the catchment during the past two years has been slightly above average for the region.

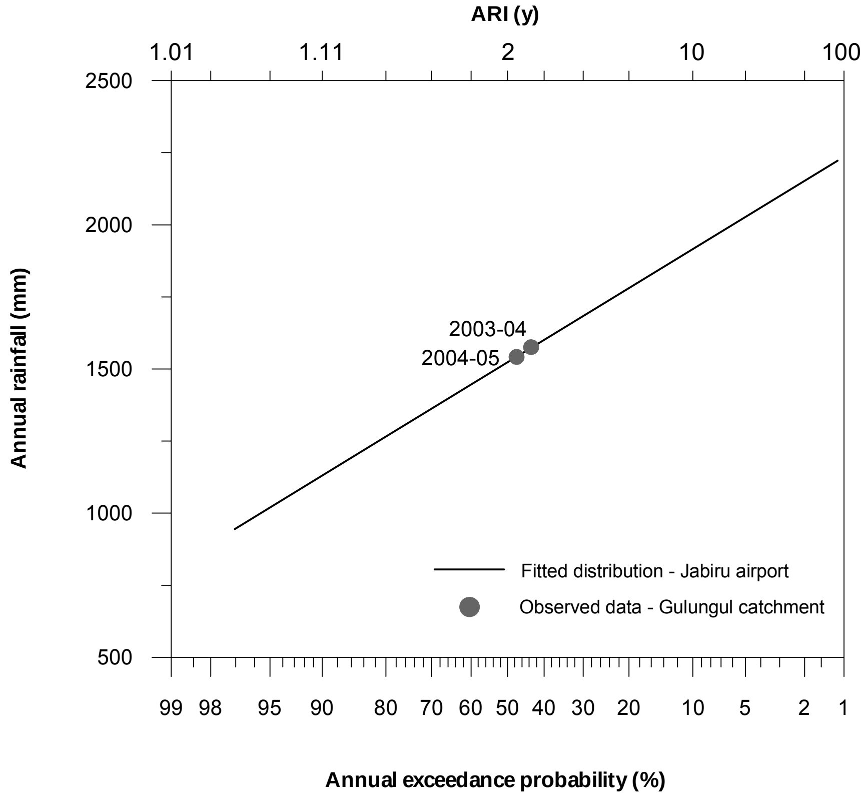

Figure 6 Annual rainfall frequency curve for Jabiru airport. The 2003–04 and 2004–05 rainfall data for the Gulungul Creek catchment are also shown.

3 Runoff data

Stage height (m) at each gauging station 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 (Appendix B).

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 stable cross section at each station at various times over a range of flows. The rating curves were fitted using the software package Hydstra.

GCUS

Velocity-area gaugings taken at GCUS throughout the two wet seasons were sufficient to derive a rating curve for that site (fig 7). Figure 7 indicates that the fitted curve is considered relatively accurate for within-channel flow (most flow conditions) but, given no gaugings were taken at overbank flow, it is not reliable for infrequent, high magnitude flood events. The highest recorded stage height at GCUS of 2.52 m, which occurred on 3 February 2005, is almost one metre above the highest velocity-area gauging (fig 8). Therefore, it is strongly recommended that several high flow velocity-area gaugings are taken during the next wet season to further refine the ‘top end’ of the rating curve.

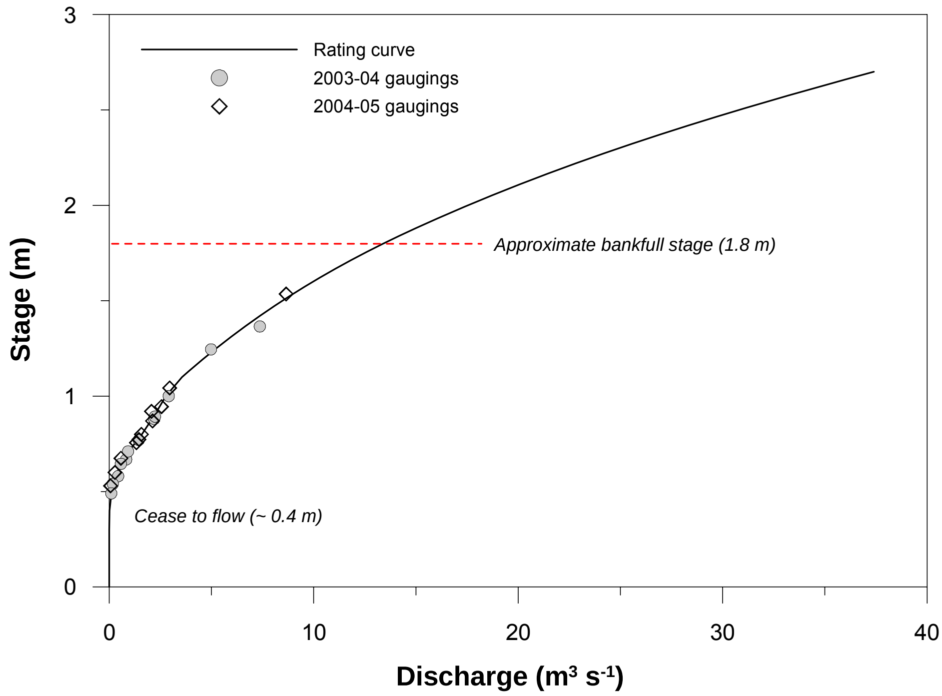

Figure 7 Rating curve for GCUS with the gauging points taken during 2003–04 and 2004–05 shown

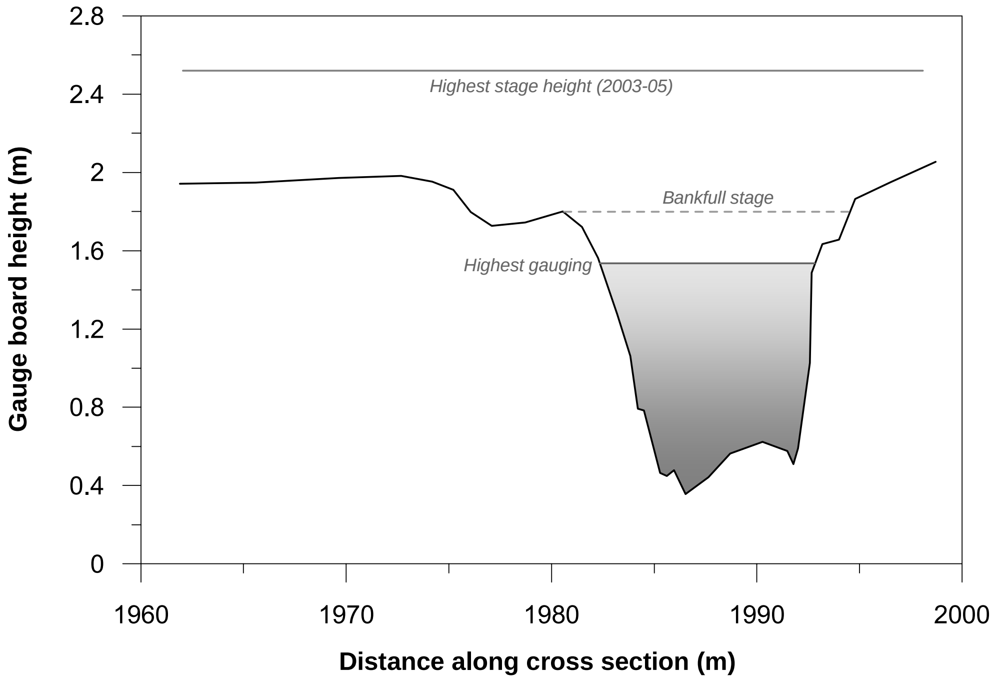

Figure 8 Cross section at GCUS taken during August 2005

G8210012

A series of rating curves were previously fitted for G8210012 by DIPE using 107 velocity-area gaugings taken between 1971 and 1993. The velocity-area gaugings taken by ***eriss*** throughout 2003–04 and 2004–05 at G8210012 fit on the most recent of these rating curves (fig 9) and, therefore, it is considered that this previously-derived rating curve was appropriate for the 2003–04 and 2004–05 wet seasons. 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 DIPE well above bankfull stage (fig 10).

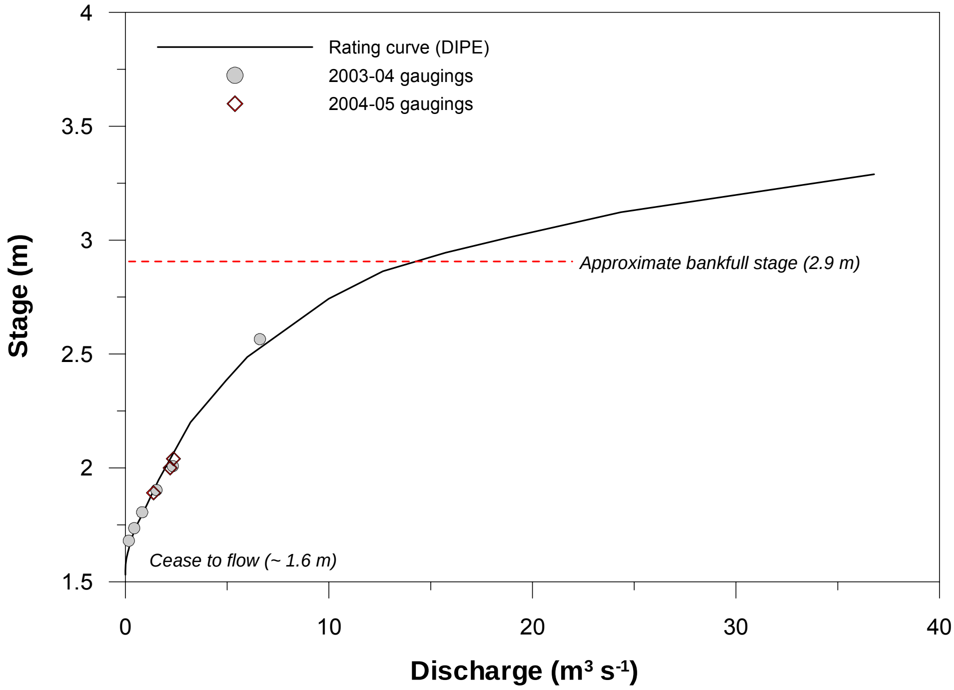

Figure 9 Rating curve for G8210012 with the gauging points taken during 2003–04 and 2004–05 shown

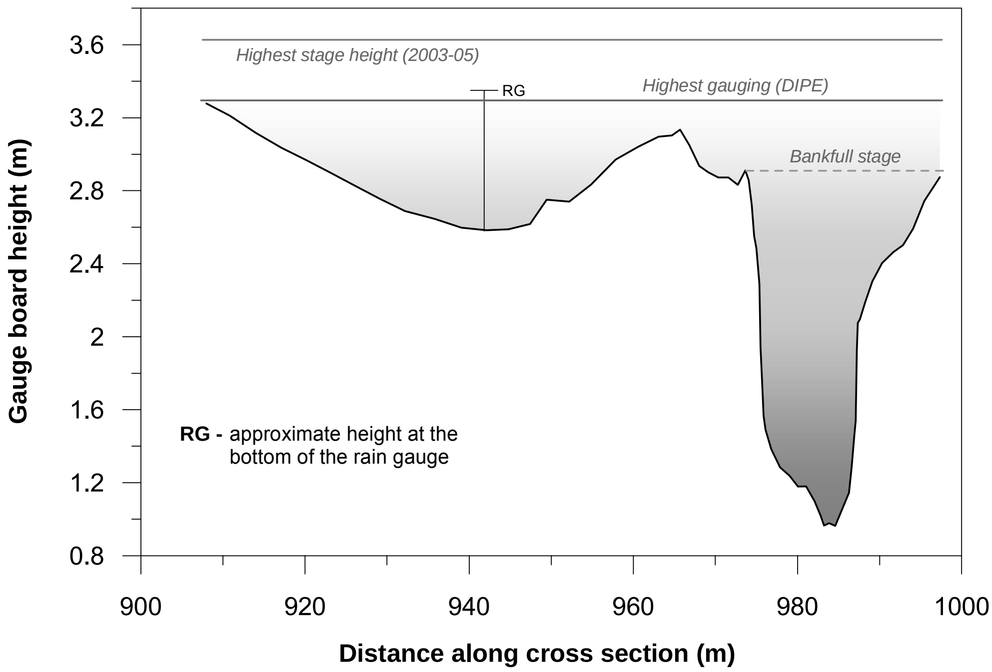

Figure 10 Cross section at G8210012 taken during August 2005

GCDS

Velocity-area gaugings were taken throughout the 2004–05 wet season at GCDS but these were insufficient to derive a rating curve for the station. More velocity-area gaugings need to be taken at this station during 2005–06 over a range of flows and particularly at higher flows.

3.2 Annual hydrograph

The complete hydrographs for GCUS and G8210012 for the 2003–04 and 2004–05 wet seasons are shown in figures 11 and 12. The stage data collected at GCDS for the second half of the 2004–05 wet season are shown in figure 12.

The total runoff for each wet season at GCUS and G8210012, determined as the area under the hydrograph, is given in table 3. Total annual runoff at GCUS and G8210012 during 2003–04 is incomplete. Gaps in the runoff record occurred between 20–24 February 2004 and 30 January – 2 February 2004 at GCUS and G8210012, respectively (fig 11). Based on the rainfall record, it is considered that only relatively minor runoff events occurred during these gaps. In both cases when the gap occurred, the corresponding volume of runoff observed at the other station equated to less than 4% of the total annual runoff.

The total annual runoff at G8210012 during 2004–05 (table 3) is similar to the average annual runoff volume of 25 548 ML, derived using the historical runoff record by Moliere (2005). This is an expected result given that the total annual rainfall recorded within the Gulungul Creek catchment corresponded to a 1:2.1 rainfall year (slightly above average).

Overbank flow

Survey data taken across the cross section at GCUS and G8210012 (figs 8 and 10 respectively) indicate that the channel bankfull stage is approximately 1.8 m and 2.9 m at the two sites, respectively. Using the rating curves derived for these two stations (figs 7 and 9), the bankfull discharges for GCUS and G8210012 are 13.4 $m^3 s^{-1}$ and 14.3 $m^3 s^{-1}$, respectively. Figures 11a and 12a show that overbank flow occurred five and four times during 2003–04 and 2004–05, respectively, at GCUS. At G8210012 overbank flow occurred seven and four times during 2003–04 and 2004–05, respectively (figs 11b and 12b). This is relatively frequent compared to studies by McDermott and Pilgrim (1983) and Pilgrim (2001) who established an annual occurrence interval of one year for bankfull discharge in tropical streams (particularly given that these two wet seasons were average rainfall years).

As discussed in Section 3.1, no velocity-area gaugings were conducted during overbank flow at GCUS, so the discharge during these nine events is unreliable. It is well known that during overbank flow a minor rise in stage can result in a dramatic increase in stream discharge, but the current rating curve for GCUS (fig 7) does not reflect such a trend. As a consequence, it is likely that the hydrographs for these nine overbank runoff events are substantially underestimated. Therefore, the total annual runoff at GCUS for both years (given in table 3) is also likely to be underestimated. The total amount of time that flow at GCUS exceeded bankfull discharge was only 34 h and 53 h during 2003–04 and 2004–05 respectively, which is approximately 1% of the runoff period (table 3). However, the corresponding volume of runoff at G8210012 that occurred during that same period was approximately 15% of the total annual volume of runoff for both years. This result indicates the importance of fitting an accurate rating curve for GCUS (and GCDS), particularly over the high or overbank flow range.

Antecedent rainfall

The antecedent rainfall, which is defined as the amount of rainfall between the start of rainfall and the start of streamflow, during 2003–04 and 2004–05 at GCUS and G8210012 is given in table 3. The antecedent rainfall at GCUS and G8210012 for the two years is similar to the mean antecedent rainfall derived for the Gulungul Creek catchment of 295 mm (Moliere 2005).

Table 3 Total annual rainfall and runoff at each gauging station for the 2003–04 and 2004–05 wet seasons

Year	Station	Total rainfall (mm) (from table 2)	Antecedent rainfall (mm)	Runoff period	Total runoff (ML) [Peak discharge (m^3s^{-1})]
2003–04	GCUS	1540	317	21 Dec – 1 July	27041*(1) [23.2]
	G8210012	1611	289	21 Dec – 1 July	31412(1) [67.6]
2004–05	GCUS	1591	281	18 Dec – 25 Jun	23846* [31.4]
	G8210012	1492	319	22 Dec – 10 Jun	25113 [78.8]

* Total annual flow is likely to be underestimated

(1) Gap in runoff record

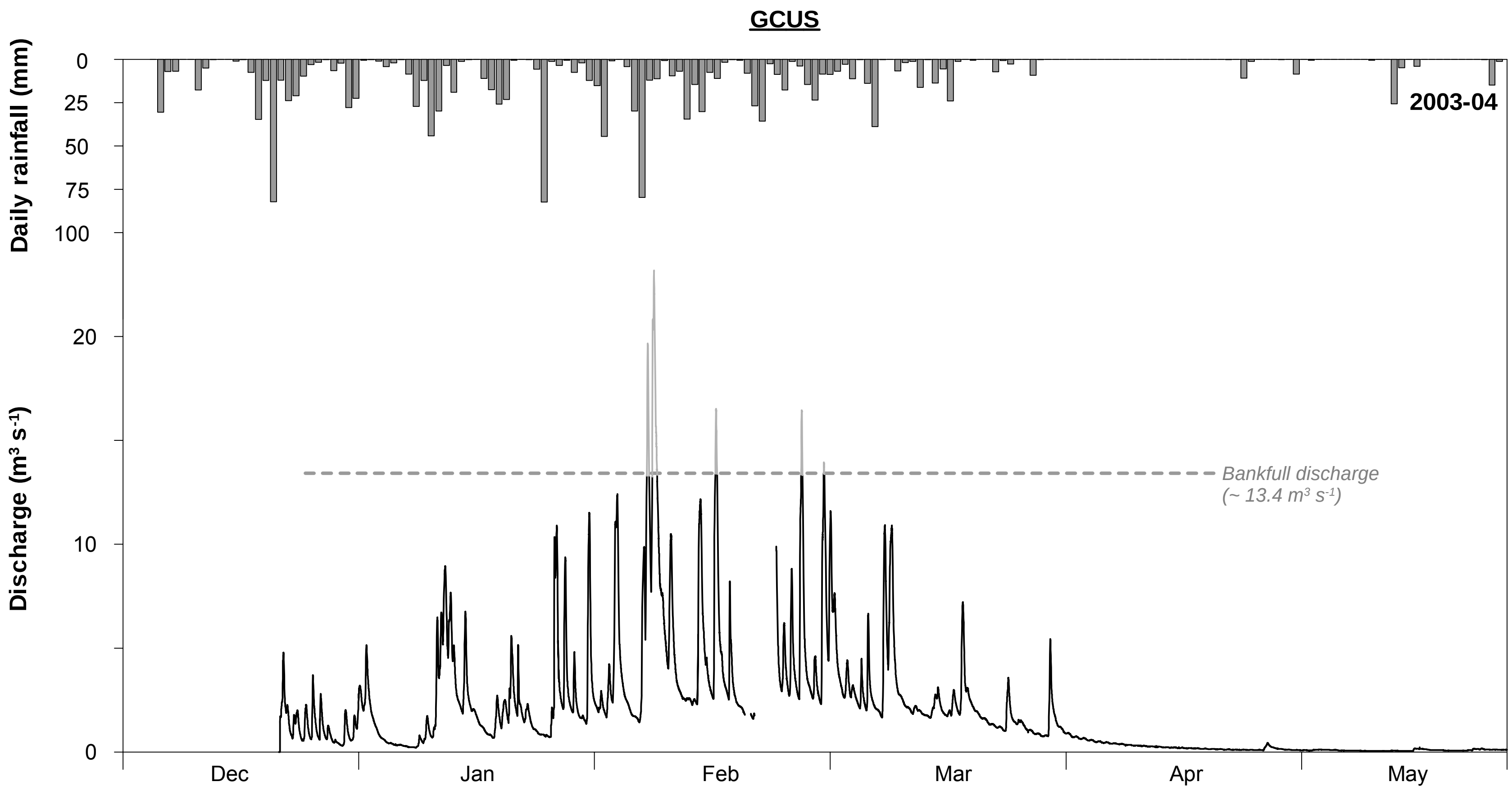

Figure 11a Daily rainfall and the hydrograph for GCUS during the 2003-04 wet season. Estimated sections of the hydrograph are shown as a grey line.

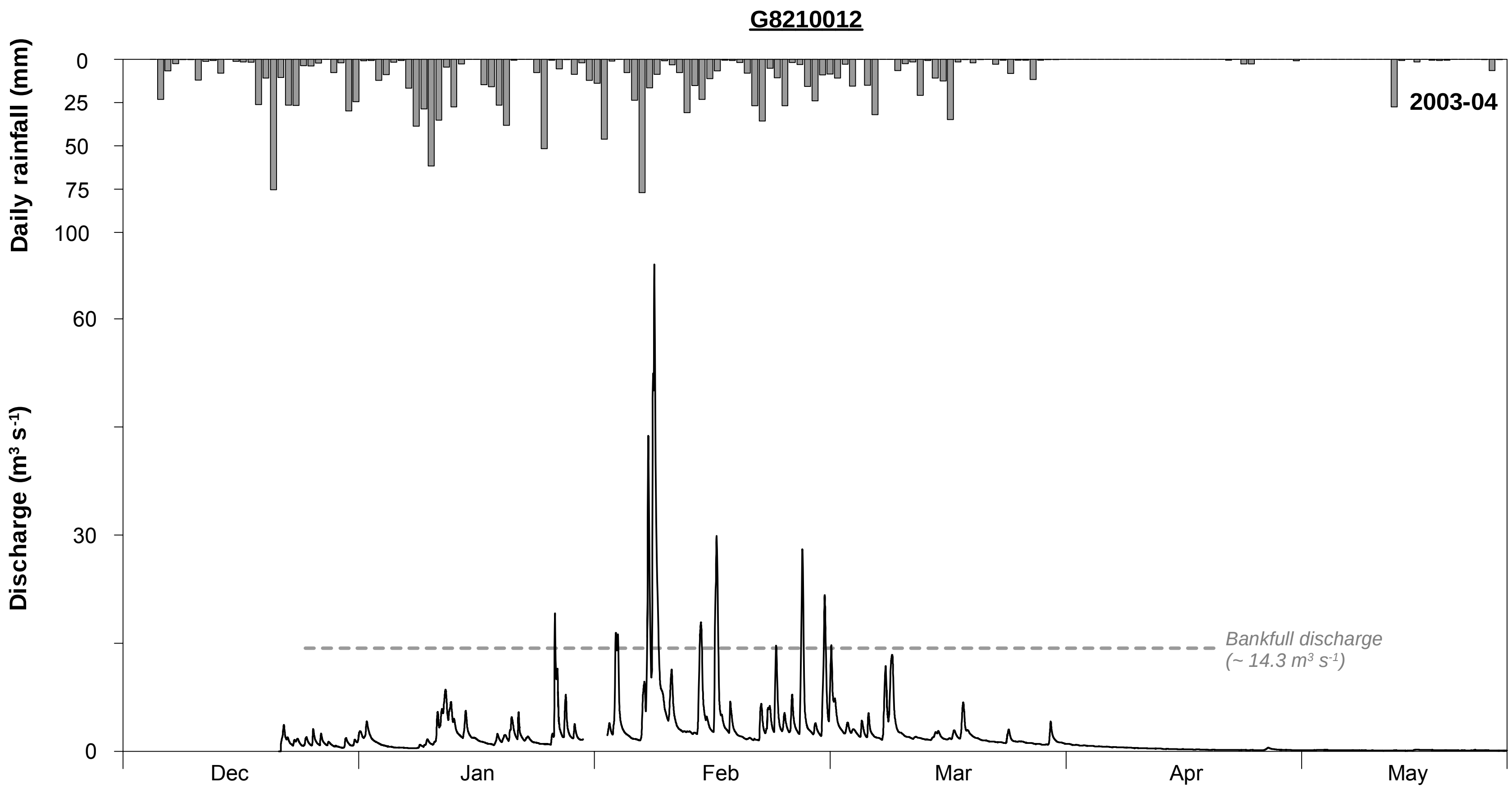

Figure 11b Daily rainfall and the hydrograph for G8210012 during the 2003-04 wet season

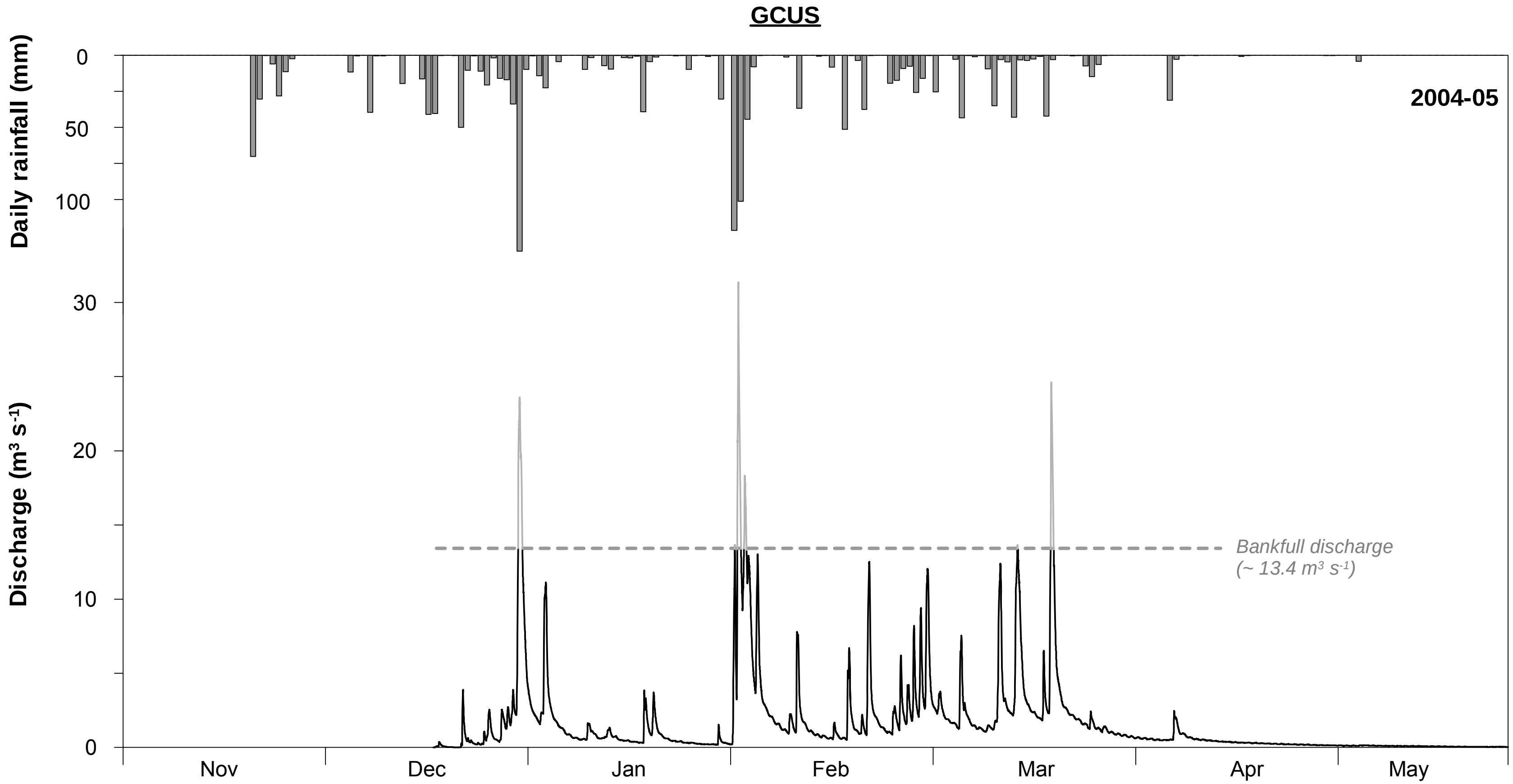

Figure 12a Daily rainfall and the hydrograph for GCUS during the 2004-05 wet season. Estimated sections of the hydrograph are shown as a grey line.

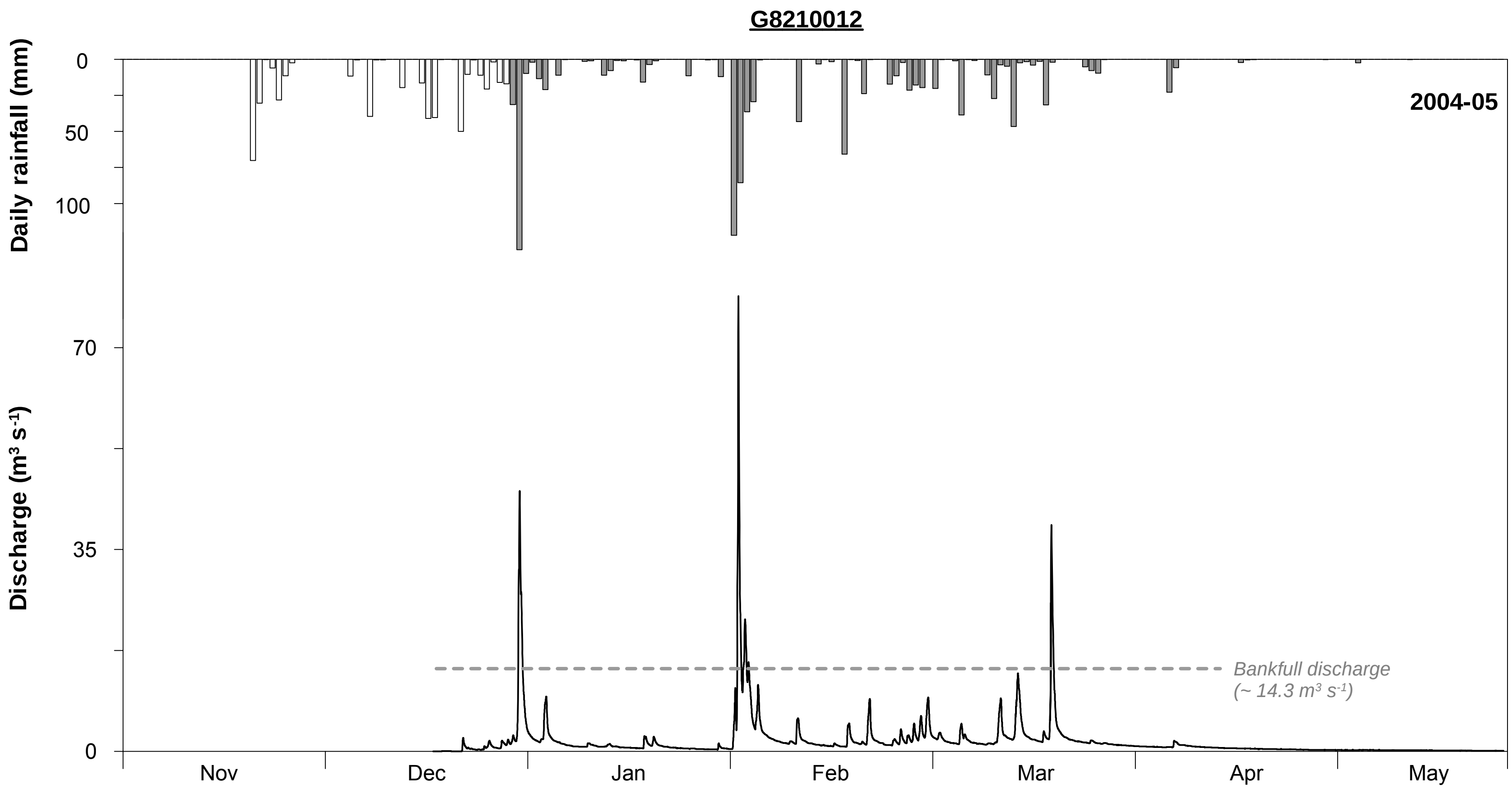

Figure 12b Daily rainfall and the hydrograph for G8210012 during the 2004-05 wet season. Rainfall data used to infill the rainfall record at G8210012 are shown as white bars.

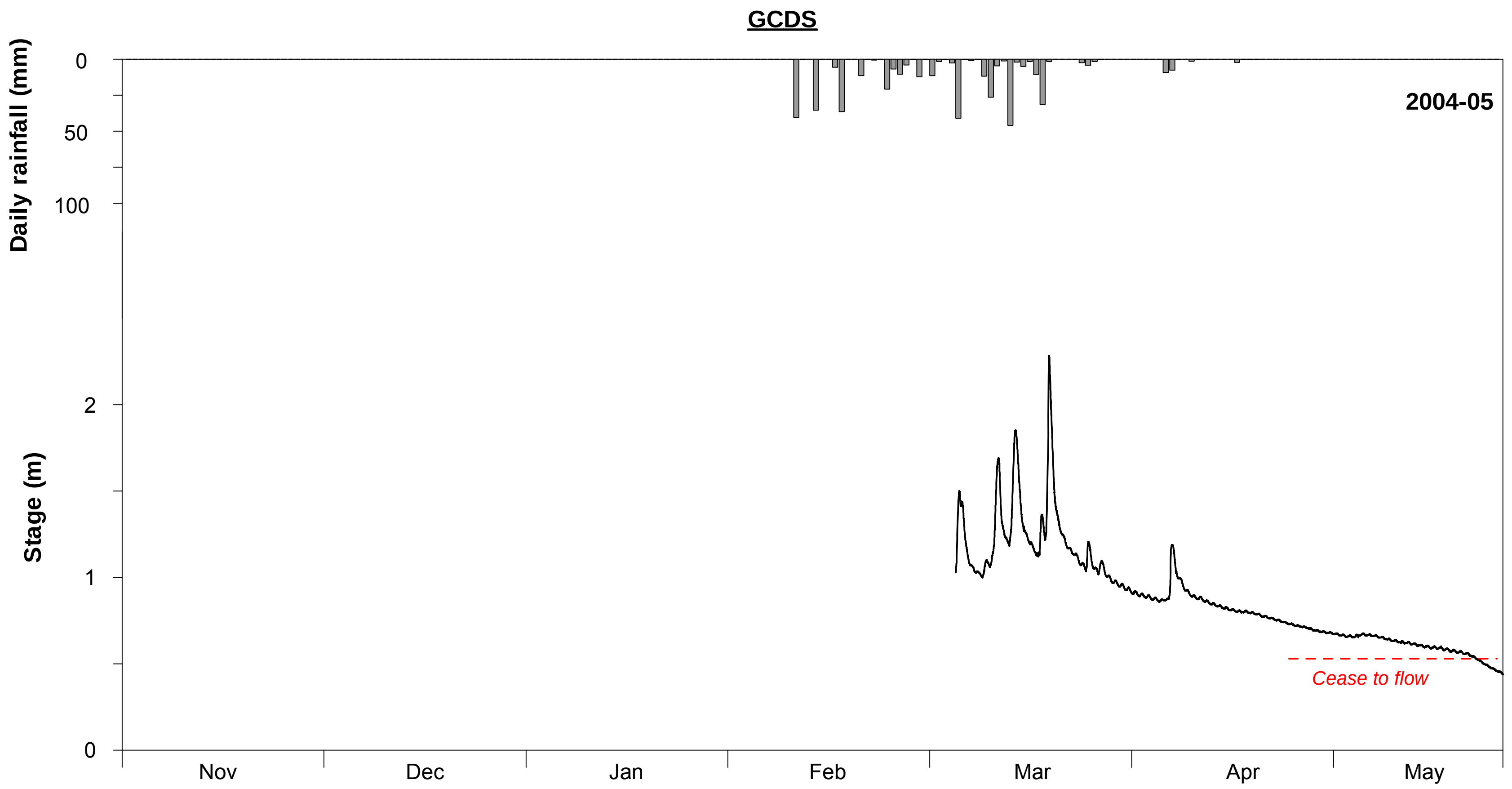

Figure 12c Daily rainfall and stage data for GCDS during the 2004-05 wet season

4 Suspended sediment data

During the 2003–04 and 2004–05 wet seasons, turbidity data were collected at GCUS at 6-minute intervals throughout the annual hydrograph by an Analite turbidity probe. The probe was calibrated in the laboratory prior to each wet season using polymer-based turbidity standards. To derive a turbidity-mud concentration (mud *C*) relationship for the station, water samples were collected by a stage-activated pump sampler during the 2004-05 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 (with a capacity of 24 water samples) was installed at GCUS and, therefore, no more than 24 samples were collected per site visit.

A significant relationship between turbidity and mud *C* was fitted for GCUS (fig 13). This relationship is very similar to that fitted for gauging stations within the Ngarradj catchment (Moliere et al 2005a), located approximately 15 km north-east of the Gulungul Creek catchment. The continuous stream mud *C* at GCUS for the 2003–04 and 2004–05 wet seasons, collected using turbidimeters and converted to concentration using the regression relationship (fig 13), is shown in figure 14.

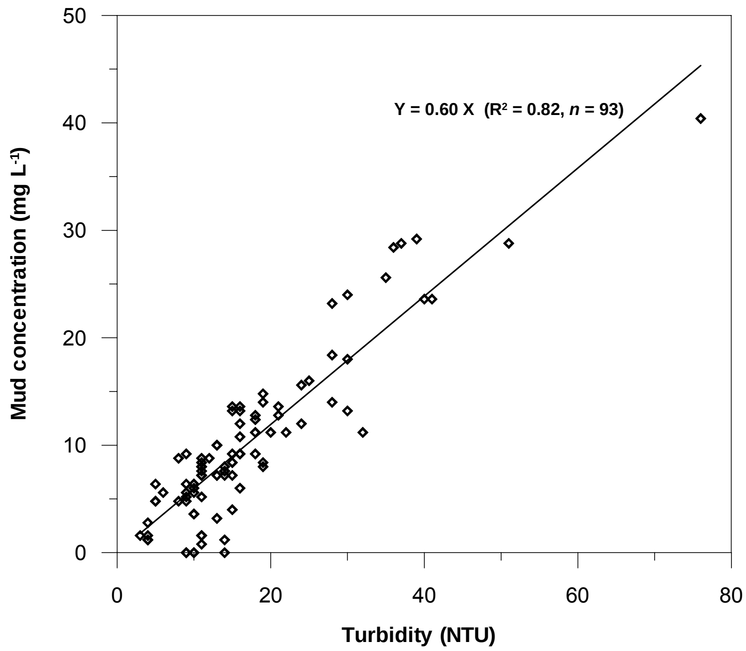

Figure 13 Relationship between turbidity and mud concentration for GCUS

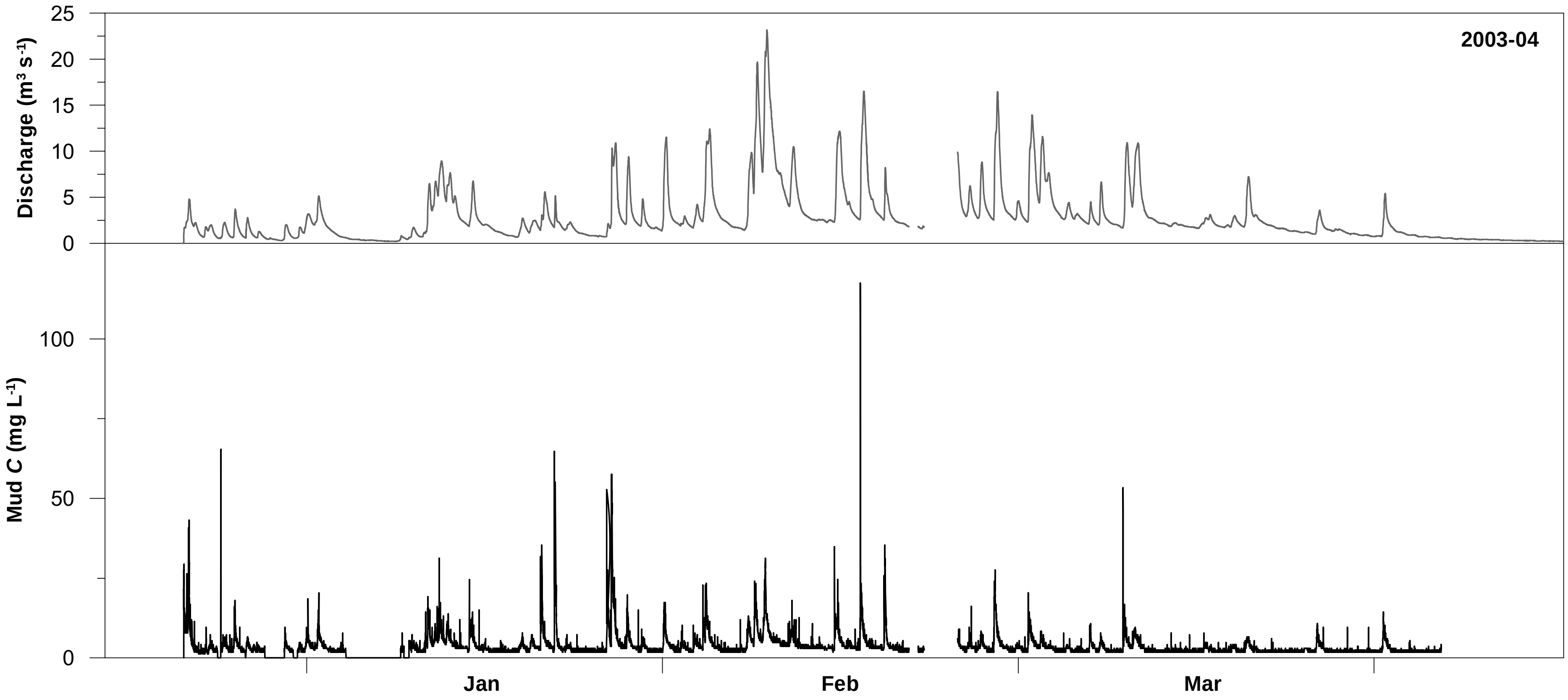

Figure 14a Continuous mud *C* data derived from the turbidimeter record for the 2003-04 wet season at GCUS. Discharge data are also shown.

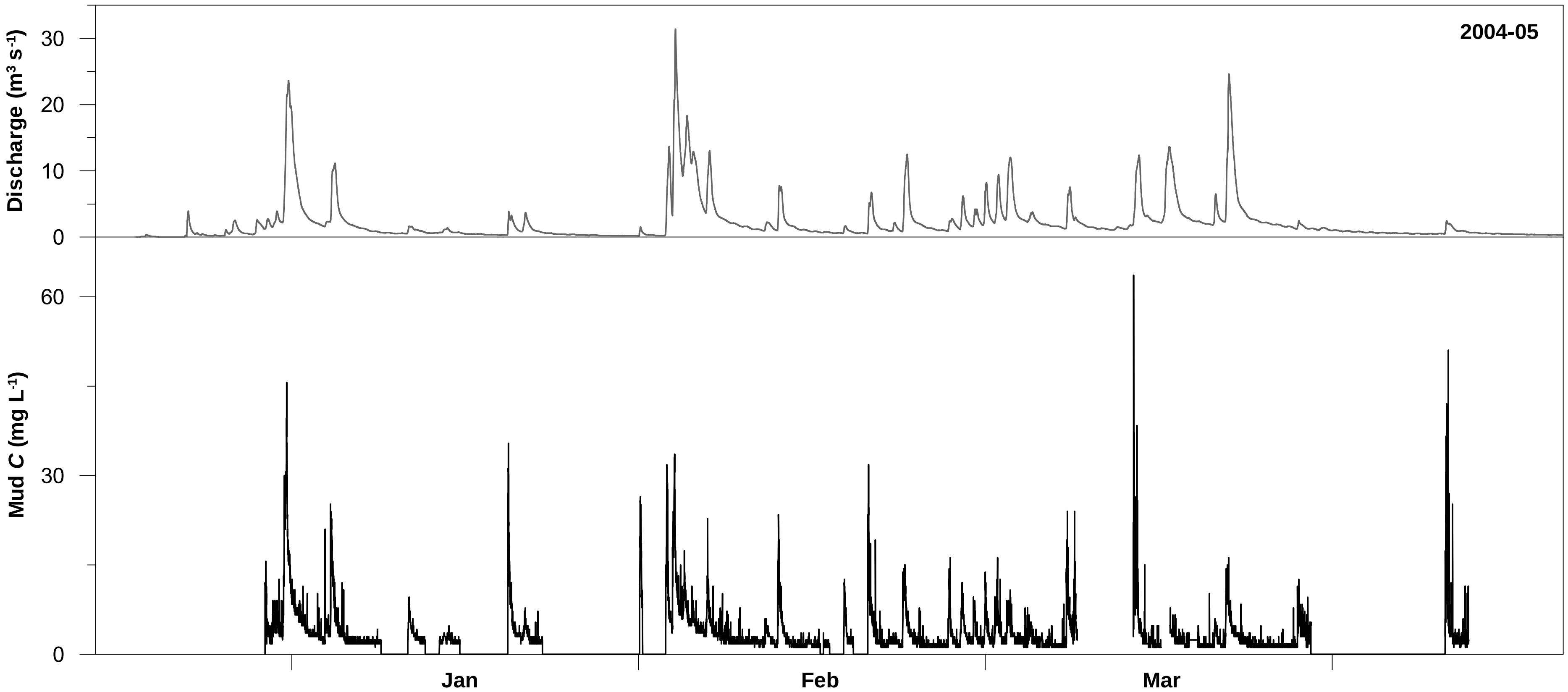

Figure 14b Continuous mud *C* data derived from the turbidimeter record for the 2004-05 wet season at GCUS. Discharge data are also shown.

4.1 Missing data

During both wet seasons there were periods where no turbidity data were recorded at GCUS, which means that the annual sedigraphs are incomplete.

Figure 14 shows that there are several periods where mud *C* is zero after flow has commenced at the station (ie a few short periods during the early part of the 2003–04 wet season and some significant periods during January, February and April 2005). 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 1–4 mg L^{-1}.

During 2003–04 there was a gap in the mud *C* data between 20–24 February 2004 (fig 14a) which occurred as a result of an error made during the download process. According to the rainfall record at GCUS and the runoff record at G8210012, two relatively minor runoff events occurred during this period. Therefore, it is likely that spikes in mud concentration, albeit small, occurred during this gap in the record.

During 2004–05 there were two periods (9–14 March 2005 and 17 March 2005) where very poor turbidity data were collected at GCUS. During these periods, rapid, unnatural spikes in turbidity measurements occurred, possibly caused by debri caught on the turbidity probe which effected the data. These data were omitted from figure 14. According to the runoff record, no events occurred during 9–14 March 2005 (fig 14b) and, therefore, it is unlikely that any spikes in mud *C* occurred during this gap in the record. However, given a relatively minor runoff event occurred on 17 March 2005, it is likely that a small spike in mud *C* occurred on this day.

5 Conclusions and future work

Continuous rainfall, runoff and mud concentration data collected within the Gulungul Creek catchment during 2003–04 and 2004–05 are presented in this report. Water samples were collected at GCUS (upstream of Ranger) to derive a turbidity-mud concentration relationship for the site.

Prior to the 2005–06 wet season it is recommended that:

- the rain gauge at G8210012 is placed on a higher stand to ensure that streamflow will not rise above the rain gauge (and affect rainfall data) during a major flood event. It is considered that the rain gauge needs to be elevated approximately 500 mm above it’s current position to ensure that streamflow associated with up to 1:30 y peak discharges will not affect the rainfall data.
- a second instrument for stage data collection connected to a second datalogger (independent of the current datalogger) is installed at GCUS and GCDS. Should one of the instruments fail during the period of flow, the other could be used as a back-up. This would significantly reduce the likelihood of gaps in the runoff record occurring in the future.

During the 2005–06 wet season it is recommended that:

- several high flow velocity-area gaugings are taken at GCUS and GCDS to refine the ‘top end’ of the rating curve for GCUS and to fit a rating curve for GCDS.

- continuous turbidity data are collected at GCDS. Similar to GCUS, water samples should also be collected during runoff events for mud concentration analysis in order to establish a turbidity-mud concentration relationship for GCDS.
- water samples continue to be collected at GCUS to validate the turbidity-mud concentration relationship fitted in this report.
- the technique of measuring the median turbidity value every 6 minutes rather than simply collecting a spot turbidity reading is investigated. For example, program the turbidimeter to record 10 turbidity readings over one 10 second period every 6 minutes. Using a median turbidity value at 6-minute intervals may reduce the 'spikey' nature of the sedigraphs (fig 14).

It is anticipated that after the completion of the 2005–06 wet season, the following analyses will be conducted:

1 Continuous mud concentration data collected at GCUS and GCDS during 2005-06 will be used to establish preliminary trigger values for an event-based Before-After-Control-Impact, paired difference design (BACIP). Similar to that derived for Ngarradj (Moliere et al 2005b), GCUS and GCDS will be treated as paired sites and the comparison of event load ratios will be used to provide the basis for future impact assessment.

2 Using three years of runoff data, observed event peak discharges at GCUS can be compared with corresponding peak discharges at G8210012 to investigate whether or not the long-term runoff record at station G8210012 can be used to extrapolate the record at GCUS. A significant relationship between event peak discharges at the two stations could be used to estimate values at GCUS for the period of record available at G8210012 (1971–1993). A flood frequency curve could then be established for GCUS using the extended runoff record.

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Appendix A – Gauging station details

Station name:	GCUS
Date installed:	November 2003 (as a temporary station)
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 – Hawk water level pressure transducer 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 fortnightly

Station location:

Site	Area (km^2)	Decimal degrees [WGS84]		AMG [Zone 53]	
		Lat	Long	Lat	Long
GCUS 40		12.40532	130.8778	270885. 3	8594555

Staff post:

The staff post in the creek channel has an assumed datum with 3 x 1.0 m gauge plates (assumed datum is 0.0 – 1.0 m, 1.0 – 2.0 m and 2.0 – 3.0 m) (fig A1).

Figure A1 Staff post and gauge plates at GCUS

Station name: G8210012

Date re-installed: November 2003 (originally installed November 1971 by PAWA and ceased operation December 1993)

Custodian: Environmental Research Institute of the Supervising Scientist

Data collected: Rainfall and stage at 6-minute intervals

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

Stage – Hawk water level pressure transducer

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

Download frequency: Approximately fortnightly

Station location:

Site	Area (km²)	Decimal degrees [WGS84]		AMG [Zone 53]	
		Lat	Long	Lat	Long
GCUS 46		12.68945	132.8839	270197.7	8596274

Staff post:

The staff posts at G8210012 have an actual datum tied to a benchmark. However, we use an assumed datum with 4 x 1.0 m gauge plates. The staff post in the creek channel has 2 x 1.0 m plates (assumed datum is 0.0 – 1.0 m and 1.0 – 2.0 m); the staff post on the channel bank has 1 x 1.0 m plate (assumed datum is 2.0 – 3.0 m), and; the staff post on the stilling well has 1 x 1.0 m plate (assumed datum is 3.0 – 4.0 m) (fig A2).

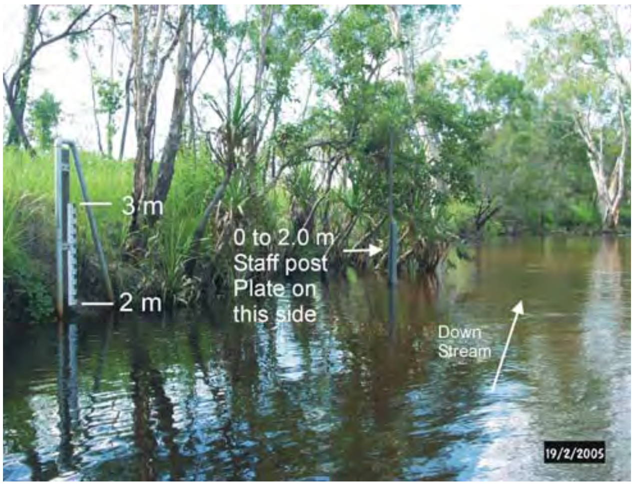

Figure A2 Staff posts and gauge plates at G8210012

Station name: GCDS

Date installed: February/March 2005 (as a temporary station)

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 – Hawk water level pressure transducer

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 fortnightly

Station location:

Site	Area (km^2)	Decimal degrees [WGS84]		AMG [Zone 53]	
		Lat	Long	Lat	Long
GCUS 66		12.65825	132.8783	269561.3	8599721

Staff post:

The staff post in the creek channel has an assumed datum with 3 x 1.0 m gauge plates (assumed datum is 0.0 - 1.0 m, 1.0 - 2.0 m and 2.0 – 3.0 m) (fig A3).

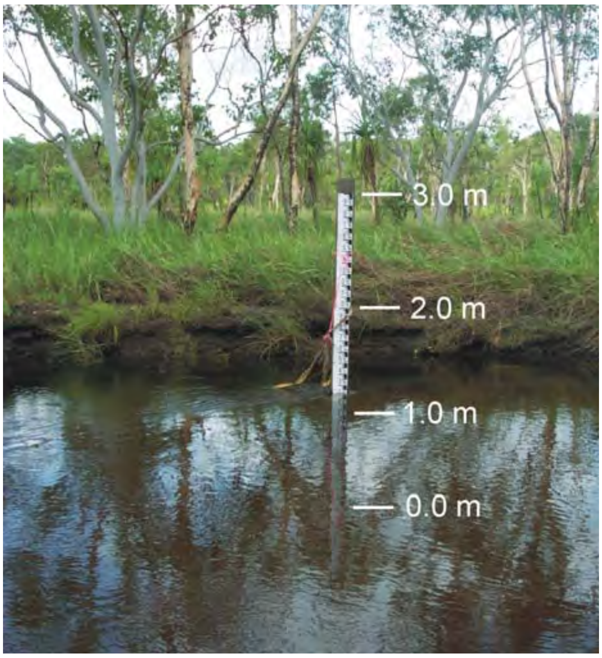

Figure A3 Staff post and gauge plates at GCDS

Appendix B – Gauge board readings

Table B.1 Stage measured at the gauge board and by the pressure transducer at each site (2003–05)

	Stage height (m)					
	GCUS		G8210012		GCDS	
Date	Gauge board	PT	Gauge board	PT	Gauge board	PT
23 Dec 03	0.76	0.78	1.89	0.91		
23 Dec 03	0.79	0.80				
06 Jan 04	0.58	0.59	1.74	1.74		
06 Jan 04	0.58	0.58				
19 Jan 04	0.78	0.77	1.91	1.90		
19 Jan 04	0.77	0.76	1.90	1.90		
28 Jan 04			2.11	2.11		
02 Feb 04	0.87	0.87	2.06	2.06		
02 Feb 04	0.89	0.89				
03 Feb 04			2.07	2.06		
03 Feb 04			2.09	2.08		
16 Feb 04	1.00	0.99				
17 Feb 04	1.38	1.38	2.59	2.60		
17 Feb 04	1.35	1.35				
02 Mar 04	1.25	1.25				
16 Mar 04	0.90	0.89	2.01	2.00		
30 Mar 04	0.71	0.70				
06 Apr 04	0.65	0.64				
20 Apr 04	0.54	0.53	1.68	1.68		
04 May 04	0.49	0.49				
13 May 04	0.46	0.46				
29 Dec 04	0.76	0.76	1.86	1.85		
06 Jan 05	0.79	0.79	1.94	1.94		
24 Jan 05	0.62	0.62	1.76	1.76		
07 Feb 05	0.95	0.95				
08 Feb 05	0.87	0.87	2.00	2.04		
08 Feb 05	0.87	0.86				
09 Feb 05	0.80	0.80				
10 Feb 05	0.76	0.75				
25 Feb 05	0.77	0.77	1.89	1.90		
09 Mar 05	1.05	1.06	2.15	2.13	1.45	1.46
09 Mar 05	1.04	1.04				
10 Mar 05	0.87	0.87			1.25	1.24
22 Mar 05	0.92	0.93	2.04	2.04	1.29	1.28
05 Apr 05	0.68	0.66	1.82	1.81	0.92	0.92
19 Apr 05	0.60	0.60	1.76	1.75	0.82	0.83
02 May 05	0.53	0.53	1.69	1.69	0.71	0.71
16 May 05	0.48	0.48	1.66	1.65	0.63	0.63
31 May 05	0.43	0.44	1.62	1.63		
Average Difference		<0.01 m		<0.01 m		<0.01 m