REVIEW OF WA DESIGN RAINFALL FOR FLOOD MANAGEMENT

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Abstract

Local authorities design and maintain urban and rural drainage systems in WA, relying on the basic input of rainfall data. In 1987 rainfall statistics were derived and published nationally and have not since been revised.

This paper investigates certain aspects of the methods used to calculate rainfall statistics, particularly with respect to the Intensity Frequency Duration (IFD) curves and highlights some issues which may require further investigation. The options for local authorities in terms of continuing to use 1987 results or commission new studies are discussed.

1. Introduction

The primary reference for this paper is Institution of Engineers (1987) Australian Rainfall and Runoff – a Guide to Flood Estimation, Volumes 1 and 2, reissued in 1999 unchanged. These two references are referred to in this paper as ARR 87 and ARR 99.

Design rainfall is a probabilistic or statistical estimate, being generally based on some form of probability analysis of rainfall data. An average recurrence interval (ARI) or annual exceedance probability (AEP) is attributed to the estimate. If a design rainfall is used in the estimation of a flood, it is not intended to apply that if a rainfall of that amount occurred at a given time, the estimated flood would result. Rainfall on a wet catchment might result in a very large flood, while rainfall on a dry catchment might result in relatively little or even no runoff. A feature of rainfall is that it varies both temporally and spatially.

Design of drainage works to pass or safely contain a flood of a given probability implies that a failure will result with the occurrence of a larger flood, referred to here as "surcharging".

For local authority drainage systems, the design intention is often that surcharging will occur, but that the resulting damages will be socially and politically acceptable, and with allowance for resulting damages, the average annual cost will be less than those of constructing a drainage system for larger flows.

For minor and medium size structures, a consequence of designing on a probability basis is that failure or surcharging should occur relatively frequently, perhaps with average recurrence intervals between 2 and 5 years. With tens of thousands of these structures in Western Australia, several thousand (about 20% of the total number) should be surcharged every year. For a given region however, many years may pass with very few if any occurrences of surcharging, as average recurrence intervals and exceedance probabilities refer to average numbers of recurrences over long periods of time.

It is highly probable that an extreme flood with an average recurrence of interval of the order of thousands of years will occur on at least one of them in any given year. The extreme rainfall over 15 minutes in Rockingham on 15 February 2003 (60mm) is an example.

This paper updates a previous investigation (Davies & Ruprecht, 1996).

2. Probability Concepts

Probability concepts and terminology are fundamental to design rainfall estimation. In specifying probabilities, the terms in common use include “recurrence interval”, “return period”, and “annual exceedance probability”. These terms have been used loosely, although ARR 99 attempts to bring order.

In this paper the distinction is made between design rainfalls based on an annual series, consisting of the highest event in each year of record, and the probability of exceedance of a value within a given period. Usually this period is 1 year and the appropriate term is Annual Exceedance Probability (AEP). A recurrence interval is frequently calculated as the reciprocal of the AEP, which is the average period between years in which the value is exceeded whether once, or more than once.

A partial series consists of events greater than an arbitrary base value, and recurrence interval or return period refers to the average value of the periods between exceedances of a given event magnitude.

With respect to rainfall data ARR 99 states that average recurrence interval (ARI) is the correct terminology as data and procedures are based on partial series analysis.

3. Local Government Responsibility for Design Rainfall

In Australia, local government, particularly Engineering Departments have the prime responsibility for stormwater drainage infrastructure. One of the primary factors in determining the appropriate size of these assets is the intensity of storm rainfall expected to occur. It follows that local governments rather than state or federal governments have the greatest interest and responsibility for ensuring that appropriate design rainfalls are used.

Whereas real time forecasting of rainfall has been accepted as a federal government responsibility, the responsibility for derivation of design rainfalls is not so clear. Traditionally in Australia the role has been filled by the Commonwealth Bureau of Meteorology (CBM), most recently in the development of rainfall statistics for durations from 5 minutes to 72 hours and for Average Recurrence Intervals (ARI) up to 100 years as published in ARR 87, updated without change to ARR 99. The reprint in 1999 was undertaken without review or revision to the design rainfalls.

The question is to what extent local government should take the initiative in reviewing or revising results which are 15 years old. In other sectors of the water industry, such as water supply, the effect of climate variability has been investigated. For example, in WA the Water Corporation has de-rated the water supply yield of their surface sources (reservoirs) to take account of the lower annual rainfall and associated catchment runoff since 1975.

This reduction in annual rainfall totals in the south west of WA generally has been documented by the Indian Ocean Climate Initiative Program (IOCI, 2002b). A corresponding increase in annual rainfall appears to have occurred in the north west part of the state, perhaps due to the same ocean and climatic influences over the Indian Ocean.

Government agencies, including local government authorities, have to–date not recognised a need to question the published ARR 87 design rainfalls, even in light of the well documented climate variability, generally changed rainfall patterns since 1975, and approximately 20 more years of rainfall data on which to base design rainfall estimates.

This paper considers the need for local governments to be proactive in relation to this issue, given their responsibility for management of extensive drainage assets, the performance of which depends crucially on rainfall.

This paper presents some preliminary analysis for such a review of rainfall statistics for WA conducted by JDA, with coverage around the entire WA coastline from South Australia to Northern Territory, and also along an east west transect through Perth to WA's eastern border. As well as reviewing the climate variability issue, the paper also remarks on aspects of the data analysis performed by CBM for ARR 87, particularly the process of smoothing rainfall statistics between different locations, and how this might have resulted in unrealistic rainfall statistics, particularly in areas of steep rainfall gradient such as over the Swan Coastal Plain and the Darling Scarp.

4. Published Design Rainfalls (ARR 87 & ARR 99)

Figure 1 shows the rainfall intensity frequency duration (IFD) curve for Perth derived from ARR 87 and ARR 99. This graph was produced by the following process summarised from ARR 99.

- Correction of restricted (8:00am to 8:00am) daily rainfall data to unrestricted by factors.
- Annual maximum analysis of data using lognormal probability distribution (LN) with zero skew.
- Adjustment of LN intensities for ARI of 2 and 5 years to partial series.
- Estimation of 1 year ARI rainfalls from 2 and 50 year ARI rainfalls.
- Spatial smoothing of 7 standard parameters (1, 12, 72 hour duration) 2 and 50 year ARI LN intensities, and skew to provide maps from which design rainfalls can be estimated.

This analysis used reliable data generally up to 1983 for all rainfall stations across Australia. Volume 2 of ARR 87 (produced as a CD for ARR 99) shows maps of the above 7 standard parameters. Most local government engineers will have used these maps at some time to derive an IFD similar to that shown in Figure 1. Software is available for generation of this map to save manual calculation. Most practicing engineers would not be familiar with the statistical methods used, but would assume that the published information is reliable and can be used without question, even in 2003.

The following issues perhaps deserve more attention and are considered in this paper :

- **Effect of Spatial Smoothing**
  The extent of smoothing of single station analysis in the ARR 99 rainfall estimates. The methods used for spatial smoothing are not well described in ARR 99 and may have resulted in either conservative (overestimation) or optimistic (underestimation) of design rainfalls.

- **More Recent Rainfall Data (1984 - 2003)**
  The fact that ARR 99 design rainfalls do not take into account the most recent 20 years of rainfall data since 1983. In many aspects of local government engineering particularly where risk management is involved, such a situation would not be considered acceptable. It is of interest that 4 of the highest 5 recorded 24 hour rainfalls in Perth since 1880 have occurred since 1986. Figure 1 shows several recent storm events in relation to the Perth IFD curve. The February 1992 event indicates that the storm exceeded 100 year intensities between approximately 6 and 24 hours. Figure 2 shows Perth annual maximum rainfall data for 1 day duration from 1880 to 2002, showing the highest value on record in 1992, occurring since ARR 87.

- **Consideration of Climate Change/Variability**
  The Indian Ocean Climate Initiative (IOCI) recently published a consolidated report on 5 years of strategic research (IOCI, 2002a). In terms of rainfall IOCI (2002a) finds southern Western Australia appears to have undertaken a step change since 1975 with less annual rainfall. Little

research to-date has however been undertaken with regard to short duration rainfall events. IOCI (2002a) concludes that climate affected sectors in southern Western Australia should actively revise their previous climate baseline and adapt accordingly to both natural and human induced changes in climate and climate variability.

Annual Maxima vs Partial Series Analysis
The low ARI (less than 5 year) values on which most piped drainage systems are designed, and the difference between annual maxima and partial series. That is, an event which occurs as an annual maximum will occur more often in a partial series (Table 1). ARR 99 rainfall data is for partial series and includes ARI's down to 1 year. For more frequent events (less than 1 year ARI) ARR 99 is silent and additional analysis is required on a project basis at the moment. This may be relevant for the design of Stormwater Pollution Traps (SPT's) which may be required to only cater for perhaps the 3 months ARI event and bypassing larger events

Table 1: Comparison of ARI's from Annual Maxima and Partial Series

Partial Series ARI (Yrs)	Annual Maximum Series ARI (Yrs)
0.20	1.01
0.50	1.16
1.00	1.58
1.45	2.00
2.00	2.54
5.00	5.52
10.00	10.50

5. Design Rainfalls Across WA

Figure 3 shows a map of Western Australia with a transect along the coastline from South Australia to Northern Territory annotated with town location numbers. Figure 4 shows the coastal transect with the values of standard rainfall intensities from ARR 99. Figure 5 shows corresponding information along an east west transect through Perth to the South Australian border.

The coastal transect (Figure 4) shows generally constant values of rainfall intensity in the south west corner of the State, with increasing trend over the Mid West and Pilbara, plateauing in the Kimberley.

The average regional skewness has a positive value at approximately 0.7 in the South West, decreasing to 0.0 through the Mid West and increasing gradually to 0.2 in the Kimberley.

6. Review of Existing Design Rainfall Estimates

The analysis presented in this paper is of rainfall data at 4 key stations (Perth, Exmouth, Kununurra, Northam) using daily rainfall data aggregated to 2 day and 3 day totals. Correction factors of 1.1, 1.05 and 1.02 have been applied to the 1, 2, 3 day totals to convert from restricted to unrestricted amounts. Shorter duration rainfall data from pluviographs could also be analysed in the same way.

Figures 6 to 9 show the frequency analysis plots for these four centres. Results are shown for calculations using long term historical records (to 2002), plotted against design rainfalls using ARR 99. The x-axis of these figures is average recurrence interval in the partial series derived from the annual maxima series ARI (Beran, MA & Nozdryn-Plotnicki, MJ,1977), refer Table 1. Table 2 compares the rainfall parameters from ARR 1999 with the review analysis conducted for this paper. Summarising the results of Figures 6 to 9 and Table 2 :

- For Perth and Northam, the spatial smoothing in ARR 87 has resulted in design rainfalls higher than those based on historical data alone (shown in Table 2 as ratios generally >1.0). That is, the smoothing process over the Swan Coastal Plain appears to have increased the rainfall intensities above those which were obtained from analysis of Perth and Northam rainfall data. ARR 87 therefore appears to give conservatively high values of rainfall intensity in this region.

- If the ARR 87 rainfall analysis technique was repeated using more recent data, and the same degree of spatial smoothing applied, it seems likely that the derived design rainfalls would be higher than those published in ARR 87 and ARR 99.

- Results are similar for Kununurra where ARR 99 appears to overestimate design rainfalls compared to those based on historical data.

- For Exmouth analysis of daily data 1968 to 2002 indicates that 1, 2, and 3 day intensities for ARI's up to 5 years are underestimated by ARR 99. For higher ARI, ARR 99 appears to overestimate the data analysis. JDA has been previously advised by the CBM that no change to the design rainfalls in ARR 99 is required following the recent high rainfalls in Exmouth in 1999 and 2002.

With regard to climate change and variability, the above analysis was based on using long term historical records including the last 20 years of record to 2002, and the effect of climate variability on short duration storm events to 72 hours has not been investigated in this paper. Higher values of design rainfall intensity are considered likely if this analysis were conducted on the basis of a change in climate state since 1975.

Table 2: Comparison of Calculated Design Rainfall Including 1983-2002 Data to ARR 99

Location	Duration (hours)	Ratio - ARR 99 IFD Estimates to Calculated Design Rainfall Including 1983-2002 Data					
		2 yr ARI	5 yr ARI	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI
Perth	24	1.04	1.06	1.05	1.08	1.11	1.14
	48	1.04	1.09	1.09	1.14	1.20	1.25
	72	1.00	1.07	1.09	1.16	1.23	1.30
Northam	24	1.20	1.10	1.04	1.02	1.00	1.00
	48	1.11	1.09	1.04	1.05	1.07	1.10
	72	1.08	1.08	1.06	1.09	1.13	1.17
Exmouth	24	0.93	0.10	1.01	1.09	1.15	1.19
	48	0.76	0.98	1.02	1.09	1.20	1.27
	72	0.95	1.00	1.06	1.12	1.19	1.25
Kununurra	24	1.19	1.18	1.14	1.12	1.06	1.03
	48	1.15	1.15	1.08	1.05	1.00	0.97
	72	1.10	1.10	1.06	1.05	1.04	1.03

7. Designing for Risk

As an alternative to the concept of designing for a specific ARI, an alternative is to consider the probability that a drainage structure will have its capacity exceeded once or more times during its design life. The design life may be clearly defined, as for example by a temporary cofferdam used during the construction phase of a project. Local authority asset manages may also define a design life for components of a drainage system.

The risk one or more exceedances of design capacity during a design life, using the partial series concept is:

$R = 1 - \exp(-L / Y)$

where R = risk of one or more exceedances in L years

L = design life in years.

Y = design ARI in years.

Table 3 presents specific values derived from this equation. For example, if a structure has a design life of 50 years then design for a 5 year ARI event will result in a risk and almost certainty (1.00 to the nearest 0.01) of one or more exceedances of this event. Alternatively, with a design life of 10 years and a design ARI of 10 years, the risk of one or more exceedances is 0.63.

Table 3 remains valid irrespective of any revisions to rainfall intensities discussed earlier in this paper.

Table 3: Risk of One or More Exceedences During Design Life

Design Life **L (Yrs)**	**Risk of One or More Exceedences for Given Design ARI** Design ARI Y (Yrs)			
	5	**10**	**50**	**100**
1	0.18	0.10	0.02	0.01
2	0.33	0.18	0.04	0.02
5	0.63	0.39	0.10	0.05
10	0.87	0.63	0.18	0.10
20	0.98	0.87	0.33	0.18
50	1.00	0.99	0.63	0.39

All values to nearest 0.01

8. Conclusions

Local authorities design and maintain urban and rural drainage systems in WA, relying on the basic input of design rainfall data. In 1987 rainfall statistics were derived and published nationally and have not since been revised.

With regard to Perth, this is despite 4 of the highest 5 recorded 24 hour rainfalls in Perth having occurred since 1986, and IOCI findings of a step change in climate since 1975. The recommendation is made that climate affected sectors in southern Western Australia should actively revise their previous climate baseline and adapt accordingly to both natural and human induced changes in climate and climate variability.

Government agencies, including local government authorities, have to–date not recognised a need to question the published ARR 87 design rainfalls.

Based on the outcomes of research conducted for this paper, it is considered that a review of design rainfalls for Western Australia is required. As a primary user of this data for design purposes, local governments are encouraged to be proactive in relation to this issue, given their responsibility for management of extensive drainage assets and associated risk, the performance of which depends crucially on rainfall.

The options for local government include : i) the continued use of ARR87 rainfall data, ii) requesting CBM to review the data including the last 20 years of rainfall record, iii) commission local studies to review rainfall data.

9. References

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Davies, J. R. & Ruprecht, J. K. (1996) Perth Rainfall IFD Revisited. Institution of Engineers, Australia, Hydrology and Water Resources Symposium, Hobart May 1996, pp 687-688.

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Indian Ocean Climate Initiative (2002b) *Investigating Climate Variability and Change, IOCI 2002 Towards Informed Adaptation, Symposium & Workshop* – 28/11/02-29/11/02

Institution of Engineers Australia (1987) *Australian Rainfall and Runoff – a guide to flood estimation Volumes 1 and 2*. ACT: Institution of Engineers, Australia.

Institution of Engineers Australia (1999) Revised edition *Australian Rainfall and Runoff – a guide to flood estimation Volumes 1 and 2*. ACT: Institution of Engineers, Australia.

FIGURES

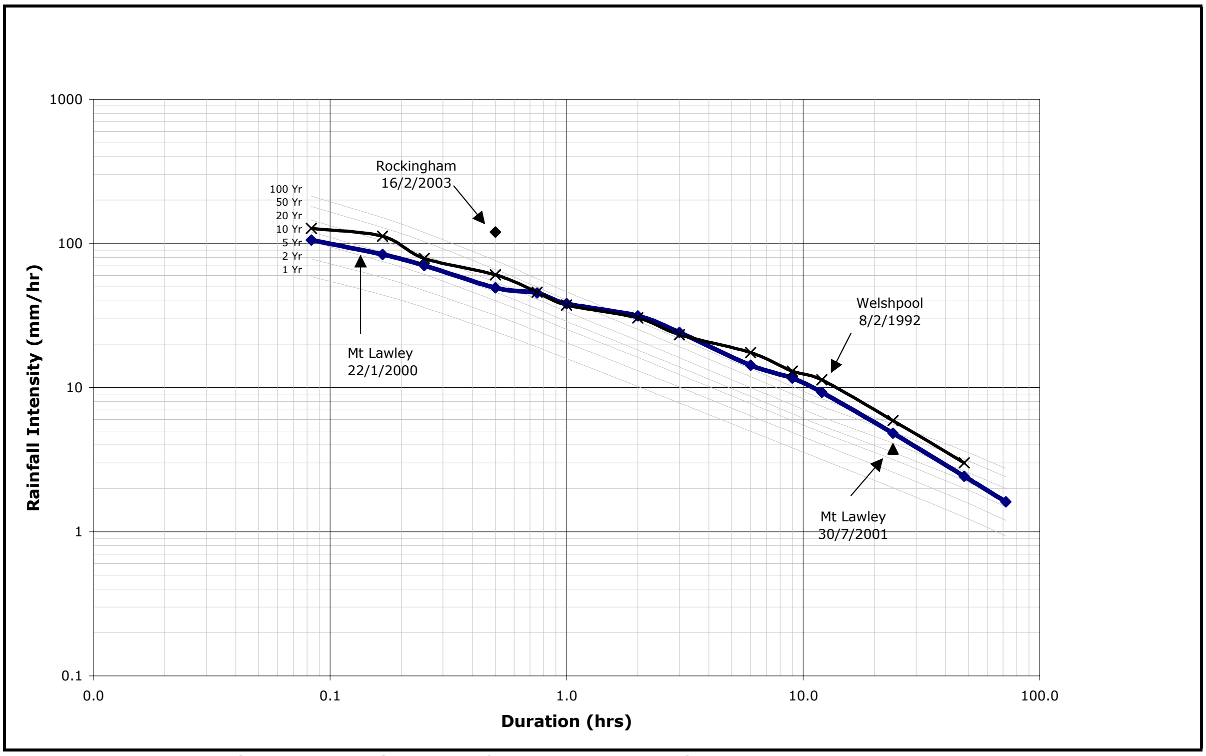

Figure 1 : Perth IFD Curves with Overlay of Various Recent Storm Events

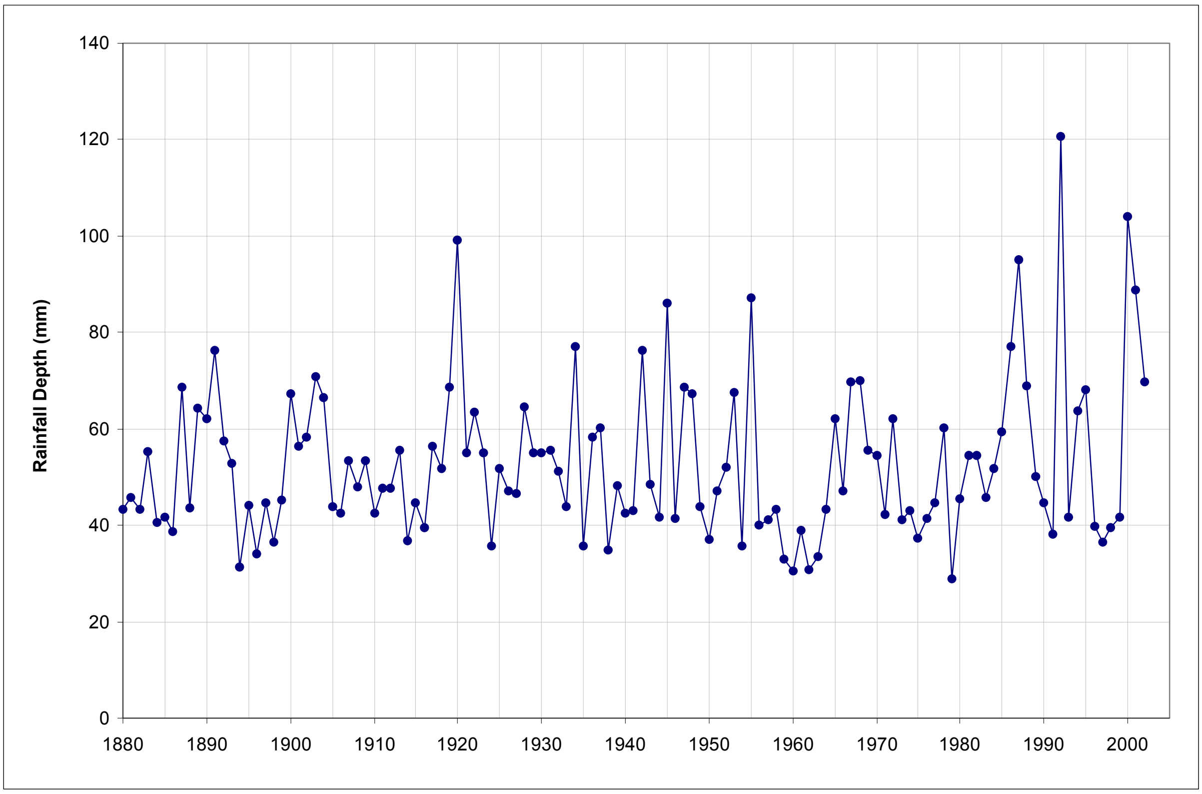

Figure 2 : Perth Annual Maximum 1 Day Rainfall Totals (1880-2002)

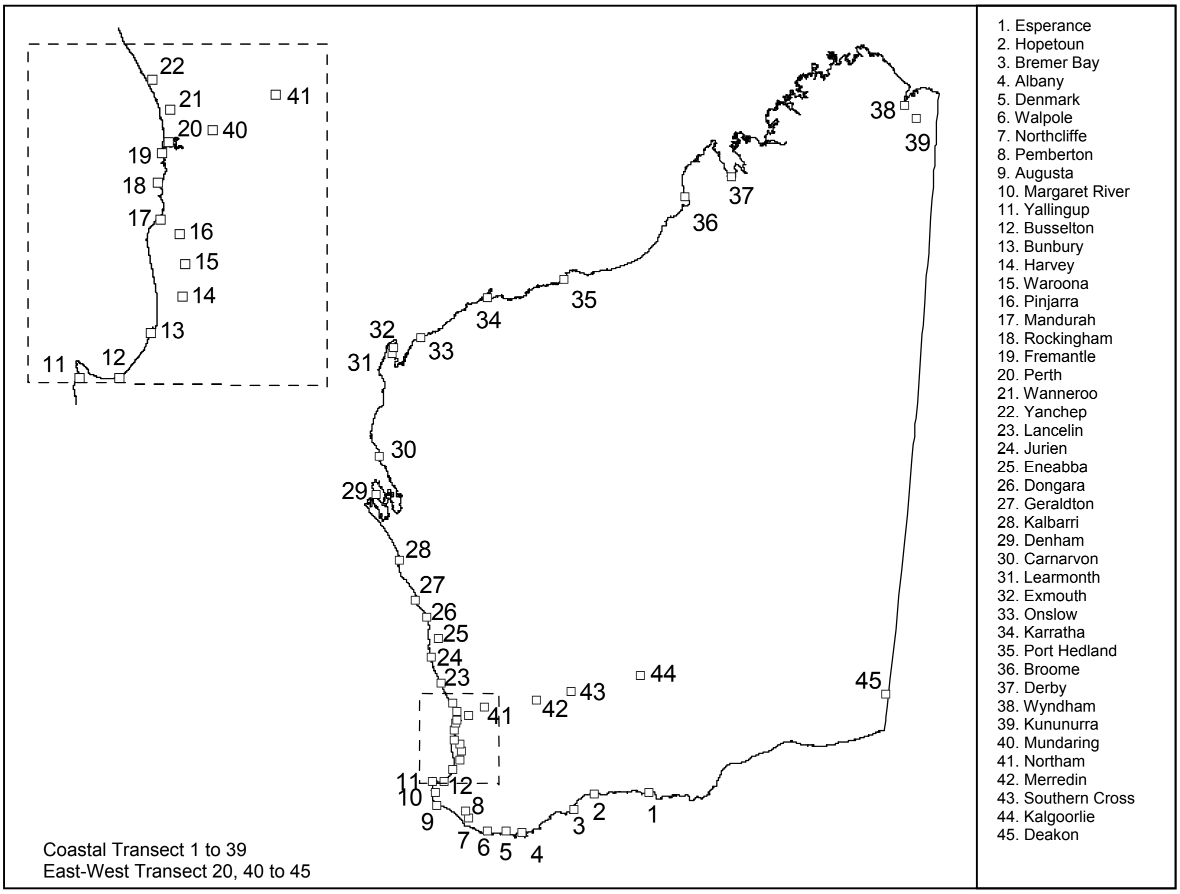

Figure 3 : West Australian IFD Transect Locations – Coastal and East West

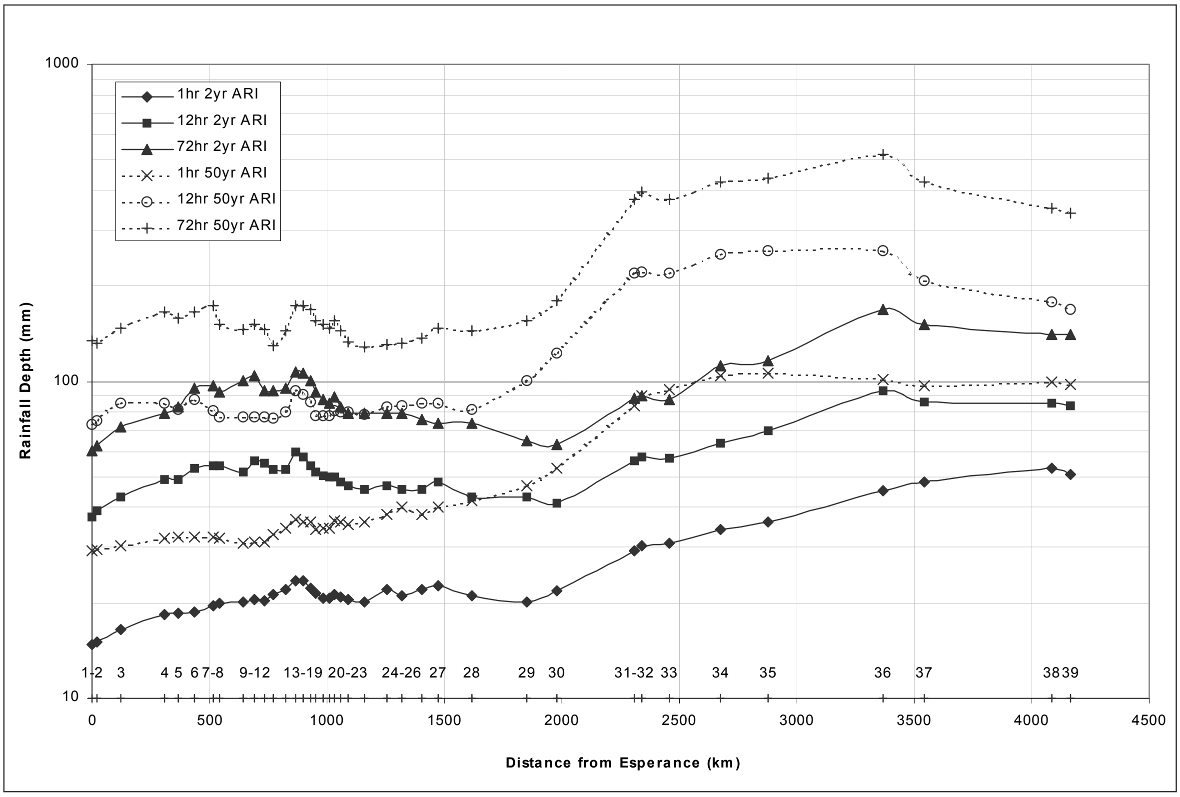

Figure 4 : West Australian Rainfall Parameters : Coastal Transect

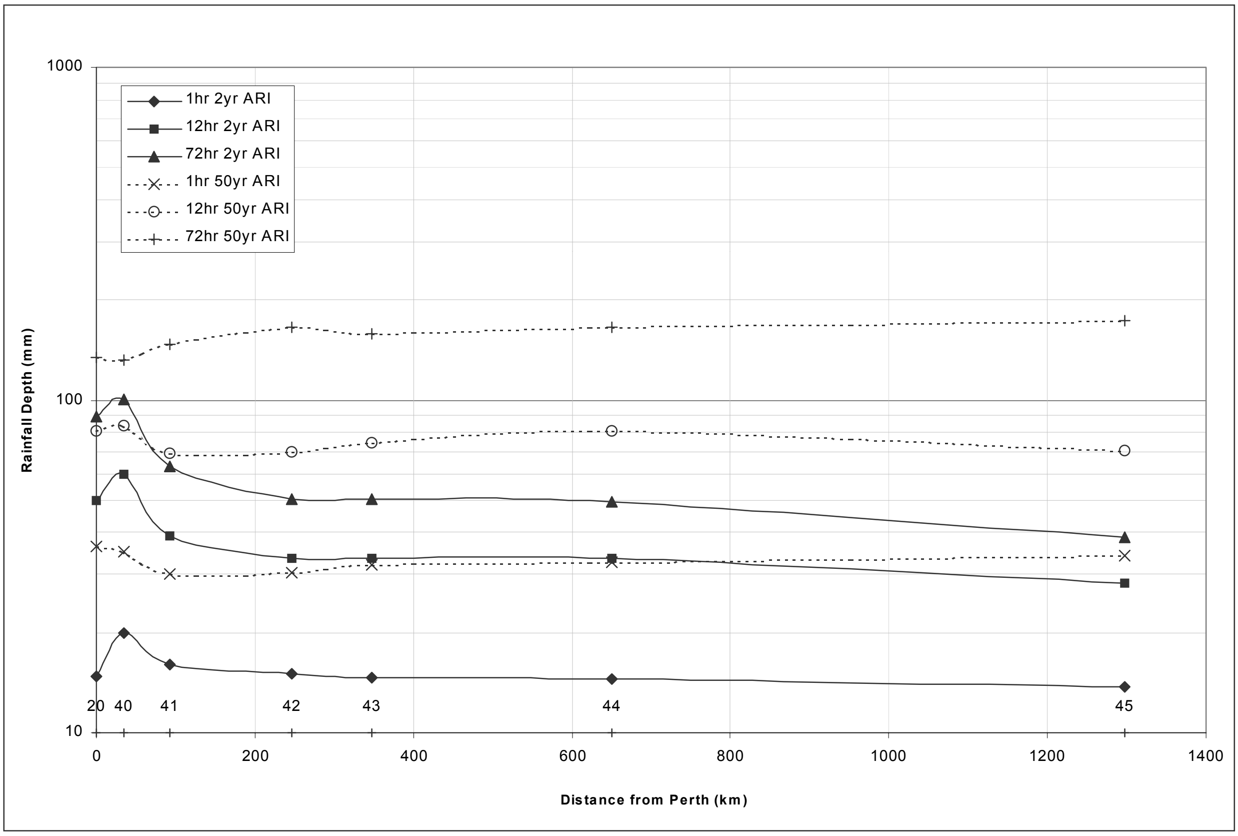

Figure 5 : West Australian Rainfall Parameters : East West Transect

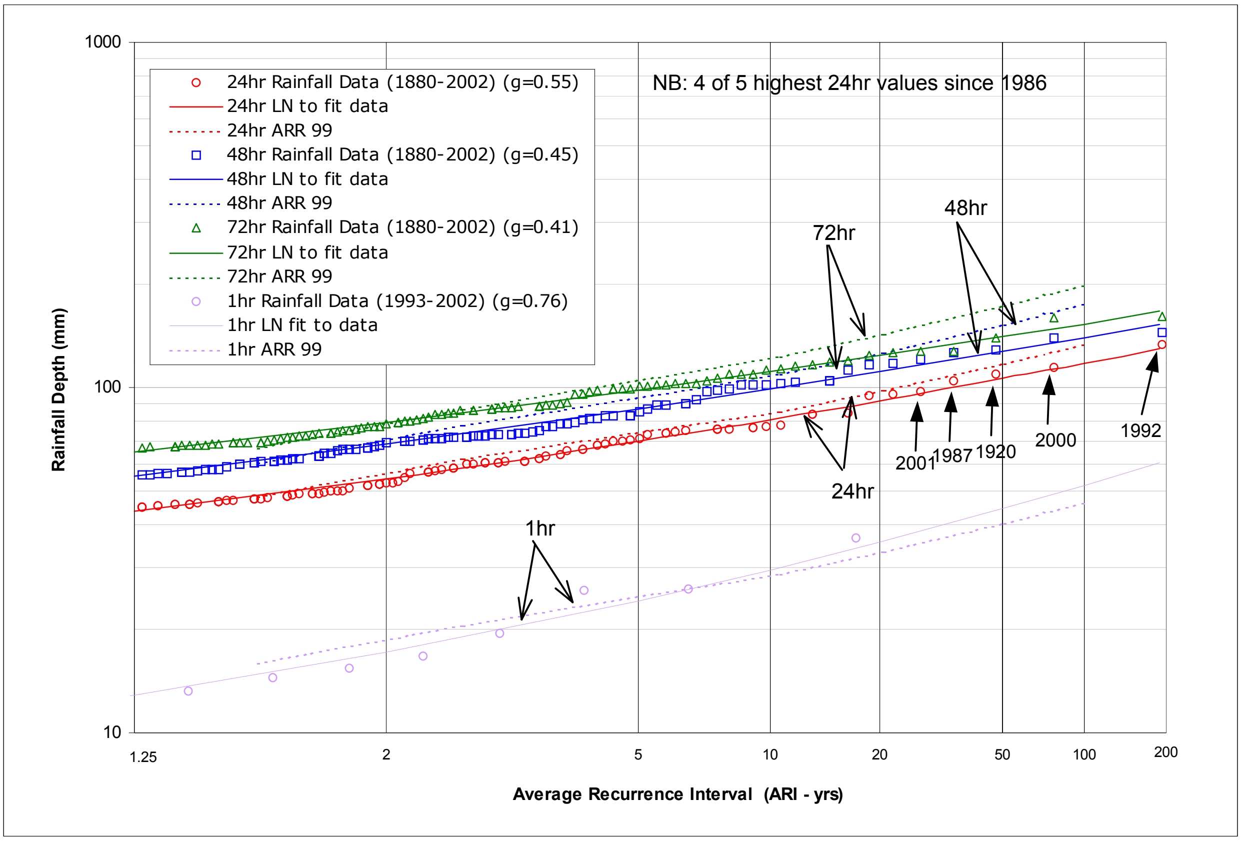

Figure 6 : Perth Annual Maximum Rainfall Analysis

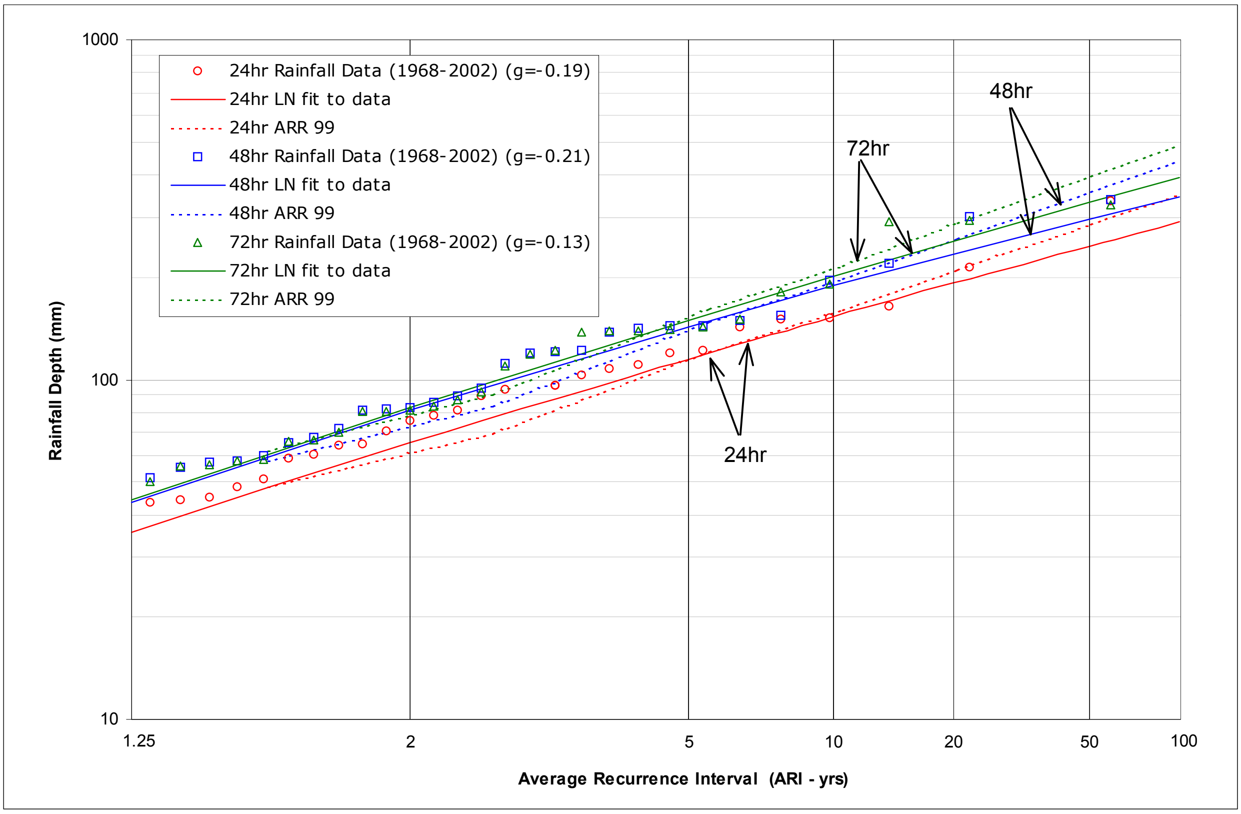

Figure 7 : Exmouth Annual Maximum Rainfall Analysis

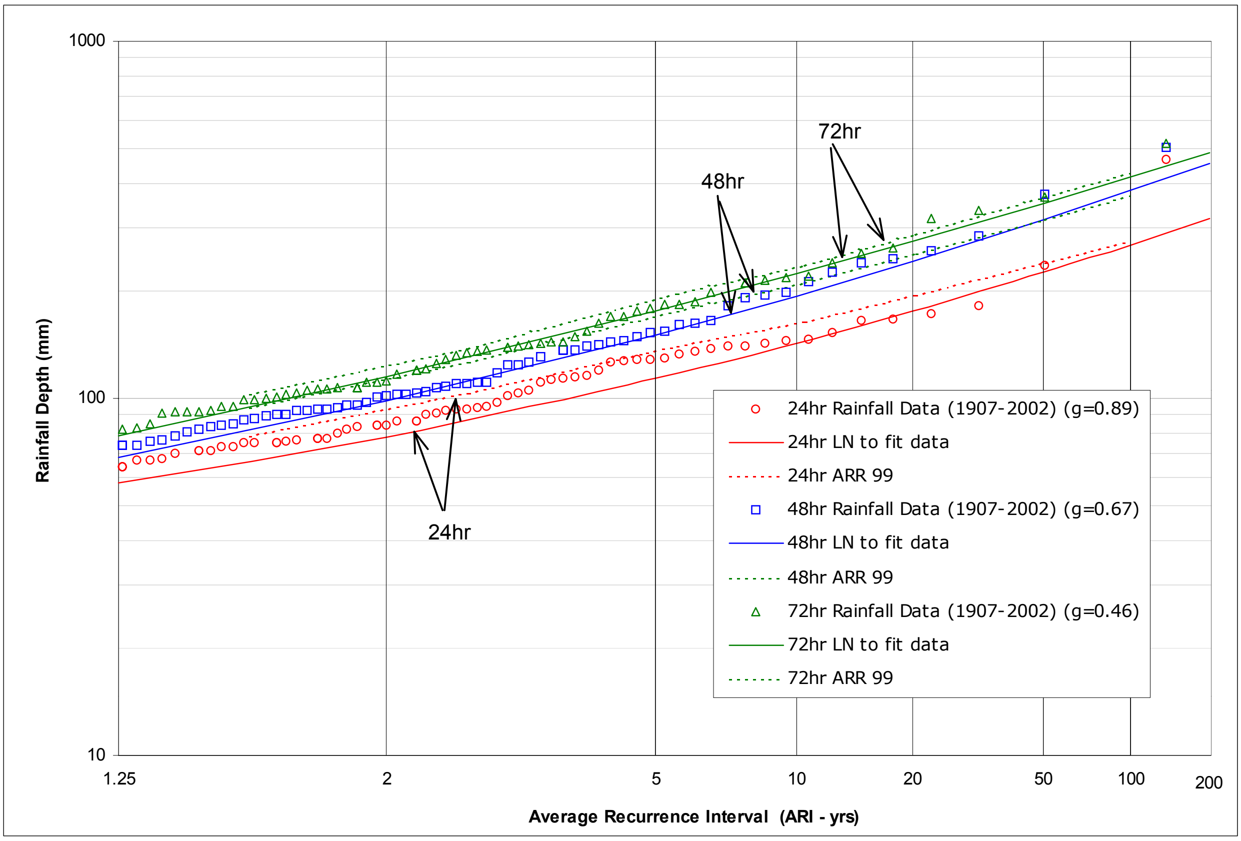

Figure 8 : Kununurra Annual Maximum Rainfall Analysis

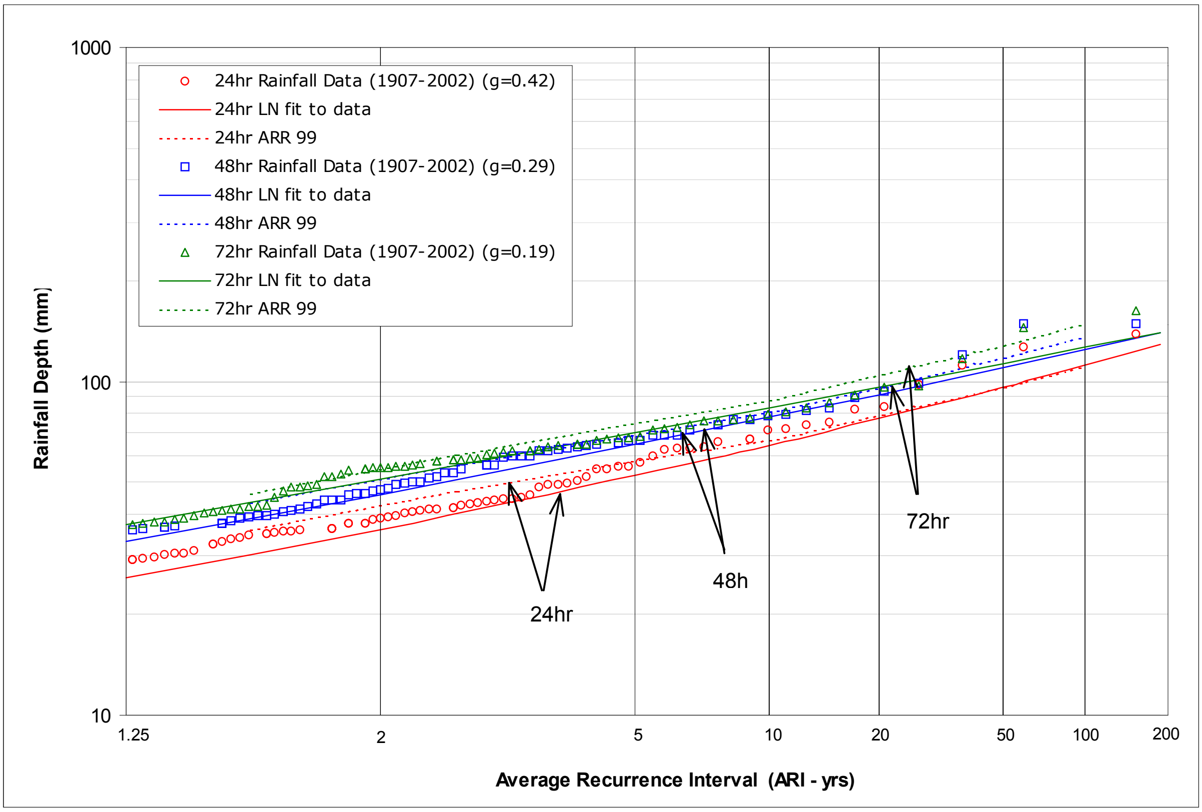

Figure 9 : Northam Annual Maximum Rainfall Analysis