4 Flood frequency analysis

To establish a better understanding of the hydrological characteristics of the Gulungul Creek catchment, a flood frequency curve was derived for the station G8210012. The flood frequency curve, which was fitted mathematically to the historical observed data, can be used to estimate the probability of exceedance for runoff events of a certain magnitude (Pilgrim 2001). As a consequence, the flood frequency curve has important applications for sediment transport analysis and flood risk assessment in the Gulungul Creek catchment.

As discussed above in Section 3.1, six of the 22 years of record have significant gaps in the annual runoff data (table 3). Before undertaking flood frequency analysis, it was necessary to determine whether it was likely that the annual peak discharge (Q_p) for these six years occurred during the gaps in the data or not.

4.1 Missing records

Rainfall records on the catchment or streamflow data from nearby catchments can be used to indicate the likelihood of a large flood having occurred during a gap (Pilgrim 2001).

The nearest gauging station to G8210012 with a significant runoff record is G8210009, which is located along Magela Creek, downstream of Ranger mine (fig 1). The catchment area upstream of G8210009 is adjacent to the Gulungul Creek catchment. The gauging station G8210009 was installed in 1971, the same year as G8210012, and is still operating today. Before the record at G8210009 can be used to indicate the likelihood of a large flood having occurred during the gap at G8210012, it is important to determine if there is a strong relationship between the two concurrent records.

4.1.1 Relationship between G8210012 and G8210009 flow data

Regression analysis was conducted for concurrent flow records (1971 to 1993) to determine the strength of the correlation between the two stations. Major event peak discharges observed at G8210012 were compared to the corresponding peak discharge at G8210009 for the same storm. The storms that contributed to the observed Q_p at G8210012 were used in this analysis. (For all but two of the 22 years of record, the corresponding runoff event at G8210009 was one of the largest peak discharges of the year. For the two remaining years, there was little evidence of a corresponding runoff event having occurred at G8210009, and as a result, they were not included in the regression analysis.)

Figure 6 shows that the relationship between floods that occurred in the same storm at the two adjacent catchment areas is statistically significant. The Magela Creek catchment area upstream of G8210009 (approximately 600 km^2 (DIPE pers comm)) is considerably larger than the Gulungul Creek catchment area upstream of G8210012 (46 km^2). Therefore, given the strong correlation between peak discharges observed at the two station locations, this analysis indicates that the annual peak discharge at G8210012 is usually a result of a very large, widespread storm event that occurs over the upper reaches of both catchment areas.

The regression analysis indicates that the streamflow data from the Magela Creek catchment may indicate the likelihood of a large flood having occurred during the gap in the runoff record at Gulungul Creek. However, figure 6 also shows that the degree of correlation is insufficient to enable a missing flood to be reliably estimated. For example, if a runoff event occurred at G8210009 with a peak discharge of approximately 500 m^3 s^{-1} (mean annual peak discharge), the corresponding peak discharge at G8210012 is 78 m^3 s^{-1}, with a 95% probability of being between 34 m^3 s^{-1} and 180 m^3 s^{-1}.

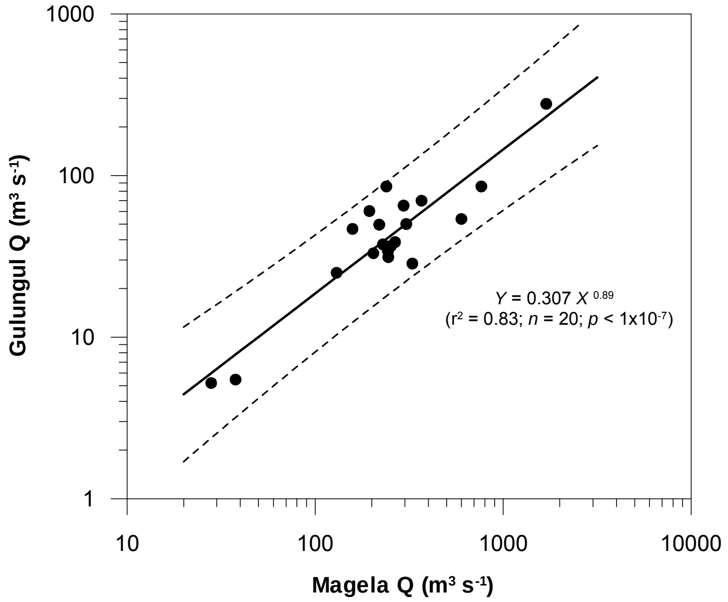

Figure 6 Fitted relationship between peak flood discharges observed at G8210012 (Gulungul) and G8210009 (Magela). The 95% prediction limits (dashed lines) are also shown.

4.1.2 Flow (G8210009) and rainfall during gaps in the record at G8210012

Both the runoff data observed at G8210009 and the daily rainfall data collected at Jabiru airport and the Tailings Dam were used to determine the likelihood of the annual peak discharge having occurred during a gap in the record at G8210012. Table 3 shows that there were six years with significant gaps in the runoff record at G8210012, and the likelihood of Q_p occurring during each gap is discussed below.

1972–73

As discussed in Section 3.1, it is considered that during these many small gaps in the annual hydrograph, runoff data were not recorded because flow dropped below instrument height. Only very minor rainfall occurred at Jabiru airport during these gaps in the record (Appendix B). Therefore, the observed Q_p (table 2) was used in the flood frequency analysis.

1973–74

The observed Q_p at G8210012 occurred on 19 March 1974 (table 2). The 24 h rainfall total that preceded Q_p between 1800 h on 18 March to 1800 h on 19 March was one of the largest 24 h totals for the year. The corresponding peak discharge at G8210009 was the second largest for the year.

Only relatively minor runoff events at G8210009 occurred during the gap in the record. There were no 24 h rainfall totals during the gap that exceeded that recorded on the 18–19 March. For these reasons, it is considered that the observed Q_p was larger than the runoff event that may have occurred during the gap in the record.

1974–75

The observed Q_p at G8210012 occurred on 15 February 1975 (table 2) and was the largest peak within a long duration, multi-peaked runoff event (Appendix B). The total rainfall for the week preceding this runoff peak was approximately 260 mm. The corresponding event at G8210009 on 15 February 1975 was the second largest peak discharge for the year.

The Q_p at G8210009 occurred during the gap in the record at G8210012 on 10 April 1975, however, the daily rainfall recorded at Jabiru airport for 9 April was only relatively minor

(< 40 mm (Appendix B) with a maximum rainfall intensity of < 7 mm h^{-1}). This indicates that the rainfall which contributed to the annual peak discharge at G8210009 may have primarily occurred over the upper reaches of the Magela catchment.

The largest rainfall event that occurred during the gap in the runoff record was 68 mm on 21 March 1975 (Appendix B) – the fourth largest daily total of rainfall for the year. The corresponding runoff event at G8210009 was the sixth largest peak discharge for the year.

In this case, because the observed Q_p corresponded to significant rainfall at Jabiru airport and to one of the largest runoff events at G8210009 for the year, it is considered that the observed Q_p was larger than the runoff event that may have occurred during the gap in the record.

1981–82

The observed Q_p at G8210012, which occurred on 12 March 1982 (table 2), was a result of the largest daily rainfall recorded for the year (91 mm at the Tailings Dam and 98 mm at Jabiru airport (Appendix B)). The corresponding event at G8210009 was the third largest peak discharge for the year.

The Q_p at G8210009 occurred during the gap in the record at G8210012 on 28 March 1982, however, the daily rainfall recorded at the two rain gauges for this event – the only period of rainfall to occur during the gap in the runoff record at G8210012 – was only relatively minor (< 45 mm) (Appendix B). Similar to 1974–75, this indicates that the rainfall that contributed to the annual peak discharge at G8210009 may have primarily occurred over the upper reaches of the Magela catchment.

In this case, because (1) the rainfall during the gap in the record was only relatively minor, and (2) the observed Q_p corresponded to the largest daily rainfall recorded for the year at both gauges and a significant runoff event at G8210009, it is considered that the observed Q_p was larger than the runoff event that may have occurred during the gap in the record.

1987–88

Both station rainfall records indicate that several significant rainfall events occurred during the gap in the runoff record at G8210012, all of which were larger than the rainfall that contributed to the observed Q_p (which was less than 25 mm at both stations on 15 March 1988). One of the largest rainfall events occurred on 9 February 1988 (68 mm at the Tailings Dam and 53 mm at Jabiru airport (Appendix B)). Q_p at G8210009 occurred on 13 February 1988, also during the gap in the record (table 3). However, the corresponding observed rainfall on 13 February that contributed to this event was only relatively minor at both Jabiru airport and the Tailings Dam.

The rainfall data indicate that it is likely Q_p occurred during the gap in the record (although it may not have occurred on the same day Q_p occurred at G8210009). Therefore, this year was omitted from the flood frequency analysis.

1990–91

The Q_p at G8210009 occurred during the gap in the record at G8210012 on 12 January 1991. This event corresponds to the largest daily rainfall for the year recorded at the Tailings Dam (73 mm) and the second largest at Jabiru airport (63 mm) (Appendix B). The rainfall event on 12 January 1991 was larger than that which contributed to the observed Q_p at G8210012 (< 30 mm at both stations) that occurred on 20 February 1991 (table 2).

In this case, both the streamflow data at G8210009 and the rainfall data indicate that it is likely that Q_p occurred at G8210012 during the gap in the flow record on 12 January 1991. Therefore, this year was omitted from the flood frequency analysis.

In summary:

- The observed Q_p at G8210012 during 1972–73, 1973–74, 1974–75 and 1981–82 were used in the flood frequency analysis, and
- 1987–88 and 1990–91 were omitted from the analysis.

4.2 Analysis

A log Pearson III distribution was fitted for the annual peak discharges for G8210012 using annual peak discharges for 20 years of record. Previous studies in the region have used a log Pearson III distribution to fit frequency curves to annual peak discharges observed along Magela Creek at G8210009 (Water Division 1982) and several streams within the Ngarradj catchment (Moliere et al 2002a, Boggs et al 2003), which is located approximately 15 km north-east of the Gulungul Creek catchment.

The following is a brief description of the method used for fitting and plotting a log Pearson III distribution to the annual peak discharge data based on Pilgrim (2001).

- The annual peak discharges for each wet season for the period of record were ranked in order of magnitude. The mean (M), standard deviation (S) and skewness (g) of the logarithms of the annual peak discharges were calculated (fig 7).
- Peak discharges for a range of annual exceedance probabilities (AEPs) were calculated using equation (1) (Pilgrim 2001):

  $$Ry = M + Ky\,S \qquad (1)$$

  where, Ry = the logarithm of peak discharge having an AEP of 1 in y years; Ky = frequency factor found from tables in Pilgrim (2001) for the required AEP.

  The fitted frequency curve is shown in figure 7.
- The plotting positions ($PP(m)$) of each annual peak discharge value (table 2) were calculated as a percentage using equation (2) and plotted on figure 7.

  $$PP(m) = (m - 0.4)/(N + 0.2) \times 100 \qquad (2)$$

  where, N is the number of years of record (20); m is the rank of the annual peak discharge value.

Figure 7 shows that while the frequency curve gives an adequate fit to most of the plotted annual floods (ie most of the data fit within the 5% and 95% confidence limits), it diverges 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.

A test for low outliers was performed as described in Pilgrim (2001). The test indicated that there was one outlier in the data series (fig 7). This low outlier was deleted from the dataset and a revised log Pearson III distribution was fitted to the remaining data (fig 8).

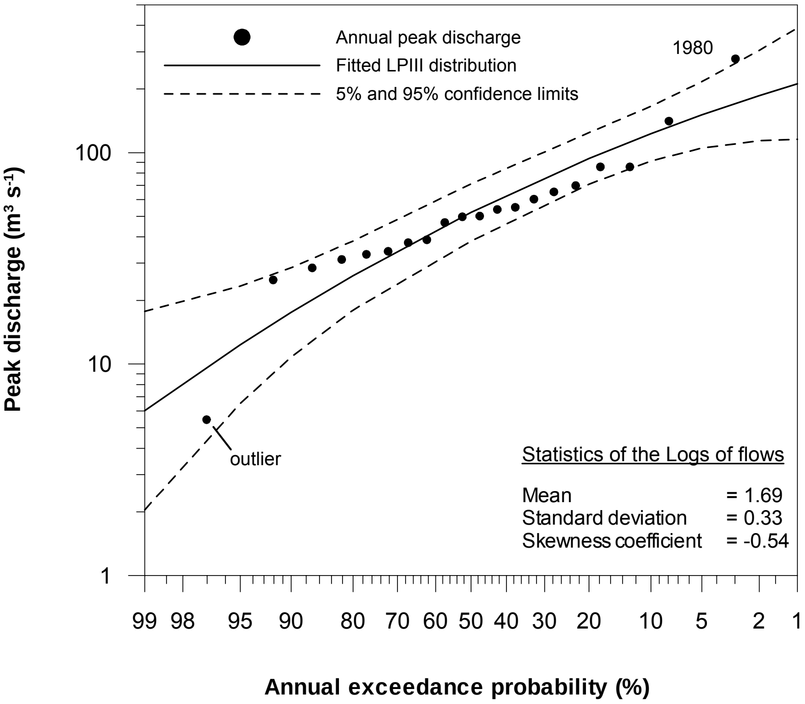

Figure 7 Frequency curve of annual peak discharge at G8210012

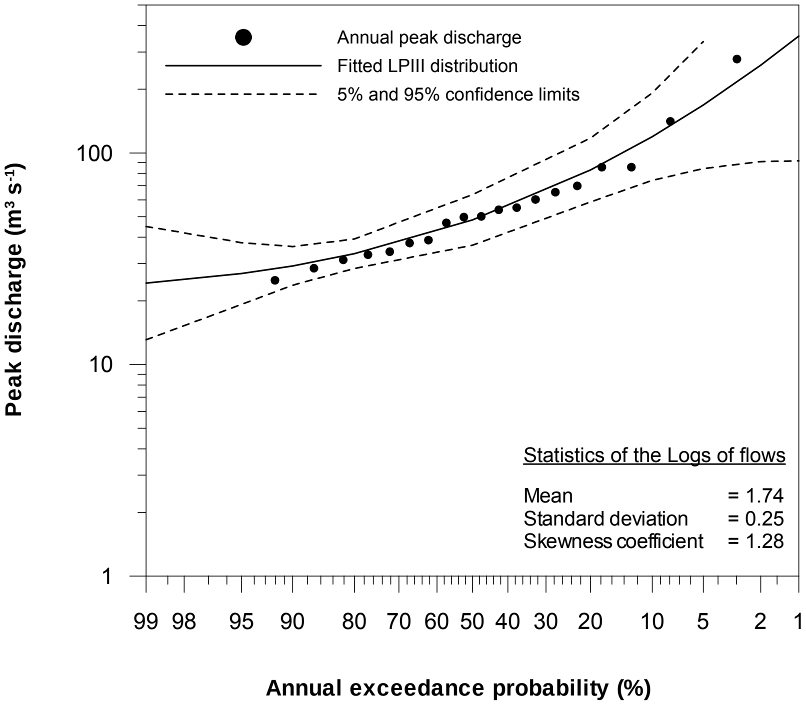

Figure 8 Adjusted frequency curve of annual peak discharge at G8210012 with one year omitted from the original dataset

Figure 8 shows that the adjusted frequency curve better fits the remainder of the observed peak discharge data compared with the frequency curve calculated for all 20 annual peak discharges. A summary of the AEPs and the corresponding peak discharges for G8210012 are shown in table 5.

Table 5 Summary of the fitted flood frequency distribution for G8210012

Annual Recurrence Interval (y)	Annual Exceedance Probability (%)	Peak discharge (fig 8) ($m^3 s^{-1}$)
2	50	48.2
5	20	83.1
10	10	119
20	5	168
50	2	260
100	1	357

4.2.1 Storm event – 4 February 1980

A detailed description of this extraordinary storm event on 4 February 1980 is given in Water Division (1982). Total rainfall recorded at the Jabiru airport and the Tailings Dam for the 48 h period between 0900 h on 3 February and 0900 h on 5 February 1980 was 301 mm and 346.4 mm respectively. The storm featured a very intense 5 h period between 0700 h and 1200 h on 4 February 1980 where a total of 226 mm fell at the Tailings Dam (an average of 45.2 mm h^{-1}) (Commonwealth Department of Housing and Construction 1980). Rainfall intensity over a 3 h, 6 h and 24 h duration corresponded to a greater than 1:100 y event (Moliere et al 2002a). Given that the period of record of flow data used in the above flood frequency analysis is only relatively short (19 y), the plotting position of this event only corresponded to a 1:34 y flood event (fig 8). However, the fitted flood frequency curve indicates that the peak discharge of this event may actually be greater than a 1:50 y event (table 5). Water Division (1982) considered that the return period for the corresponding peak discharge observed at G8210009 is likely to be 100 years. It is clear that on 4 February 1980 both the rainfall over the Gulungul Creek catchment and the resulting streamflow at G8210012 were statistically rare events.

4.3 Further work

A gauging station was installed at the upstream sampling site along Gulungul Creek (GCUS) (fig 1) in November 2003. Flow measurement equipment was also re-installed at G8210012 at the same time. It is proposed that a third gauging station is installed at the downstream sampling site along Gulungul Creek (GCDS) (fig 1) prior to the 2004–05 wet season.

Flood frequency curves for these two new stations within the Gulungul Creek catchment will be used to determine the long-term trends and flood risk assessment both upstream and downstream of the Ranger mine. This is particularly important to develop before rehabilitation at the mine site commences.

The reliability and the accuracy of the flood frequency analysis is increased the larger the runoff record. It is unlikely that the two new stations will have a significant runoff record for flood frequency analysis by the time rehabilitation at Ranger mine commences. 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 regression of observed peak discharges at the two new stations on 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).

4.3.1 Extreme flood events

Little is currently known of extreme flood events on the Magela Creek system (Evans & Johnston 1997, Erskine & Saynor 2000). An understanding of these extreme events in terms of their potential effect on mining operations within the Magela catchment is particularly important. For example, it is essential that estimates of high magnitude flood events in the Gulungul Creek catchment are reliable to ensure that the rehabilitated Tailings Dam can withstand the resultant high erosional forces (Pickup et al 1987, Erskine & Saynor 2000). Therefore, it is likely that the observed runoff record used for the above flood frequency analysis (Section 4.2) will need to be extended to develop a better understanding of these extreme events. The current observed record is too short (22 y) and only includes a maximum peak discharge 4.3 times greater than the mean annual flood. (Floods at least 10 times greater than the mean annual flood have destroyed many channels and floodplains in Australia (Erskine & Saynor 2000).)

The methods that could be used to extend the runoff record at gauging stations along the Gulungul Creek are:

1 Calibrate a catchment-based rainfall-runoff model using observed gauging station data (G8210012, GCUS and GCDS) and catchment characteristics. The calibrated model can then be used to (1) extend the runoff record from long-term rainfall records to establish a more reliable flood frequency curve; and (2) determine the resultant event hydrograph of extreme rainfall events.

2 Use palaeoflood hydrology to extend hydrologic records back in time (ie Pickup et al 1987, Erskine & Saynor 2000). Pickup et al (1987) suggest that the most successful palaeoflood technique is based on the use of slackwater deposits. Sand and fine material deposited on areas of backflow or sheltered areas during flood events provide a datable stratigraphic record from which a partial flood history can be reconstructed.

5 Runoff response

Using the 22-year runoff record at G8210012 and the rainfall data collected at Jabiru airport during the same period, an attempt has been made to characterise the runoff response of Gulungul Creek, both on a long-term average basis and on an individual event basis. As observed in the Ngarradj catchment (Moliere et al 2002b), the understanding of the runoff response in streams has important implications for the design of an effective sediment monitoring regime.

As discussed above (Section 2.1), the rainfall data collected from the rain gauge at the Tailings Dam, although within the Gulungul Creek catchment, were not suitable for this type of analysis and, therefore, were not used in this section. The rainfall data collected at Jabiru airport are not statistically different from rainfall at the Tailings Dam (Section 2.1) and, as a result, the rainfall intensity data collected at Jabiru airport were used in the analysis of runoff response in the Gulungul Creek catchment.

5.1 Diurnal rainfall and runoff

The mean hourly runoff for the complete period of record (22 y) at G8210012 exhibits a strong diurnal cycle with a peak early in the morning (fig 9). The average peak in runoff (Q_p) at G8210012 occurs at approximately 0330 h.

A small feature of the diurnal runoff cycle is that instead of a smooth curve from the Q_p to the average minimum in runoff, there is a slight ‘bulge’ in the diurnal cycle at approximately