Hydrometeorological analyses relevant to Jabiluka

March 1999

Hydrology Unit

Commonwealth Bureau of Meteorology

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1 Introduction

In response to a request from the Supervising Scientist, the Bureau of Meteorology Hydrology Unit has undertaken a range of hydrometeorological analyses relevant to Jabiluka for input to projects being undertaken by the University of Melbourne and CSIRO. The analyses undertaken for this report included:

- Extraction of rainfall, evaporation and other relevant climate data from the Bureau's climatological database;
- Infilling of missing data to provide a complete, long term, record of daily rainfall;
- Analysis of the annual series (September to August) of rainfall data to determine the best estimate of the 1:10,000 AEP annual rainfall including the provision of confidence limits on the estimates;
- Comment on the methodology used in the Jabiluka EIS and associated documents and discussion of any other techniques which may be used to estimate the 1:10,000 AEP annual rainfall; and,
- Derivation of the design Probable Maximum Precipitation estimates of relevance to the Jabiluka project area.

2 Availability of rainfall, evaporation and other relevant climate data

The Bureau of Meteorology's climate database was analysed to determine the availability of rainfall, evaporation and other relevant climate data. Table 1 identifies the stations found when implementing the Hydrology Unit's rainfall station and climate search procedure.

Table 1 Rainfall, evaporation and climate data stations in the region surrounding the Jabiluka project

Proximity	Rainfall	Record	Evaporation	Record	Climate	Record
Within 100 km	Oenpelli	1911–1998	Jabiru Airport	1974–1998	Oenpelli	1979–1998
	Jabiru Airport	1972–1998			Jabiru Airport	1979–1998
	Jabiru Council	1984–1998				
	Kapalga CSIRO	1988–1994				
	Mudginberri	1965–1980				
	Munmalary	1965–1980				
Within next 100 km	Cape Don	1919–1988	Middle Point	1966–1998	Cape Don	1961–1988
	Koolpinyah	1914–1972	Maningrida	1968–1998	Middle Point	1966–1998
	Middle Point	1959–1998			Maningrida	1968–1998
	Maningrida	1958–1998			Wurruwi	1961–1998
	Wurruwi	1917–1998				
	Pine Creek	1875–1998				
Key sites further away	Darwin Airport	1942-1998	Darwin Airport	1942–1998	Darwin A/P	1942–1998
	Darwin PO	1870–1961			Darwin PO	1900–1961
	Katherine	1874–1998			Katherine	1969–1998

Table 2 lists the details of the data that were supplied by the Bureau's National Climate Centre to the University of Melbourne for analyses of the relationships between the data recorded at the various sites.

Table 2 Details of data provided to the University of Melbourne

Data type	Station number	Station name
Daily and monthly precipitation data	014198	Jabiru Airport
	104400	Maningrida
	014090	Middle Point
	014016	Darwin PO
	014015	Darwin Airport
	014042	Oenpelli
Daily and monthly evaporation data (Pan)	014198	Jabiru Airport
	014400	Maningrida
	014090	Middle Point
	014015	Darwin Airport
Daily		
Maximum temperature	014198	Jabiru Airport
Minimum temperature	014198	Jabiru Airport
Wind run	014198	Jabiru Airport
Sunshine hours	014198	Jabiru Airport
Other climate data		
3-hour T_{dry}	014198	Jabiru Airport
3-hour T_{wet}	014198	Jabiru Airport

3 Infilling of missing rainfall and evaporation data

Following discussions with the University of Melbourne after their analysis of the available climate data, the Bureau of Meteorology was requested to infill the daily rainfall record for the Oenpelli site and the monthly rainfall and evaporation data for the Jabiru Airport site.

The accumulated daily rainfall data for Oenpelli were infilled by distributing the accumulated totals by the pattern of rainfall at the nearest rainfall station for which records were available. The missing data were infilled using the data from the closest available station. If a monthly total was available for Oenpelli, the nearest station data were adjusted by multiplication by the ratio of the Oenpelli monthly total to the nearest station monthly total. If an Oenpelli monthly total was not available, the nearest station data were adjusted by multiplication by the ratio of the annual mean rainfall at Oenpelli to the annual mean rainfall at the nearest station.

In summary, there was very little missing data in the Oenpelli daily rainfall record and the 88 years of data (1911–1998) is an excellent record.

The monthly rainfall and evaporation data for Jabiru Airport was provided by the ERA (Energy Resources of Australia). A check of these data against the Jabiru Airport data in the Bureau of Meteorology's database indicated that these data sets were similar, but the ERA data set was more complete and up to date. As only the monthly and annual data were to be used from this site, it was not necessary to infill the daily record.

The above data sets were supplied to Melbourne University for them to undertake the Hydrological Modelling Study of Water Management at the Jabiluka Site (Chiew & Wang, 1999).

4 Estimation of 1:10,000 AER annual rainfall

The annual rainfall totals (September to August) were derived using the data sets described above. The 1:10,000 AEP annual rainfall was estimated for both the Oenpelli and Jabiru Airport rainfall stations using all of the available data. This estimate of the 1:10,000 AEP annual rainfall is based on the assumption of a statistically stationary climate and does not take account of any expected or unexpected impact of the enhanced greenhouse effect. Furthermore, there is no known method of reliably estimating the 1:10,000 AEP annual rainfall from a sample of the order of 100 years. The method employed relies on the assumption that annual rainfalls which reasonably fit a normal distribution for the sample of available data, continues to do so into the extreme high end of the actual distribution. Nevertheless, where, for practical reasons, an estimate *must* be made, this is the main method currently employed in Australia.

4.1 Analysis of Oenpelli annual rainfall data

The length of rainfall record for Oenpelli is 88 years (1911–1998) and the annual characteristics of the annual rainfall data are given in table 3. These values were derived using the data provided in Appendix A. The maximum and minimum observed annual rainfall during the period are 2012 mm (1975–76) and 720 mm (1941–42) respectively.

Table 3 The annual characteristics of Oenpelli rainfall data

Statistic	Magnitude	Standard Error
Mean (mm)	1397	30.3
Standard deviation (mm)	284.5	21.4
Coefficient of skewness	-0.018	0.257

Chi-squared test results (test statistic – 4.39/chi-square value (0.05%) – 9.49) and Kolmogorov Smirnov test results (test statistic – 0.05881/value – 0.145) indicate that the annual rainfall data series for Oenpelli is normally distributed. It should also be noted that the coefficient of skewness of the annual rainfall series is small. The use of the normal distribution is also supported by the analyses undertaken by Vardavas (1992). The plot of the observed data and the fitted line are shown in figure 1. The x-axis has a normal probability scale and plotting position is determined by the rank of annual rainfall (plotted on the y-axis). Data that are normally distributed plot as a straight line on this type of graph. The 1:10,000 AEP annual rainfall estimate is 2455 mm with a standard error of 85 mm. This estimate was derived using equation (1) (IE Aust 1987):

$$Q_y = M + K_y S \tag{1}$$

where: Q_y = the annual rainfall having an Annual Exceedance Probability (AEP) of 1 in y,

M = mean of annual rainfall series,

S	=	standard deviation of the annual rainfall series,
K_y	=	frequency factor for the normal distribution for AEP of 1 in y, and
y	=	10 000 years (in this case).

In the case of the normal distribution equation (1) can be expressed as:

$$Q_{10,000} = M + Z_{0.9999} \times S \tag{2}$$

where: Z is the z-statistic, which simply specifies the distance of a point from the mean in units of standard deviation. The subscript to Z denotes the 0.9999 quantile (the 99.99 percentile). From normal probability tables, $Z_{0.9999} = 3.719$.

The 95% confidence limit for this estimate, rounded to the nearest 10 mm is **2460 ± 170 mm**.

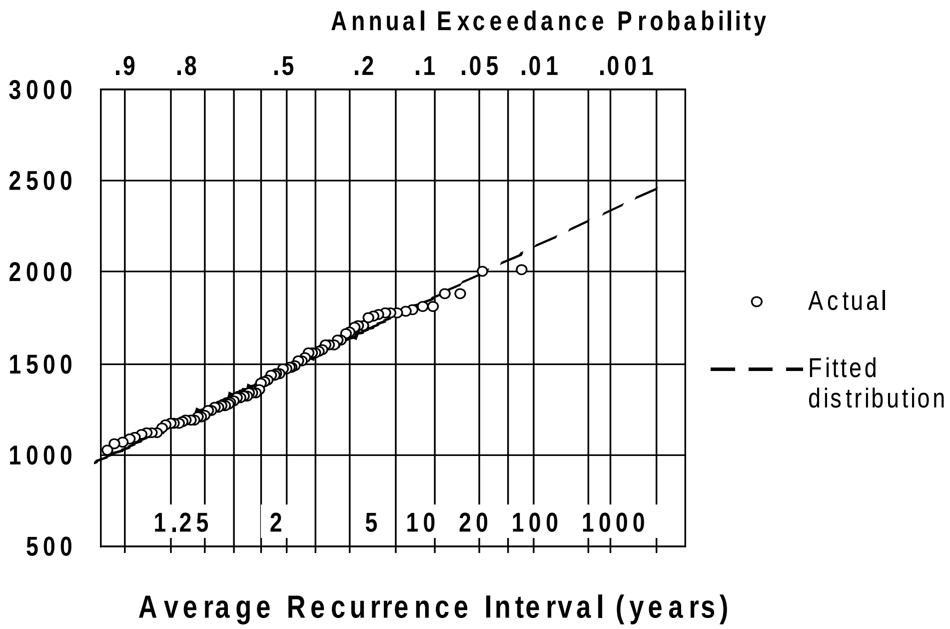

Figure 1 Distribution of annual rainfall for Oenpelli

4.2 Analysis of Jabiru Airport annual rainfall data

The length of the rainfall record for Jabiru Airport is 27 years (1972–1998) and the annual characteristics of the annual rainfall data are given in table 4. These values were derived from the data presented in Appendix A. The maximum and minimum observed annual rainfall during the period are 2223 mm (1975–76) and 945 mm (1987–88) respectively.

Table 4 The annual characteristics of Jabiru Airport rainfall data

Statistic	Magnitude	Standard Error
Mean (mm)	1,483	58.2
Standard deviation (mm)	302.5	41.2
Coefficient of skewness	0.288	0.448

Chi-squared test results (test statistic – 0.33/chi-square value (0.05%) – 7.81) and Kolmogorov Smirnov test results (test statistic – 0.04895/test value – 0.256) indicate that the annual rainfall data series for Jabiru Airport is normally distributed. The coefficient of skewness of the annual rainfall series is again small. The plot of the observed data and the fitted line are shown in figure 2. The 1:10,000 AEP annual rainfall estimate is 2608 mm with a standard error of 164 mm. The 95 % confidence limit for this estimate, rounded to the nearest 10 mm is **2610 ± 320 mm**. The large standard error and the wider confidence band are due to the short length of the data. The 1975–76 annual rainfall for Jabiru Airport (2223 mm) was tested to determine if it could be treated as an outlier. The test showed 2300 mm as the lower limit for high outliers and hence there is no evidence to exclude the1975–76 value. However, given the close relationship between the Oenpelli and Jabiru Airport rainfall data (Chiew & Wang 1999) and the fact that 1975–76 annual rainfall is also the highest annual rainfall for Oenpelli, it is feasible to adopt an AEP of 1 in 88 years (the length of record available at Oenpelli) for the 1975–76 annual rainfall at Jabiru Airport.

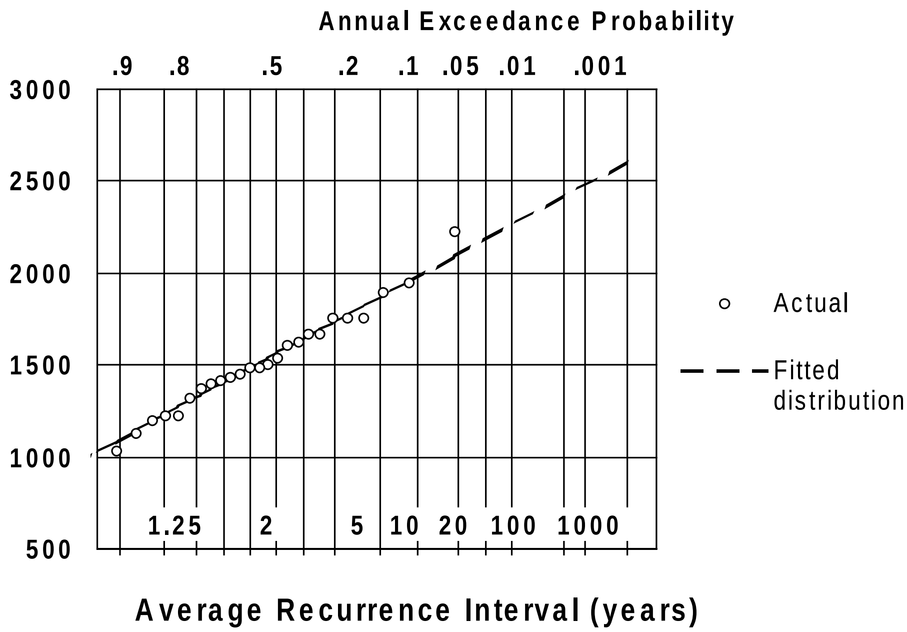

Figure 2 Distribution of annual rainfall for Jabiru

4.3 Summary of analysis of annual rainfall

The best estimate of the 1:10,000 AEP annual rainfall for the region considered is **2460 mm** with a standard error of 85 mm using the rainfall data recorded at Oenpelli. It should be noted that the estimate for the 1:10,000 AEP annual rainfall using the full Jabiru Airport record (2610 mm) falls within the confidence limits for the Oenpelli estimate (2460 ± 170 mm).

4.4 Comparison with estimates made in the Jabiluka EIS

The estimate of the 1:10,000 AEP annual rainfall recommended on page 5–22 of the Jabiluka Project Supplement (Kinhill Engineers 1996) to the draft EIS is 2450 mm. This has been derived from the Jabiru Airport record with the 1975–76 rainfall attributed a recurrence period of 85 years and by hand fitting the probability curve. As indicated above, this is a feasible approach, given the close relationship between the Oenpelli rainfall records and the Jabiru Airport rainfall records**.** While there is no statistical evidence for treating the 1975/76

Jabiru rainfall as an outlier, the fact that Oenpelli also experienced it's highest annual rainfall report on record in 1975/76 provides some physical justification for reassigning its plotting position. Hand fitting of probability curves is not recommended. It is felt that the analysis of the full record from Oenpelli provides the best estimate of the 1:10,000 AEP annual rainfall. It is interesting to note that the analysis of the Jabiluka Airport annual rainfall data, not including the 1975–76 year, leads to an estimate of the 1:10,000 AEP annual rainfall of 2,460 ± 290 mm.

5 Comment on methodology used

The assumptions involved in the method used were raised at the beginning of the previous section. With respect to the assumption that the distribution of annual rainfalls is normal throughout the entire range of values, it should be noted that uncertainty involved in using this assumption is *not* accounted for in the 95% confidence limits stated above.

An alternative method of calculating annual exceedance probability (AEP) from a relatively short record is to calculate expected probability (Institution of Engineers, Australia 1987, Beard 1960). Here, 'expected' is used in the statistical sense and the name would be more precisely expressed as 'Expected Annual Exceedance Probability'. This approach takes the view that one record, such as the Oenpelli record, is just one sample from a normally distributed population, and it can be shown that, on average, over a large number of samples, the expected probability of estimates of the 1 in Y AEP event is always greater than 1 in Y. This implies a higher annual rainfall because it is the rainfall for the expected probability rather than that for the sample probability. The concept is a complex one and the subject is still debated in the literature. However, if the procedures recommended by Beard (1960) are followed, the estimate of the 1:10,000 AEP annual rainfall for Oenpelli is 2510 mm. This estimate is not significantly different from the 2460 mm recommended above.

As mentioned earlier in the report, these methods of analysis assume stationarity of the data series being used. In this regard, the proposed analysis of the potential impact of climate change on the 1:10,000 AEP annual rainfall by the CSIRO (Jones & Abbs 1999) will be of interest. If no definitive alteration to the 1:10,000 AEP annual rainfall estimate can be made in this regard, one conservative option is to adopt the higher confidence limit of the estimate provided above (2460+170 = 2630 mm) as the 1:10,000 AEP design annual rainfall.

The above analysis adopted a normal distribution for the annual data series. ERA staff (Kinhill Engineers 1996), in their analysis, have used both a hand fitted probability curve and a log Pearson type III distribution. Hand fitting of probability curves is not recommended because it is subjective and the results are difficult to reproduce. Also, no indication of the accuracy of the estimate can be derived. As shown above, statistical tests applied to the annual series of rainfall data indicate that it can be analysed as a normally distributed data set. It is not clear why ERA have applied a log Pearson type III distribution to annual rainfall from these stations. Applying a logarithmic transformation to the non-skewed initial distribution would have produced a negative skew, but presumably the procedures for dealing with skew, inherent in the (log) Pearson type III approach, handled this effectively and yielded answers much the same as were obtained here.

There is no known method of using annual rainfall data on a regional basis to provide an estimate of the 1 in 10,000 annual rainfall in which we could have greater confidence. It has been suggested that the FORGE (FOcussed Rainfall Growth Estimation) technique, which has been used by Monash University to estimate the 1 in 2,000 short-duration (24 hours to 72 hours) rainfalls, may be utilised. However, in this report we are dealing with annual rainfalls, and as the FORGE methodology has been developed based on rainfall growth or storm growth assumptions it is not applicable in this case. Also, the Hydrological Modelling Study of Water Management at the Jabiluka Site (Chiew & Wang 1999) has shown the close relationship between the Oenpelli and Jabiru Airport data sets. These facts, and the limited availability of other good-quality long-term rainfall data sets in close proximity to the project site, suggest that the use of a technique similar to FORGE would not provide any additional confidence in the estimate made here.

6 Derivation of Probable Maximum Precipitation (PMP) estimates for use in design

6.1 6-Minute PMP estimate

6.1.1 Derivation of the 6-minute PMP

The 6-minute point-value PMP was estimated using two different techniques:

- **Extrapolation of the PMP curve**. Point-value PMPs for durations from 15 minutes (the minimum duration normally calculated) to 6 hours were calculated for Jabiluka using the Generalised Short Duration Method (GSDM) (Bureau of Meteorology 1994). Then, each PMP (depth in mm) was converted to intensity (mm hr^{-1}) and plotted against duration using linear scales. The best fit to this intensity *vs.* duration curve was a power law (R^2 = 0.99). The curve was extrapolated back to obtain an estimate of the 6-minute intensity of 1380 mm hr^{-1}.
- **Use of IFD ratio**. IFD (Intensity-Frequency-Duration) information was produced for the nearest grid point (Latitude 12.50°S, Longitude 132.925°E) to Jabiluka. For 100 year ARI, the ratio of the 6-minute to the 15-minute intensities (read from the curve) was calculated. The 15-minute PMP intensity was then multiplied by this ratio to estimate a 6-minute intensity of 1320 mm hr^{-1}.

These calculated values differ by less than 4%, lending some confidence to the estimate. In the interest of conservatism, the larger value of 1380 mm hr^{-1} is preferred.

6.1.2 Recommended 6-minute PMP Estimate

The recommended 6-minute point PMP intensity is **1,380 mm hr^{-1}**.

The recommended PMP depth for a 6-minute duration, rounded to the nearest 10 mm, is **140 mm**.

6.1.3 Comment on the 6-minute PMP Estimate

The 6-minute PMP estimate provided by ERA (on page J3 of Appendix J of the Draft EIS, (Kinhill Engineers 1996)) for the Jabiluka Project is 1150 mm hr^{-1}. It has not been possible to find out how ERA estimated this value. The 15-minute PMP estimate from the Bureau of Meteorology is 920 mm hr^{-1}. As expected the intensity of the 6-minute PMP is greater then that for the 15-Minute PMP. The difference between the Bureau of Meteorology and ERA estimates (+20%) is considered significant and the Bureau of Meteorology value of 1380 mm hr^{-1} should be adopted, particularly as it provides a more conservative approach.

6.2 15 minutes to 72 hours PMP estimates

6.2.1 Derivation of 15 minutes to 72 hours PMP estimates

Estimates of PMP at the Jabiluka project area can be made for durations of 0.25 to 6 hours using the method as detailed by the Bureau of Meteorology (1994, amended Dec 1996) in Bulletin 53: 'The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method'. Estimates were made for areas A and B in the project area. Area A represents the 0.09 km^2 evaporation pond and, area B (0.17 km^2) represents the remainder of the total containment zone for the Jabiluka mill alternative with all tailings being returned to the mine void. The resulting PMP values for areas A and B within the Jabiluka mine site for durations of 0.25 to 6 hours are given in columns 3 of tables 5 and 6 respectively (see figs 3 & 4 also). The 6-minute PMP estimate described above is also included in the tables.

Estimates of PMP for durations of 12 to 72 hours at the location of the Jabiluka mine site can be derived from the Generalised Tropical Storm Method (GTSM). The method was developed for those parts of Australia affected by storms of tropical origin (Kennedy (1982) and Kennedy & Hart (1984)). It is based on storms associated with synoptic weather features, which affect larger areas over longer durations than the storms used in the derivation of the GSDM. The GTSM is applicable to catchments larger than 1 km^2 in area. Areas A and B within the Jabiluka project area are both much smaller than 1 km^2 in area, having areas of 0.09 and 0.17 km^2 respectively. Therefore, it is important to note that the estimates given for durations longer than 6 hours should be used with caution when applied to areas of less than 1 km^2.

The resulting GTSM values for a 1 km^2 catchment at the location of Areas A and B are shown in columns 4 of tables 5 and 6. Final PMP values derived from fitting a smooth enveloping curve to this set of estimates are shown in column 5. Figures 3 and 4 show these enveloping curves for areas A and B respectively.

6.2.2 Design temporal distributions of PMP estimates

Figure B.1 in Appendix B gives the GSDM design temporal distribution appropriate for durations of 0.25 to 6 hours.

Figure B.2 and table B.1 in Appendix B give the design temporal distributions of GTSM PMP for durations of 12 to 72 hours.

6.2.3 Notional probability of PMP events

The PMP concept, as defined in the introduction, effectively involves zero probability of exceedance. However, estimates made by the various PMP methodologies have a non-zero probability of exceedance. Probabilities of exceedance can therefore be associated with the **methodology** used to estimate the PMP, **not the concept** of PMP itself. Kennedy and Hart (1984) used notional AEPs for various PMP methods as a means of indicating the different security levels provided by the different methods. The notional AEPs for the PMP estimation methods are reviewed by Pearce (1994). The AEP for GTSM Remaining Tropical Zone estimates and the revised AEP for GSDM estimates are estimated at approximately 10^{-6}. With the imminent release of the revised edition of Australian Rainfall and Runoff, Book VI — Estimation of Large to Extreme Floods (IE Aust 1998), this advice will be superseded. All future reference to the AEP of the PMP will derive from Book VI.

Table 5 Generalised PMP estimates for area A

Duration (hours)	Best estimate PMP (mm)	Area A GSDM PMP (mm)	GTSM RTZ 1 SQ KM Area PMP (mm)	Final PMP (mm)
.1	140	–	–	140
.25	–	230	–	230
.5	–	330	–	330
.75	–	430	–	430
1	–	530	–	530
1.5	–	680	–	680
2	–	810	–	810
2.5	–	910	–	910
3	–	1000	–	1000
4	–	1150	–	1150
5	–	1250	–	1250
6	–	1330	–	1330
12	–	–	1050	1370
18	–	–	–	1390
24	–	–	1380	1460
36	–	–	–	1650
48	–	–	1830	1830
72	–	–	2040	2040

Note: (i) All values are rounded to the nearest 10 mm.
The estimates are for unrestricted durations (ie not 9am to 9am raindays).
The estimates for the 12-, 18-, 24- and 36-hour durations are interpolated values.

Table 6 Generalised PMP estimates for Area B

Duration (hours)	Best estimate PMP (mm)	Area B GSDM PMP (mm)	GTSM RTZ 1 SQ KM Area PMP (mm)	Final PMP (mm)
.1	140	–	–	140
.25	–	230	–	230
.5	–	330	–	330
.75	–	420	–	420
1	–	520	–	520
1.5	–	670	–	670
2	–	800	–	800
2.5	–	900	–	900
3	–	990	–	990
4	–	1130	–	1130
5	–	1240	–	1240
6	–	1320	–	1320
12	–	–	1050	1370
18	–	–	–	1390
24	–	–	1380	1460
36	–	–	–	1650
48	–	–	1830	1830
72	–	–	2040	2040

Note: (i) All values are rounded to the nearest 10 mm.
The estimates are for unrestricted durations (ie not 9am to 9am raindays).
The estimates for the 12-, 18-, 24- and 36-hour durations are interpolated values.

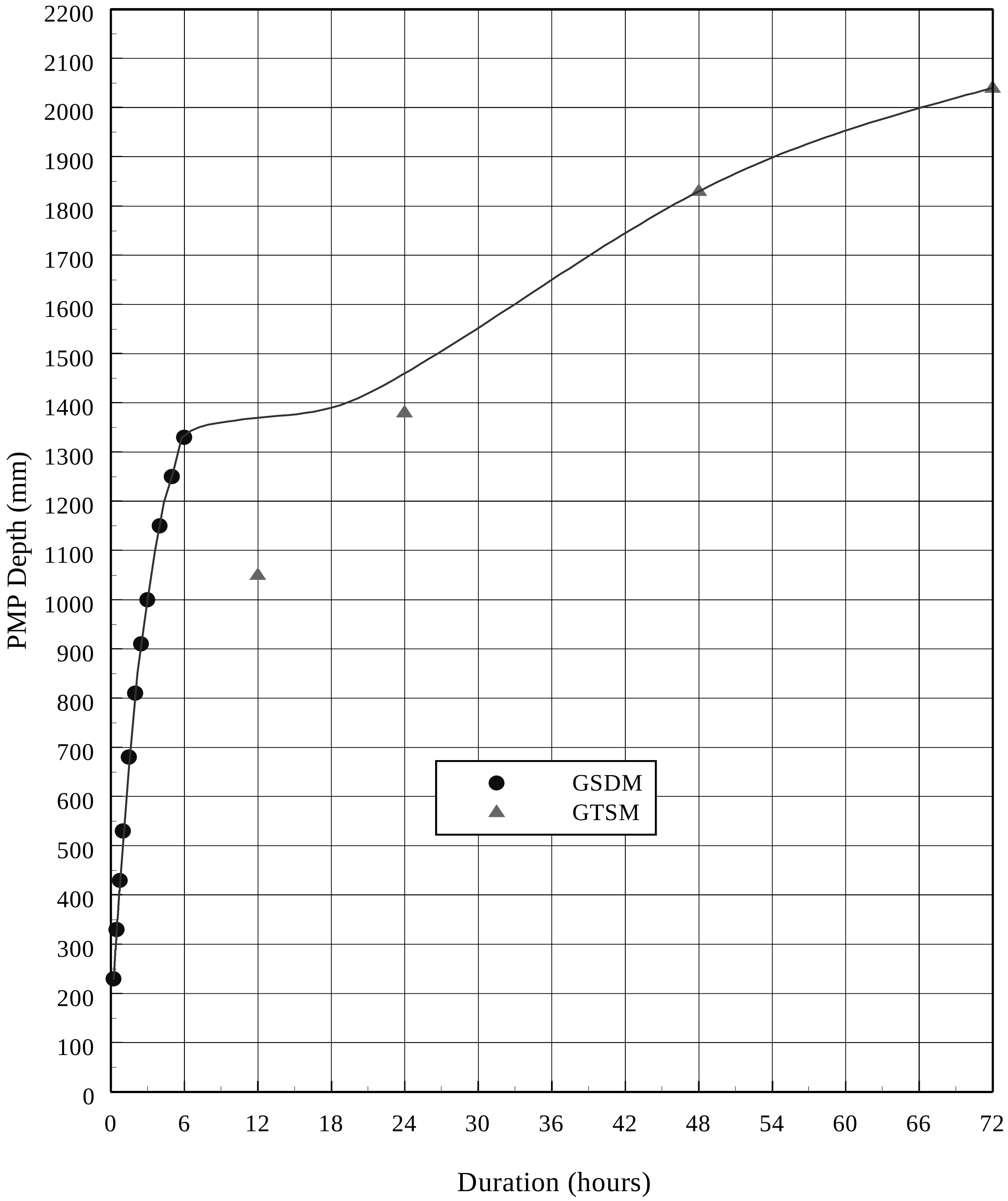

FIGURE 3 Envelope of Final PMP Depths for Area A within the Jabiluka Mine Site

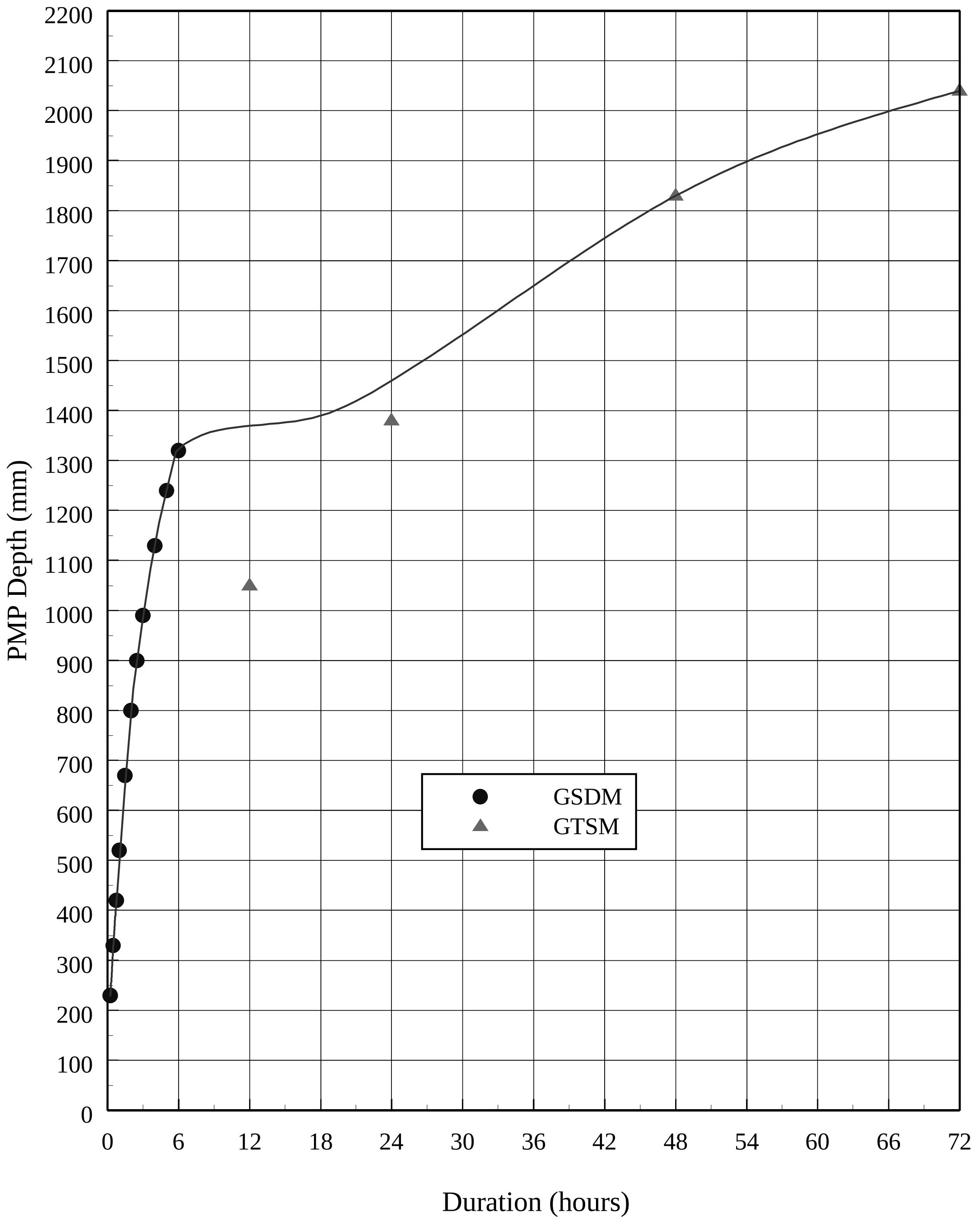

FIGURE 4 Envelope of Final PMP Depths for Area B within the Jabiluka Mine Site

6.2.4 Katherine January 1998 event

It has been suggested that the Katherine 1998 event be examined to determine if further analysis of this event would alter the current estimates of PMP. It should be noted that the Katherine event was not the highest on record in the Katherine Rainfall records. The 48 and 72 hour rainfall totals (380.6 mm and 398 mm respectively) were the second highest on record.

However, the 24 hour rainfall total (220.8 mm) was only the 4th highest on record. These rainfalls are considerably less than the PMP estimates for the same durations at Jabiluka and it is unlikely that the analysis of this event would alter the current PMP estimates. It should also be noted that the extreme storms used in the development of the GTSM included storms with significantly greater rainfall then that observed at Katherine in 1998.

7 Conclusion

The Bureau of Meteorology has undertaken the above analyses in response to a request from the Supervising Scientist. The results provided are considered by the Bureau to be the best possible given the data limitations and methodologies currently available.

There is close agreement between the Bureau of Meteorology and ERA estimates of the 1:10,000 AEP annual rainfall. The Bureau of Meteorology's estimate of the 6-Minute PMP is 20% greater than that derived by ERA.

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Appendix A

Table A.1 Monthly and annual rainfall data (mm) for Oenpelli

Year	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
1910–11	35.6	49.8	60.4	371.2	348.5	287.5	73.3	341.6	0.0	0.0	0.0	0.0	1567.9
1911–12	0.0	167.7	123.6	262.2	396.8	252.6	402.2	24.4	0.0	0.0	0.0	0.0	1629.5
1912–13	0.0	81.7	56.7	184.6	574.7	349.1	531.7	22.1	11.2	0.0	0.0	0.0	1811.8
1913–14	0.0	0.0	55.0	178.0	388.4	164.4	459.1	31.5	42.3	0.0	0.0	0.0	1318.7
1914–15	0.0	0.0	6.4	135.9	183.4	301.3	151.8	8.6	46.0	0.0	0.0	10.2	843.6
1915–16	12.2	17.5	93.2	583.3	449.3	237.5	229.6	31.7	4.1	0.0	0.0	0.0	1658.4
1916–17	0.0	106.4	221.5	201.8	526.0	272.0	324.5	130.2	17.8	10.9	0.0	0.0	1811.1
1917–18	11.9	114.5	127.5	248.8	336.6	505.1	115.4	33.9	19.8	0.0	0.0	0.0	1513.5
1918–19	0.0	6.4	61.4	144.3	776.7	215.7	358.5	111.6	0.0	0.0	0.0	0.0	1674.6
1919–20	3.8	0.0	56.3	165.6	223.6	488.5	75.2	94.0	0.0	2.3	0.0	0.0	1109.3
1920–21	0.0	3.8	88.8	262.8	389.3	239.6	384.1	37.1	0.0	0.0	2.3	0.0	1407.8
1921–22	0.0	63.5	157.4	314.9	406.7	336.9	314.0	28.5	0.0	0.0	3.0	0.0	1624.9
1922–23	0.0	77.2	86.8	166.4	288.9	178.4	533.1	96.7	16.4	0.0	0.0	0.0	1443.9
1923–24	0.0	13.9	60.9	528.8	175.1	176.4	230.1	2.8	2.8	0.0	1.0	0.0	1191.8
1924–25	0.0	5.9	157.0	244.2	269.3	280.2	303.1	208.4	1.1	0.0	0.0	0.0	1469.2
1925–26	0.0	1.8	10.9	55.2	372.4	210.2	156.4	10.6	0.5	0.0	0.0	0.0	818.0
1926–27	0.3	45.5	110.0	258.3	234.5	271.1	223.8	56.9	4.6	1.3	0.0	0.0	1206.3
1927–28	2.3	101.5	222.4	323.0	134.8	196.3	351.3	26.9	0.0	0.0	0.0	0.0	1358.5
1928–29	0.0	0.0	98.3	142.9	245.3	295.0	287.4	98.0	0.0	0.0	0.0	0.0	1166.9
1929–30	0.0	0.0	193.8	161.9	310.3	499.7	593.6	11.7	0.0	0.0	0.0	0.0	1771.0
1930–31	0.0	0.0	91.5	242.4	352.0	218.9	291.5	48.5	0.8	0.0	0.0	0.0	1245.6
1931–32	0.0	0.0	190.8	193.0	460.7	176.9	514.5	30.0	5.6	0.0	0.0	0.0	1571.5
1932–33	0.0	9.6	128.0	179.2	290.5	234.2	298.5	4.6	0.0	34.7	0.0	0.0	1179.3

Year	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
1933–34	2.5	30.0	91.6	299.7	281.3	264.1	473.1	49.0	24.3	0.0	0.0	0.0	1515.6
1934–35	22.1	22.6	56.3	183.6	333.0	150.9	301.8	4.3	0.3	20.0	0.0	0.0	1094.9
1935–36	0.0	2.0	71.4	189.1	242.5	280.1	225.5	11.4	0.0	0.0	41.9	0.0	1063.9
1936–37	0.0	21.6	59.4	269.8	272.1	242.5	306.8	31.5	0.0	0.0	0.0	0.0	1203.7
1937–38	3.3	19.1	86.7	129.9	378.0	497.8	101.3	68.3	10.6	1.5	0.0	0.0	1296.5
1938–39	0.0	10.9	169.6	134.5	391.3	186.2	245.9	24.7	1.0	5.1	0.0	0.0	1169.2
1939–40	0.0	6.7	74.9	122.3	520.9	221.3	418.4	64.5	8.6	0.0	0.0	0.0	1437.6
1940–41	0.0	0.0	58.4	231.4	397.1	273.6	240.8	101.4	10.7	0.5	0.0	0.0	1313.9
1941–42	0.3	1.0	97.5	92.8	232.7	248.2	47.8	0.0	0.0	0.0	0.0	0.0	720.3
1942–43	9.7	69.4	76.3	374.9	228.1	639.7	112.2	93.4	0.0	0.0	0.0	0.0	1603.7
1943–44	0.0	4.1	276.5	214.1	214.1	281.8	243.6	48.2	0.0	0.0	0.0	0.0	1282.4
1944–45	0.0	0.0	114.6	352.1	334.3	234.8	312.5	69.0	23.9	0.0	0.0	0.0	1441.2
1945–46	10.9	19.1	40.8	206.1	245.9	384.5	211.1	0.0	0.0	0.3	0.0	0.0	1118.7
1946–47	0.3	0.5	53.6	118.6	190.1	362.4	284.6	44.8	3.3	0.5	0.0	1.6	1060.3
1947–48	32.8	26.7	91.8	179.2	153.1	279.6	98.0	413.9	2.3	0.0	0.0	0.0	1277.4
1948–49	0.0	0.0	276.4	196.1	258.1	214.1	353.2	44.7	0.0	0.0	0.0	0.0	1342.6
1949–50	0.0	9.0	178.5	237.6	447.3	320.0	164.8	34.2	0.3	0.0	0.0	0.0	1391.7
1950–51	18.1	81.9	199.5	395.4	197.3	231.2	135.1	3.6	0.0	0.0	0.0	0.3	1262.4
1951–52	0.3	59.7	19.1	129.3	257.4	113.4	174.9	0.0	18.8	0.0	0.0	0.0	772.9
1952–53	0.0	19.8	163.3	142.2	285.2	167.7	194.6	169.7	0.0	0.0	0.0	0.0	1142.5
1953–54	0.0	17.8	86.0	176.9	332.1	192.9	274.4	257.5	0.0	0.0	0.0	0.0	1337.6
1954–55	0.0	102.5	30.2	152.4	227.9	347.3	165.3	72.3	66.5	7.2	21.1	0.0	1192.7
1955–56	0.0	34.5	232.2	65.7	310.4	420.2	341.4	143.1	89.8	0.3	63.2	5.8	1706.6
1956–57	0.5	51.6	158.0	248.2	399.2	353.9	491.2	72.4	1.8	0.0	0.0	0.0	1776.8

Year	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
1957–58	0.0	0.8	68.8	319.5	246.7	225.7	278.7	86.9	99.2	8.7	1.3	3.8	1340.1
1958–59	0.0	19.9	148.3	120.3	323.0	279.5	216.8	339.8	21.2	0.0	0.0	0.0	1468.8
1959–60	0.0	0.0	31.5	272.1	317.1	296.6	336.8	43.3	21.9	0.0	0.3	0.3	1319.9
1960–61	14.7	2.8	95.6	244.8	373.6	155.7	74.3	10.0	0.0	0.0	19.8	0.0	991.3
1961–62	0.0	20.4	75.6	163.9	497.4	654.9	57.3	12.7	0.0	0.6	0.0	0.0	1482.8
1962–63	12.8	53.6	54.2	281.6	213.0	263.3	207.4	86.7	1.0	0.0	0.0	0.0	1173.6
1963–64	0.0	0.0	56.4	276.2	416.1	379.7	415.1	142.1	11.7	0.3	0.0	0.0	1697.6
1964–65	16.5	93.1	248.5	166.7	365.1	350.7	529.8	0.3	6.4	0.6	0.0	0.0	1777.7
1965–66	0.0	1.0	3.0	502.8	276.3	236.4	169.2	3.2	0.0	0.0	0.0	0.0	1191.9
1966–67	0.0	26.4	100.5	195.6	217.9	480.6	158.4	34.8	0.6	0.3	0.0	0.0	1215.1
1967–68	0.0	0.5	39.5	164.6	401.2	507.3	161.5	69.1	193.6	0.0	2.0	14.2	1553.5
1968–69	0.0	1.8	59.2	267.1	426.5	633.3	490.5	0.0	1.0	0.0	0.0	0.0	1879.4
1969–70	0.5	15.0	120.3	241.3	277.7	196.1	154.7	13.4	1.3	0.0	0.0	0.0	1020.3
1970–71	26.2	10.4	148.4	138.8	287.2	251.2	442.7	92.2	2.5	0.0	0.0	0.0	1399.6
1971–72	16.8	91.2	125.9	362.5	246.2	407.1	312.3	26.7	12.5	0.0	0.0	0.0	1601.2
1972–73	0.0	0.0	151.5	106.1	531.7	216.5	183.1	29.7	8.1	41.2	0.0	0.0	1267.9
1973–74	1.8	2.8	366.1	231.9	465.8	255.8	301.0	84.6	39.6	0.0	0.0	10.6	1760.0
1974–75	0.2	15.4	100.8	359.2	188.7	526.3	441.0	153.7	0.0	0.0	0.0	0.0	1785.3
1975–76	10.2	80.2	132.6	298.4	320.0	491.3	545.9	130.4	2.6	0.0	0.0	0.0	2011.6
1976–77	1.2	84.9	125.4	188.8	480.6	329.8	454.8	75.6	12.5	0.0	0.0	0.0	1753.6
1977–78	0.0	0.0	71.8	190.0	220.9	414.6	131.1	76.4	49.2	3.2	12.8	0.0	1170.0
1978–79	7.0	70.4	142.7	217.6	399.8	320.4	248.2	27.2	0.0	0.0	0.2	0.0	1433.5
1979–80	0.0	39.4	44.4	160.6	546.4	530.8	320.8	50.2	10.8	0.0	0.0	5.0	1708.4
1980–81	0.0	17.4	31.5	167.8	360.4	547.8	601.8	28.4	16.0	0.0	4.8	0.1	1776.0

Year	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
1981–82	26.8	22.5	309.3	286.0	337.9	384.9	218.2	15.0	1.0	0.0	0.0	0.0	1601.6
1982–83	4.4	0.0	42.8	85.8	173.6	209.4	528.7	166.1	54.8	0.0	0.0	0.0	1265.6
1983–84	0.0	27.6	96.4	68.8	261.8	626.8	464.4	2.4	6.2	0.0	0.0	0.0	1554.4
1984–85	70.2	13.0	82.4	432.2	267.4	292.2	332.6	390.2	0.0	0.4	0.0	0.0	1880.6
1985–86	7.2	0.8	135.6	185.2	524.6	191.4	118.6	85.8	0.0	0.0	40.8	19.2	1309.2
1986–87	14.2	65.2	101.4	142.8	342.8	383.3	169.2	37.8	1.2	0.0	0.0	0.0	1257.9
1987–88	0.0	1.2	79.0	206.4	208.2	201.2	298.4	69.4	57.2	0.0	0.0	0.0	1121.0
1988–89	0.0	0.4	184.2	233.2	156.0	232.0	409.2	210.0	62.8	0.0	0.2	0.0	1488.0
1989–90	0.0	3.8	88.0	157.0	266.3	153.8	256.0	99.0	91.0	2.2	0.0	0.0	1117.1
1990–91	0.0	0.0	40.2	193.8	700.4	657.8	132.4	71.8	0.0	0.0	0.0	0.0	1796.4
1991–92	0.0	0.0	50.8	65.9	243.3	385.7	134.4	64.8	0.0	0.0	0.0	0.0	944.9
1992–93	42.8	8.4	54.6	245.3	350.2	587.0	179.0	11.0	1.7	0.0	0.0	0.0	1480.0
1993–94	2.2	5.0	110.7	164.5	203.8	255.2	239.0	105.4	4.1	0.0	0.0	0.0	1089.9
1994–95	0.0	13.0	12.5	304.6	750.1	478.0	275.0	162.2	3.3	0.6	0.0	0.0	1999.3
1995–96	0.0	34.1	61.9	257.0	213.6	243.8	186.8	240.5	5.4	0.0	0.0	0.0	1243.1
1996–97	0.0	5.7	87.8	329.5	549.6	317.0	234.7	2.9	5.1	0.0	0.0	0.0	1532.3
1997–98	0.0	14.4	104.9	258.7	522.1	328.9	121.1	191.6	13.3	0.0	0.0	1.5	1556.5
1998–99	8.0	60.3	156.0	334.7	245.5								
Monthly Average	5.2	26.4	107.9	225.9	337.4	321.8	277.2	77.7	14.2	1.6	2.5	0.8	1399.5
Highest	70.2	167.7	366.1	583.3	776.7	657.8	601.8	413.9	193.6	41.2	63.2	19.2	2011.6
Lowest	0.0	0.0	3.0	55.2	134.8	113.4	47.8	0.0	0.0	0.0	0.0	0.0	720.3
Number of Years	89	89	89	89	89	88	89	88	88	88	88	88	88

Table A.2 Monthly and annual rainfall data (mm) for Jabiru Airport

Water Year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	Total	Water Year
1971/72	1	51	108	168	192	237	344	11	18	0	0	0	1129	1971/72
1972/73	0	2	188	157	460	117	464	49	7	39	0	0	1482	1972/73
1973/74	0	44	332	167	468	275	348	73	25	0	0	22	1754	1973/74
1974/75	0	17	174	218	270	431	250	178	0	0	0	0	1538	1974/75
1975/76	1	206	113	381	394	503	590	34	0	0	0	0	2223	1975/76
1976/77	0	52	182	142	342	193	376	95	13	0	0	0	1395	1976/77
1977/78	0	6	97	408	329	425	147	23	10	0	5	0	1448	1977/78
1978/79	27	20	204	302	470	322	154	4	3	0	0	0	1504	1978/79
1979/80	0	26	118	139	506	768	268	64	5	0	0	0	1895	1979/80
1980/81	0	25	49	348	325	386	457	18	16	0	0	3	1627	1980/81
1981/82	26	41	277	259	364	228	288	2	0	0	0	0	1485	1981/82
1982/83	0	0	69	148	188	131	469	175	14	0	0	0	1195	1982/83
1983/84	2	49	159	72	308	645	409	13	8	0	5	0	1671	1983/84
1984/85	81	4	224	348	311	278	286	217	0	9	0	0	1758	1984/85
1985/86	4	0	169	191	396	104	205	108	1	0	37	7	1222	1985/86
1986/87	16	51	92	139	339	551	89	30	9	0	0	0	1315	1986/87
1987/88	0	2	116	133	226	179	271	15	1	0	0	0	945	1987/88
1988/89	0	28	216	258	245	216	391	60	1	0	0	0	1415	1988/89
1989/90	0	33	88	157	251	157	202	51	90	0	0	0	1029	1989/90
1990/91	0	0	78	203	458	396	85	149	0	0	0	0	1370	1990/91
1991/92	0	0	199	85	210	345	128	48	1	0	0	0	1017	1991/92
1992/93	20	97	40	156	461	290	125	36	1	0	0	0	1225	1992/93

1993/94	3	2	50	467	324	455	198	105	1	0	0	0	1606	1993/94
1994/95	0	10	87	344	749	258	171	117	11	8	0	0	1754	1994/95
1995/96	0	9	90	342	329	270	189	192	8	0	0	0	1429	1995/96
1996/97	0	27	128	392	807	387	208	0	0	0	0	0	1950	1996/97
1997/98	0	4	182	313	520	311	151	186	0	0	0	0	1667	1997/98
1998/99	2	210	196	332	314									1998/99
Maximum	81	206	332	467	807	768	590	217	90	39	37	22	2223	Maximum
Minimum	0	0	40	72	188	104	85	0	0	0	0	0	945	Minimum
Mean	7	30	142	238	379	328	269	76	9	2	2	1	1483	Mean

Appendix B

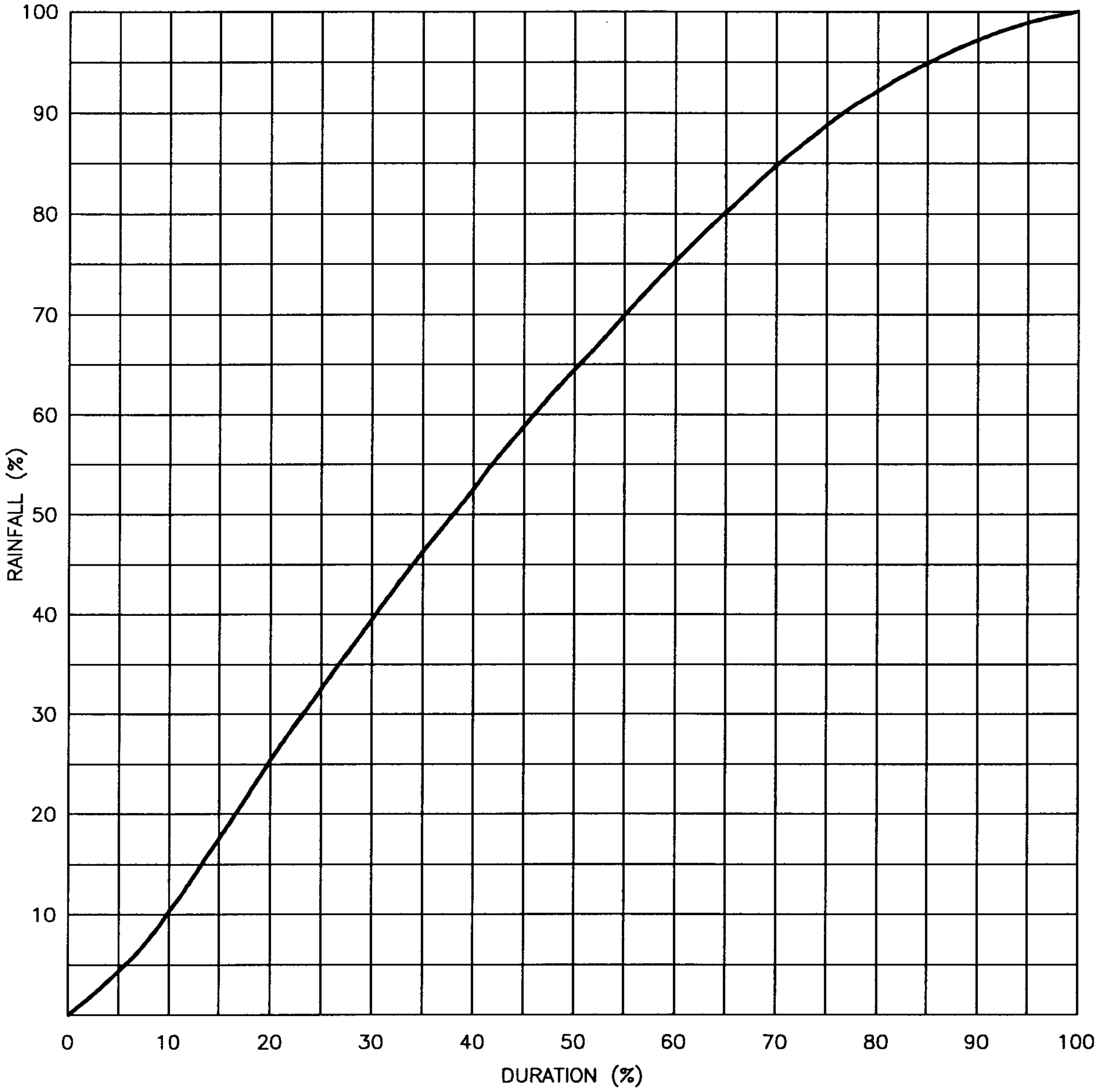

Figure B.1 GSDM design temporal distribution for 0.25 to 6 hours.

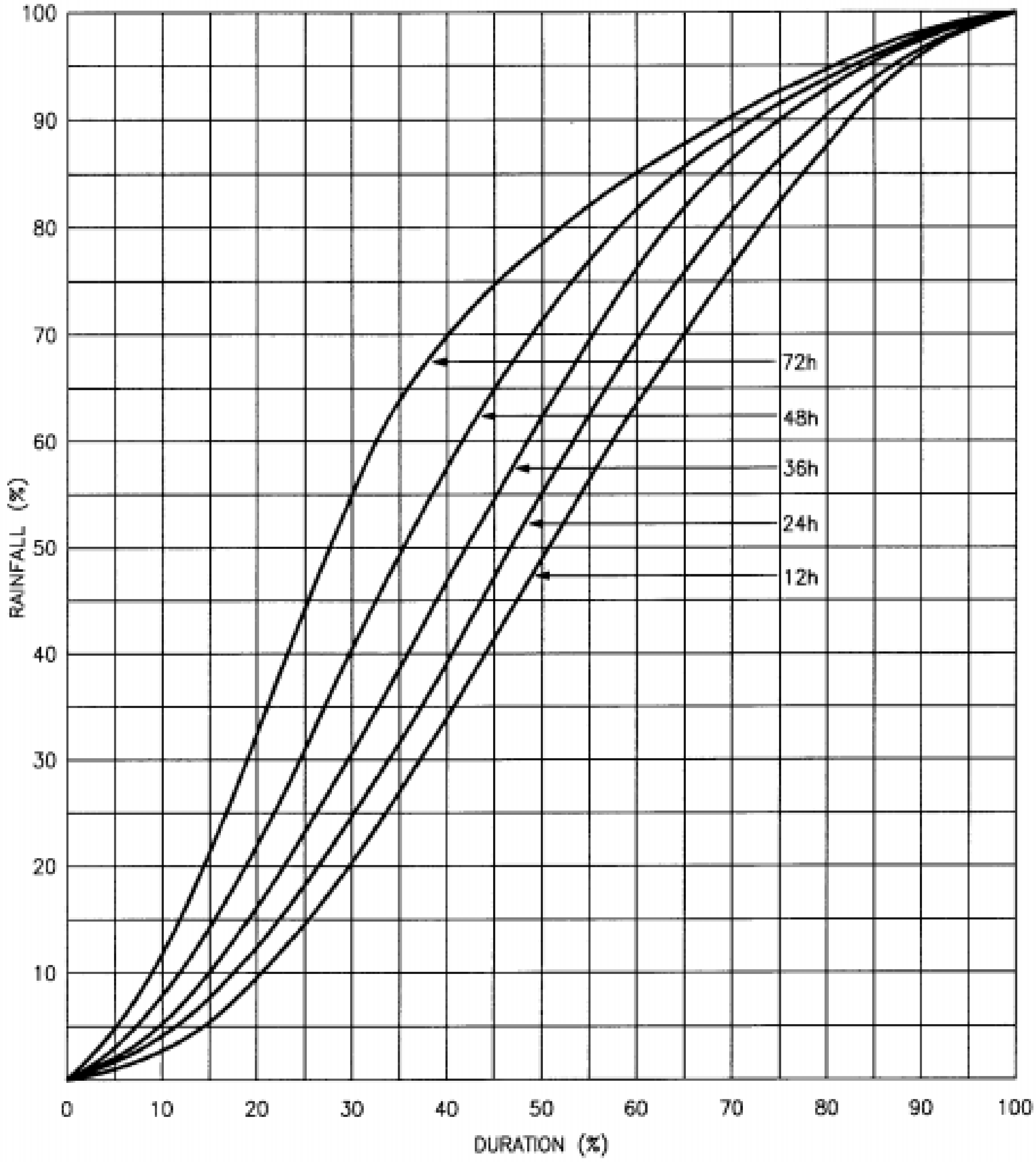

Figure B.2 GTSM PMP (RTZ) design temporal distributions for durations of 12 to 72 hours

Table B.1 GTSM remaining tropical zone design temporal distributions

Table B.1(i) Temporal distribution for a 12-hour duration

Time %	Cumulative %
2.5	0.4
5.0	1.0
7.5	1.8
10.0	2.7
12.5	3.9
15.0	5.3
17.5	7.3
20.0	9.5
22.5	12.0
25.0	14.5
27.5	17.4
30.0	20.3
32.5	23.5
35.0	27.0
37.5	30.5
40.0	33.9
42.5	37.7
45.0	41.4
47.5	45.2
50.0	49.0
52.5	52.7
55.0	56.5
57.5	60.2
60.0	63.6
62.5	66.8
65.0	70.1
67.5	73.3
70.0	76.4
72.5	79.4
75.0	82.4
77.5	85.1
80.0	87.6
82.5	90.2
85.0	92.5
87.5	94.4
90.0	96.1
92.5	97.5
95.0	98.5
100.0	100.0

Table B.1(ii) Temporal distribution for a 24-hour duration

Time %	Cumulative %
5.0	1.6
7.5	2.7
10.0	4.1
12.5	5.7
15.0	7.6
17.5	10.0
20.0	12.3
22.5	15.2
25.0	18.2
27.5	21.4
30.0	24.7
32.5	28.1
35.0	31.6
37.5	35.3
40.0	39.1
42.5	43.2
45.0	47.2
47.5	51.3
50.0	55.2
52.5	58.9
55.0	62.6
57.5	66.1
60.0	69.5
62.5	72.9
65.0	75.9
67.5	78.8
70.0	81.5
72.5	84.0
75.0	86.4
77.5	88.4
80.0	90.5
82.5	92.3
85.0	93.8
87.5	95.3
90.0	96.6
92.5	97.8
95.0	98.6
100.0	100.0

Table B.1(iii) Temporal distribution for a 36-hour duration

Time %	Cumulative %
5.0	1.9
7.5	3.4
10.0	5.2
12.5	7.4
15.0	10.0
17.5	13.0
20.0	16.1
22.5	19.5
25.0	23.2
27.5	27.0
30.0	30.6
32.5	34.6
35.0	38.6
37.5	42.8
40.0	46.9
42.5	50.8
45.0	54.5
47.5	58.5
50.0	62.4
52.5	65.9
55.0	69.6
57.5	73.0
60.0	76.3
62.5	79.3
65.0	81.9
67.5	84.3
70.0	86.4
72.5	88.3
75.0	90.0
77.5	91.5
80.0	92.9
82.5	94.2
85.0	95.4
87.5	96.5
90.0	97.4
92.5	98.3
95.0	99.0
100.0	100.0

Table B.1(iv) Temporal distribution for a 48-hour duration

Time %	Cumulative %
2.5	1.2
5.0	2.9
7.5	5.2
10.0	7.8
12.5	10.8
15.0	14.2
17.5	17.9
20.0	21.9
22.5	26.2
25.0	30.9
27.5	36.0
30.0	40.5
32.5	45.0
35.0	49.4
37.5	53.6
40.0	57.6
42.5	61.4
45.0	65.0
47.5	68.2
50.0	71.4
52.5	74.3
55.0	77.0
57.5	79.5
60.0	81.8
62.5	83.8
65.0	85.7
7.5	87.4
70.0	88.7
72.5	90.2
75.0	91.5
77.5	92.7
80.0	93.8
82.5	94.9
85.0	95.9
87.5	96.9
90.0	97.8
92.5	98.7
95.0	99.3
100.0	100.0

Table B.1(v) Temporal distribution for a 72-hour duration

Time %	Cumulative %
2.5	2.1
5.0	4.7
7.5	7.8
10.0	11.7
12.5	16.1
15.0	21.3
17.5	26.5
20.0	32.5
22.5	38.5
25.0	44.3
27.5	49.9
30.0	55.0
32.5	60.2
35.0	64.0
37.5	67.2
40.0	69.9
42.5	72.4
45.0	74.7
47.5	76.7
50.0	78.5
52.5	80.4
55.0	82.1
57.5	83.7
60.0	85.1
62.5	86.5
65.0	87.8
67.5	89.1
70.0	90.3
72.5	91.5
75.0	92.7
77.5	93.6
80.0	94.7
82.5	95.7
85.0	96.6
87.5	97.5
90.0	98.2
92.5	98.8
95.0	99.4
100.0	100.0