Regional Flood Estimation in Australia: An Overview of the Study in Relation to the Upgrade of Australian Rainfall and Runoff

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Abstract

Regional flood estimation methods are used for estimation of design floods in ungauged catchments, which is required in the design of culverts, small to medium sized bridges, causeways, farm dams, soil conservation works and many other water resources management tasks. in Australia, the regional flood estimation methods have not been upgraded since 1987. Recently, the National Committee on Water Engineering has taken necessary steps to upgrade Australian Rainfall and Runoff (ARR). In the context of ARR upgrade, Project 5 Regional flood methods focuses on collation of a national database, development and testing of various regional flood estimation methods, which will form the basis of recommendation of new regional flood estimation methods in the upcoming revised edition of ARR. This paper focuses on the data preparation and preliminary studies on various regional flood estimation methods. The data from 703 gauged stations across Australia has been collated and the initial investigations show that a regression based approach can provide more accurate design flood estimates than the Probabilistic Rational Method. The initial results of time trend analysis show that about 30% of stations' annual maximum flood series are affected by trends; although further investigation is needed before any firm conclusion can be made about the trends in Australian flood data. A region of influence approach (ROI) is being investigated for developing regional flood prediction equations where the database of all the Australian states will be combined. In the ROI approach, to develop a prediction equation for an ungauged catchment of interest, the nearby 30 to 50 gauged stations will be included in the region. The national regional flood estimation database is expected to be updated periodically in future.

Introduction

Flood is one of the worst natural disasters that causes significant damage to infrastructure, services and agriculture plus the loss of valuable lives. To minimise the future flood damage, the magnitude of floods that is likely to be exceeded in a project's lifetime need to be estimated with sufficient accuracy. A 'design flood' is generally used for this purpose, which is a flood magnitude associated with a given probability of exceedance. In flood estimation, various aspects of a flood event may be required depending on the type of application e.g. peak flow rate, flood volume, flow velocity, depth and duration of flow and time to peak.

Design flood peak can be estimated based on recorded streamflow data using flood frequency analysis. Also, rainfall and runoff models can be used to convert a design rainfall event into a corresponding flood event. In a typical design flood estimation problem, a sufficiently long period of streamflow data is desired. However, at many locations there is lack of recorded streamflow data. For example, as at 1993, of the 12 drainage divisions in Australia, seven did not have a stream with 20 or more years of data (Vogel et al., 1993). For ungauged catchments, a regional flood estimation method is generally adopted to estimate design floods, which attempts to transfer flood characteristics information from gauged catchments to the ungauged one.

Estimation of peak flows on small to medium sized ungauged catchments is probably the most common design problem in flood estimation (Pilgrim, 1987). Design flood estimation on these catchments is required for the design of culverts, small to medium sized bridges, causeways, farm dams, soil conservation works and for many other water resources management tasks. The average amount spent on these projects per year was estimated at approximately $250 million as at 1985 (Flavell, 1985; Pilgrim, 1986); this is equivalent to over $600 million per annum in 2009 (based on long term CPI series for Australian capital cities).

Australian Rainfall and Runoff (ARR) 1987 recommended various regional flood estimation techniques for small to medium sized ungauged catchments for different regions of Australia (I.E. Aust., 1987). Since 1987, the regional flood methods in ARR have not been upgraded although there have been an additional 20 years of streamflow data available and notable developments in both at-site and regional flood frequency analyses techniques. As a part of the current revision of the ARR (4th Edition), *Project 5 Regional Flood Methods for Australia* focuses on the development, testing and recommendation of new regional flood estimation methods for Australia by incorporating the latest data and techniques.

Due to changing climate, the frequency and magnitude of floods in the near future is expected to vary across Australia. It has been established that changing climate will have notable impacts on the rainfall runoff process and thus hydrologic time series (e.g., flood data) can no longer be assumed to be stationary. It has serious implications in regional flood estimation, as these are based on past data, which can no longer be taken to represent the future under a changing climate regime. A failure to take climate change into account can undermine the usefulness of the concept of return period, and can lead to underestimation/overestimation of design flood estimates, which in turn will have important implications on the design and operation of water infrastructure.

This paper presents an overview of previously adopted regional flood methods in Australia, the scope and status of the on-going research in relation to the upgrade of the ARR and future direction.

Regional flood methods in ARR1987

Regional flood methods recommended in ARR1987 for various states are summarised in Table 1. Some important points to be noted are: (i) Seperate methods or maps of runoff coefficients were recommended for different states. The state boundaries do not carry any hydrological significance. Pooling of data from adjacent states was not considered. (ii) Most of the regions/states consisted of small sample size which may results in regional prediction equations lacking in statistical significance. Also, many of these stations had very short record lengths (e.g. only 10 years of streamflow data). In at-site flood frequency analysis, method of moments was adopted, which can produce large bias in design flood estimates when using data of short length. (iii) The index flood method is based on the assumption of homogeneous regions, but the regions where index flood method was applied were not tested for regional homogeneity. (iv)There is a lack of independent testing of the methods and uncertainty in final flood estimate is not well established.

Post ARR87 research

Since the publication of ARR in 1987, there have been notable developments in regional and at-site flood frequency analyses. Kuczera (1999) developed Bayesian method of flood frequency analysis, which has been incorporated in software called FLIKE (Kuczera and Franks, 2005). This can also account for the effects of errors due to rating curve extrapolation. Hosking and Wallis (1993) presented *L* moments based at-site and regional flood frequency analyses, which are less sensitive to record length and outliers in the data. This approach was tested using south-east Australian flood data (e.g. Bates et al., 1998; Rahman et al., 1999), but had limited success due to lack of regional homogeneity. To avoid the boundary problem, Burn (1990) introduced a region of influence approach, which forms region for each individual station on the basis of similarity in geographical or catchment attribute space. Tasker and Stedinger (1989) presented an operational generalised least squares (GLS) regression approach which can account for inter-station correlation, variation in record lengths from site to site and correlated residuals in developing regression based flood prediction equations

Table 1 Various regional flood estimation methods in ARR1987

State	Method	Database used in the development	Comments
NSW (Eastern NSW)	Probabilistic Rational Method	308 gauged catchments, streamflow data length of 10 years and more.	Applicable up to 250 km^2 in area.
NSW (Western NSW)	Index flood approach	68 gauged catchments.	Applicable up to 250 km^2 in area.
Victoria	Probabilistic Rational Method	325 gauged catchments, streamflow data length of 10 years and more.	Applicable up to unlimited catchment size.
ACT	Multiple regression methods	14 gauged catchments, streamflow data length of 10 years and more.	Method for Eastern NSW (i.e. Probabilistic Rational Method) is applicable to ACT as well.
Qld	Main Roads Department Rational Method Department of Primary Industries Rational Method Methods of Eastgate, Swartz and Briggs	Methods were based on limited observed flood data.	Procedures are of arbitrary nature and are likely to be of lower accuracy than methods developed from observed flood data in other States.
SA	Rational Method	20 gauged catchments. Maximum streamflow record length of 16 years.	
SA	Department of Agriculture Method (Index flood approach)	6 gauged catchments.	Applicable up to 200 ha in area.
SA	For arid and semi-arid region: Rational Method and regression method	Regression method is based on data from 3 gauged catchments.	
WA	Rational Method Index flood method	Based on data from 12 to 27 catchments depending on the regions. WA was divided into 4 regions.	
WesternTasmania	Regional Method	Method is based on limited observed flood data.	Procedures are of arbitrary nature and are likely to be of lower accuracy.
Eastern Tasmania	Rational Method	Based on limited observed flood data.	
NT	Rational Method Cameron McNamara Method	Based on limited observed flood data.	Subject to large uncertainties depending on region.

Current research in relation to the up-coming revision of ARR

The on-going research on regional flood estimation methods which will form the basis of recommendation of regional flood methods in ARR is summarised below.

Collation of a national database for regional flood estimation: The challenge in collating a database for regional flood estimation lies in maximising the amount of useful flood information, while practically minimising the random error component (or 'noise') that may be present in some flood data. The following six criteria were adopted in selecting the stations. (i) The catchment should not be greater than 1000 km^2. (ii) The record length of the annual maximum flood series for the finally selected stations should be at least 25 years. In few states, due to limitation of stations with longer record lengths, the threshold of 20 years was deemed to be acceptable. (iii) The catchments should not have major regulation. (iv) A catchment should have less than 10%

urbanisation. (v) There should not be any major land use changes during the period of streamflow records being considered. (vi) The quality of data should be rated acceptable by the gauging authority.

Initially, the database of individual state was consulted. Data for each station was checked and prepared using appropriate gap-filling method, the outliers were identified, the rating curve error was examined, and time trend in the annual maximum flood series data was examined. The detail data preparation procedure can be found in ARR Project 5 Stage Report (I.E. Aust., 2009) and in Haddad et al. (2010). The final database (subject to change based on the results of further on-going investigation) consisted of 703 stations as summarised in Table 2 and in Figure 1. It should be noted here that arid and semi-arid parts of Australia do not have any station that satisfy the criteria of the selection of stations.

Table 2 Database for development and testing of regional flood methods in ARR (4th Edition)

State	Size of database (Number of stream gauging stations)	Streamflow record length
Victoria	131	25-52 years (mean 32 years)
NSW and ACT	96	25-74 years (mean 34 years)
Queensland	172	25-94 years (mean 40 years)
Tasmania	53	20-74 years (mean 30 years)
SA	30	17-66 years (mean 33 years)
NT	67	20-51 years (mean 34 years)
WA	154	20-56 years (mean 30 years)
Total	703	

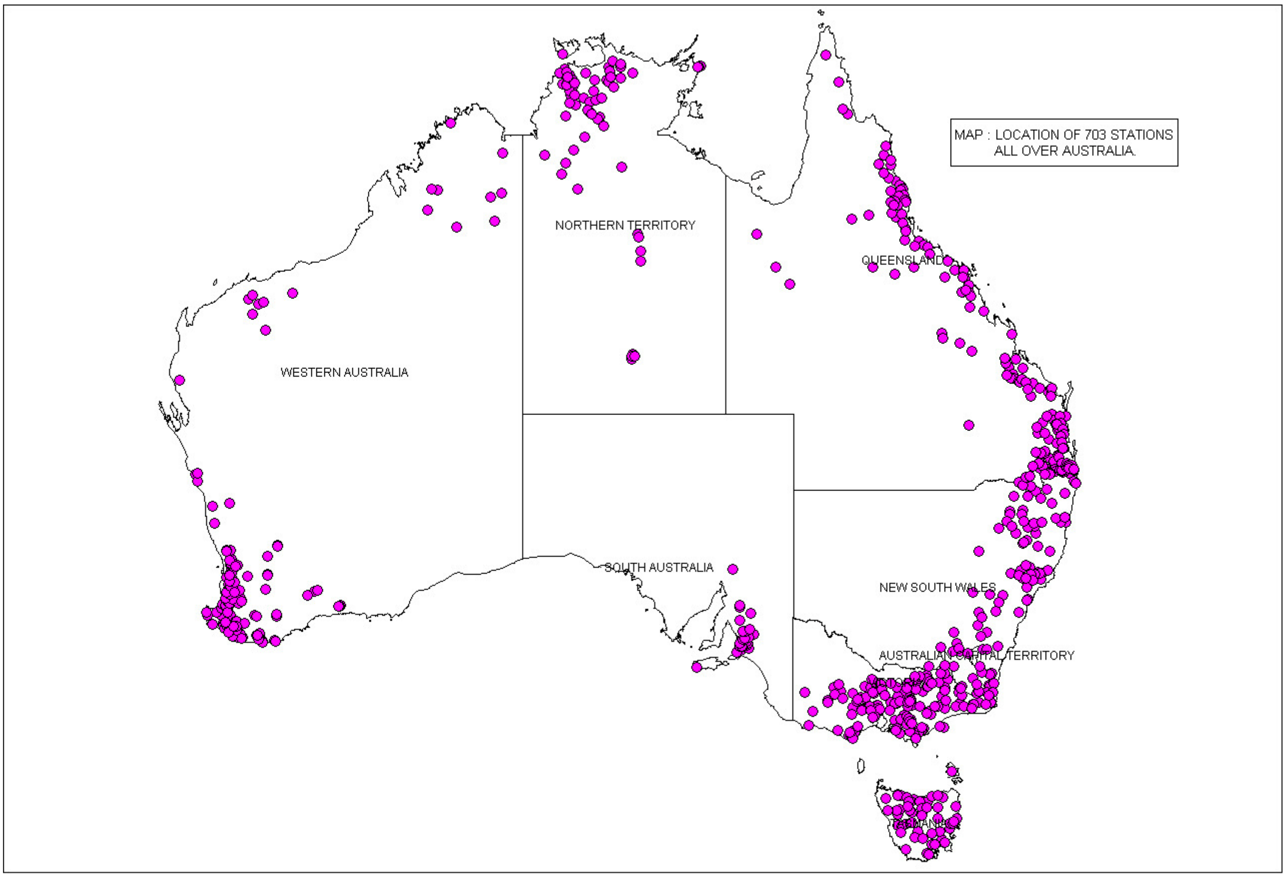

Figure 1 Locations of the selected 703 stations across Australia

Time trend analysis in annual maximum flood series: For trend tests, parametric and non-parametric tests can be adopted. Parametric tests assume that the time series data are independent and normally distributed. According to Khaliq et al. *(*2009) parametric tests that involve non-stationarity frequency analysis of hydrological variables are generally more powerful in modelling and investigating the trends in observations over the non-parametric tests. However, the trend analysis based on parametric process involves many assumptions about the trend behaviour - see Khaliq *et al. (*2006) for details about the parametric approaches. On the other hand, non-parametric methods (i.e., Mann Kendall, Spearman's Rho) are more robust with respect to non-normality, nonlinearity, missing values, serial dependence, sensitivity to outliers (extremes), and seasonality (Yue et al., 2002).

For trend analysis, stations with at least 30 years of record (range 30 – 97 years, mean: 38 years) were considered, which gave a database of 491 stations. Two non-parametric trend tests were applied: Mann-Kendall test and Spearman's Rho test. The results of statistically significant trends observed at the 90% confidence level are summarised in Table 3. Presented is the percentage of stations with significant trend for the annual maximum flood series; results are shown separately for positive and negative trends. Among the 491 stations, the total number of stations showing trend is 156 and 172 stations for Mann-Kendall and Spearman's Rho's tests, respectively. Prominently, the number of trends for the annual maximum (AM) flood variable far exceeds the critical level for establishing on site significance. Hence, the introductory conclusion is that the Australian AM flood series exhibit substantially more trends (32% and 35% from Mann-Kendall and Spearman's Rho's tests, respectively) than would be expected to occur by chance (10%). Further, Table 3 displays that the direction of the trends is, in general, downward, as established by the two tests. This result might have been affected by the shortness in record length for the majority of the tested stations (average record length of 38 years), especially by the dry period that the continent experienced in the last decade in the south-eastern and south-western parts.

Interestingly, basins located in the south-eastern Australia display negative trends only (Figure 1), suggesting a decrease in the AM flood series. Similar findings appear in the south-west of Western Australia region. However, increasing trends are noted in the north-western part of the continent, suggesting increase in the AM flood series. While, combined decreasing and increasing trends pattern were detected in some parts. Further investigation is needed before any firm conclusion can be made about the trends in Australian flood data. Future work aims to address the influence of spatial and autocorrelation on the ability to detect trend in annual maximum flood series data in Australia and assess the relationship between the observed trends in annual maximum flood data and other meteorological variables.

Table 3 Trend analysis results and percentage of stations with a significant trend

Trend tests	Number of stations	Number of stations showing decreasing trends	Number of stations showing increasing trends	Percent stations showing significant trends (%)
Mann-Kendall	491	127	29	32
Spearman's Rho		140	32	35

Development of prediction equations - pilot study: A number of regional flood estimation techniques have been applied to the pilot data set (I. E. Aust., 2009; Haddad et al., 2008, 2009a; Rahman et al., 2008; Hackelbusch et al., 2009; Pirozzi et al., 2009; Palmen and Weeks, 2009; Ishak et al., 2010). The initial testing has concentrated on the comparison of currently applied methods such as Probabilistic Rational Method and regression based approaches (e.g. ordinary least squares (OLS) and GLS based quantile regression technique (QRT)). The results for eastern NSW is summarised in Table 4. So far it has been found that QRT-GLS method with two independent variables can produce more accurate design flood estimates than the Probabilistic Rational Method (PRM).

On-going studies: A region of influence approach is being investigated for the application of QRT-GLS method and PRT-GLS method. In the PRT-GLS method, the prediction equations for the parameters of the LP3 distribution will be developed (see Hackelbusch et al., 2009 for initial results). In the ROI approach, the database of all the Australian states will be combined and to develop a prediction equation for an ungauged catchment of interest, the nearby 30 to 50 gauged stations will be included in the region. The design flood estimate will be provided with an estimate of uncertainty in the form of confidence limits. A regional flood estimate method for large to rare floods (up to 2000 years ARI) is also being investigated (see Haddad et al., 2009b for initial results).

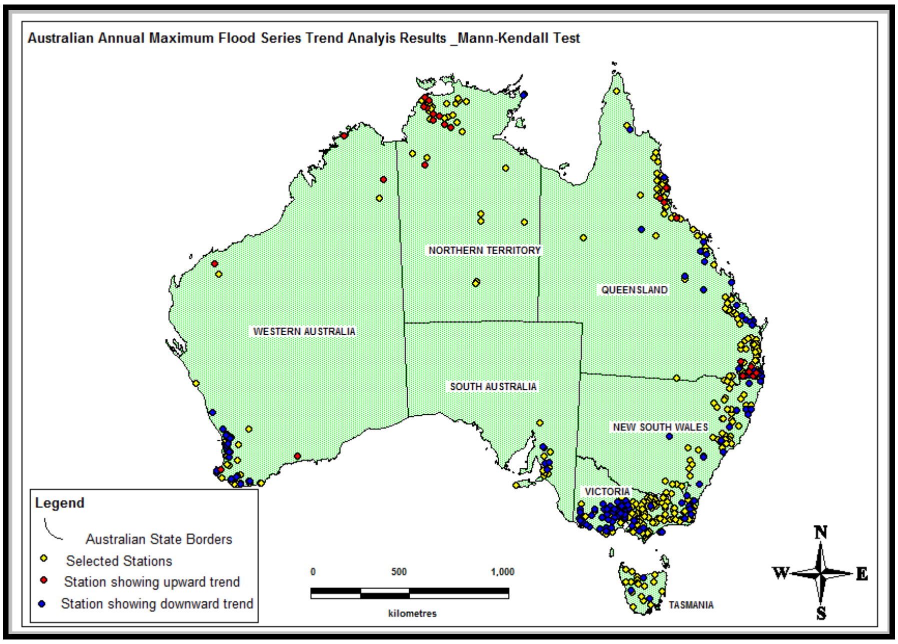

Figure 2 Results of trend analysis based on Mann-Kendall test. Red and blue circles represent positive and negative trends, respectively

Table 4 Summary of model tally based on Q_{pred}/Q_{obs} ratio values (eastern NSW) (I.E. Aust., 2009) (Here 'under' and 'over' mean underestimation and overestimation, respectively)

ARI (years)	QRT-OLS			QRT-GLS			PRM		
	Under	Acceptable	Over	Under	Acceptable	Over	Under	Acceptable	Over
2	1	6	5	3	7	2	2	8	2
5	0	8	4	0	8	4	4	6	2
10	0	10	2	0	11	1	4	6	2
20	0	10	2	0	10	1	4	6	2
50	2	8	2	2	9	1	4	6	2
100	2	7	3	3	7	3	4	6	2
Sum	5	49	18	8	52	12	22	38	12
%	7	68	25	11	72	17	30.5	53	16.5

To account for the impact of the observed trends in the annual maximum flood series data, a non-stationary probability distribution (LP3 or GEV) will be fitted to the data of selected stations across Australia and an adjustment factor for various ARI floods will be derived that can be used to adjust the stationary flood frequency estimates based on location and ARI.

Progressive update of the database and methods in future

It is expected that the database used to develop the regional flood methods will be publicly available via Engineers Australia. This database will be updated periodically e.g. flood quantiles of gauged sites will be updated with the availability of additional streamflow data, design rainfall estimates will be updated with new design rainfall data to be available as a part of the on-going revision of ARR. Also, new regional flood estimation methods can be tested with the updated database. The trends in the annual maximum flood data series will be tested in future using data of longer lengths to make necessary adjustments for climate change and long term climate variability.

Conclusions

The regional design flood estimation methods in Australia are in the process of upgrade as a part of the upcoming revision of Australian Rainfall and Runoff. For this a database of 703 small to medium sized gauged catchments has been prepared. A pilot study has shown that regression based approach can provide more accurate design flood estimates than the Probabilistic Rational Method. The initial results of time trend analysis show that about 30% stations' annual maximum flood data are affected by trends; although further investigation is needed before any firm conclusion can be made about the trends in Australian flood data. A region of influence approach is being investigated for developing regional flood prediction equations where the database of all the Australian states will be combined. The national regional flood estimation database is expected to be updated periodically in future.

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