BUREAU OF METEOROLOGY, AUSTRALIA

HYDROLOGY REPORT SERIES

HRS Report No. 7

DEVELOPMENT OF THE METHOD OF STORM TRANSPOSITION AND MAXIMISATION FOR THE WEST COAST OF TASMANIA

Hydrology Unit
Melbourne
January 2001

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DEVELOPMENT OF THE METHOD OF STORM TRANSPOSITION AND MAXIMISATION FOR THE WEST COAST OF TASMANIA

K.C. XUEREB, G.J. MOORE AND B.F. TAYLOR

Hydrology Unit
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1. INTRODUCTION

Storm transposition and **maximisation** is a method which was used widely in Australia from the late 1960s to the early 1970s to estimate **probable maximum precipitation** (PMP). PMP is defined by the **WMO** (1986) as '*the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends.*' It represents the physical upper limit to the rainfall over an area in a given time. Together with its spatial and temporal distributions, PMP is used in the design of hydraulic structures where a low risk of failure is required, e.g. tailings dams and spillways of large dams.

Storm transposition implies a displacement of the characteristics of a storm from the location where it occurred to a target location if the storm could just as easily have occurred there. Maximisation is the process of adjusting the rainfall upward assuming maximum moisture inflow into the storm. Storm transposition and maximisation evolved from *in situ* maximisation in which only storms which had occurred over a location of interest were considered for **moisture maximisation**. Since the mid-1970s there has been a trend towards development of **generalised methods of PMP estimation**, which use all the storm data over a large region.

Central to the concept of PMP, is the hypothesis that PMP involves the optimum combination of storm efficiency and moisture availability (Minty *et al.*, 1996; United States Weather Bureau, 1960). Maximum storm efficiency is reasonably approximated by analysing the most outstanding storms on record, the assumption being that at least one would have been operating at or near maximum efficiency. The hypothesis of maximum moisture availability is approximately satisfied by assuming maximum moisture inflow into the storm.

The transition from *in situ* maximisation to storm transposition and maximisation to generalised methods involves use of a larger storm sample with each stage in the transition, which has tended to generally increase estimates of PMP due to the increased likelihood of containing an outlier. It follows that estimates produced using storm transposition have a lower **annual exceedance probability** (AEP) than *in situ* maximisation estimates, while estimates produced using generalised methods have even lower annual probabilities of exceedance than those produced using *in situ* maximisation and transposition methods. The AEP of the PMP from generalised methods occupies the upper limit range of the continuum of the AEP of extreme rainfall, which is defined in Nathan and Weinmann (1999) as rainfall having AEP between about 1 in 2000 to the AEP of the PMP.

In Australia, several generalised methods of estimating PMP have been developed. The Generalised Short Duration Method (**GSDM**), for short durations and small catchment areas was developed in the early 1980s (Bureau of Meteorology, 1985; Bureau of Meteorology, 1994). The Generalised Tropical Storm Method (**GTSM**) for PMP estimation is applicable for the region of Australia affected by tropical storms (Kennedy, 1982; Kennedy and Hart, 1984). The Generalised Southeast Australia Method (**GSAM**) is applicable for catchments outside the region of applicability of the GTSM, but not the west coast of Tasmania or the southwest region of Western Australia (Kennedy *et al.*,

1988; Minty *et al.*, 1996). The region boundaries and zones for application of the GSAM and GTSM are shown in Figure 1.1.

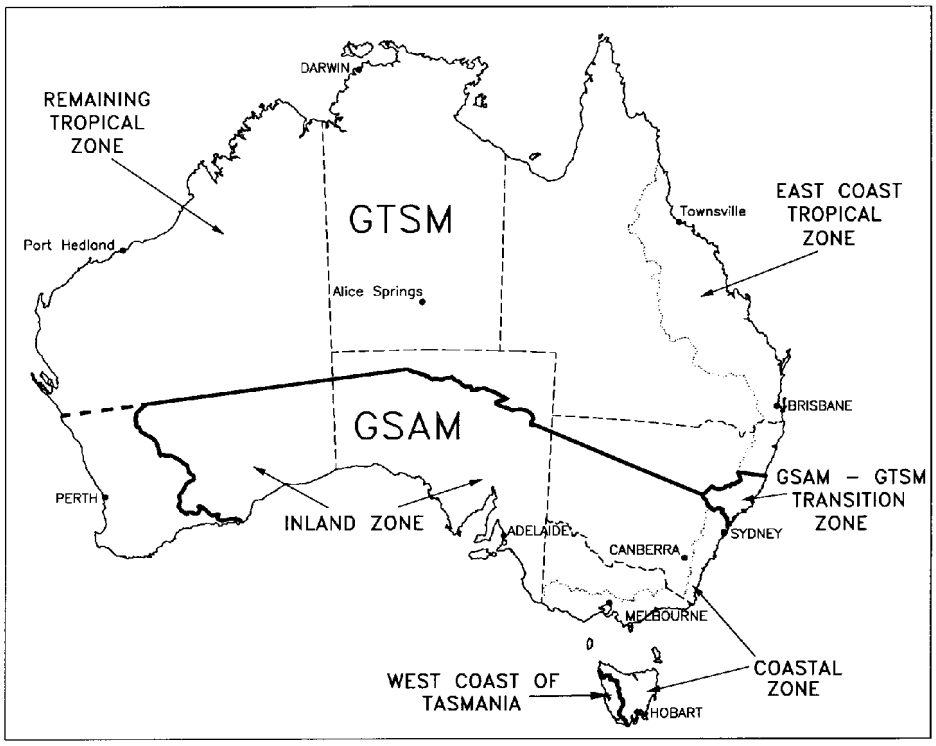


Figure 1.1: Generalised long duration PMP method zones and the west coast of Tasmania.

In the absence of a more appropriate method, the southwest region of Western Australia has been assigned to the GTSM. This leaves the west coast of Tasmania, defined as the region within Tasmania outside the region of applicability of the GSAM Coastal Zone (Figures 1.1 and 1.2), as the only region for which no method for long-duration PMP estimation exists. It was excluded in the development of the GSAM because of lack of data and hence understanding of heavy rainfall events in the area (Minty *et al.*, 1996). Hydro Tasmania (formerly known as the Hydro-Electric Corporation of Tasmania (HEC)) requires estimates of extreme rainfall up to 72 hours for some 10 catchments in Tasmania's west. In 1998, the Bureau of Meteorology evaluated several alternatives for estimating extreme rainfall. Among those considered were: application of **flood frequency techniques**, **paleohydrologic techniques**, numerical simulations of extreme events, *in situ* maximisation and analysis of regional rainfall which has already been carried out by Hydro Tasmania. These methods were not recommended because they would not yield estimates to a low enough AEP. Applicability of the GSAM was also considered. However, a preliminary analysis of some of the most significant events in western Tasmania had demonstrated that western Tasmania experiences large/extreme events through entirely different mechanisms to the storms included in the GSAM database, therefore application of the GSAM in the region is not appropriate. Development of generalised methodology would yield estimates with the lowest AEP, however this method was not considered feasible at that stage, because it would consume a large amount of resources for a relatively long period of time. The method of storm

transposition and maximisation could yield estimates to AEP of about 1 in 10^4 (as desired by Hydro Tasmania) for catchment areas of the order of 1000 km^2 using Kennedy and Hart (1984) guidelines for estimating the AEP of the PMP. The method of storm transposition and maximisation had the advantage that it could be developed within a relatively short period of time and it was therefore proposed and accepted by Hydro Tasmania. This document records development of that method.

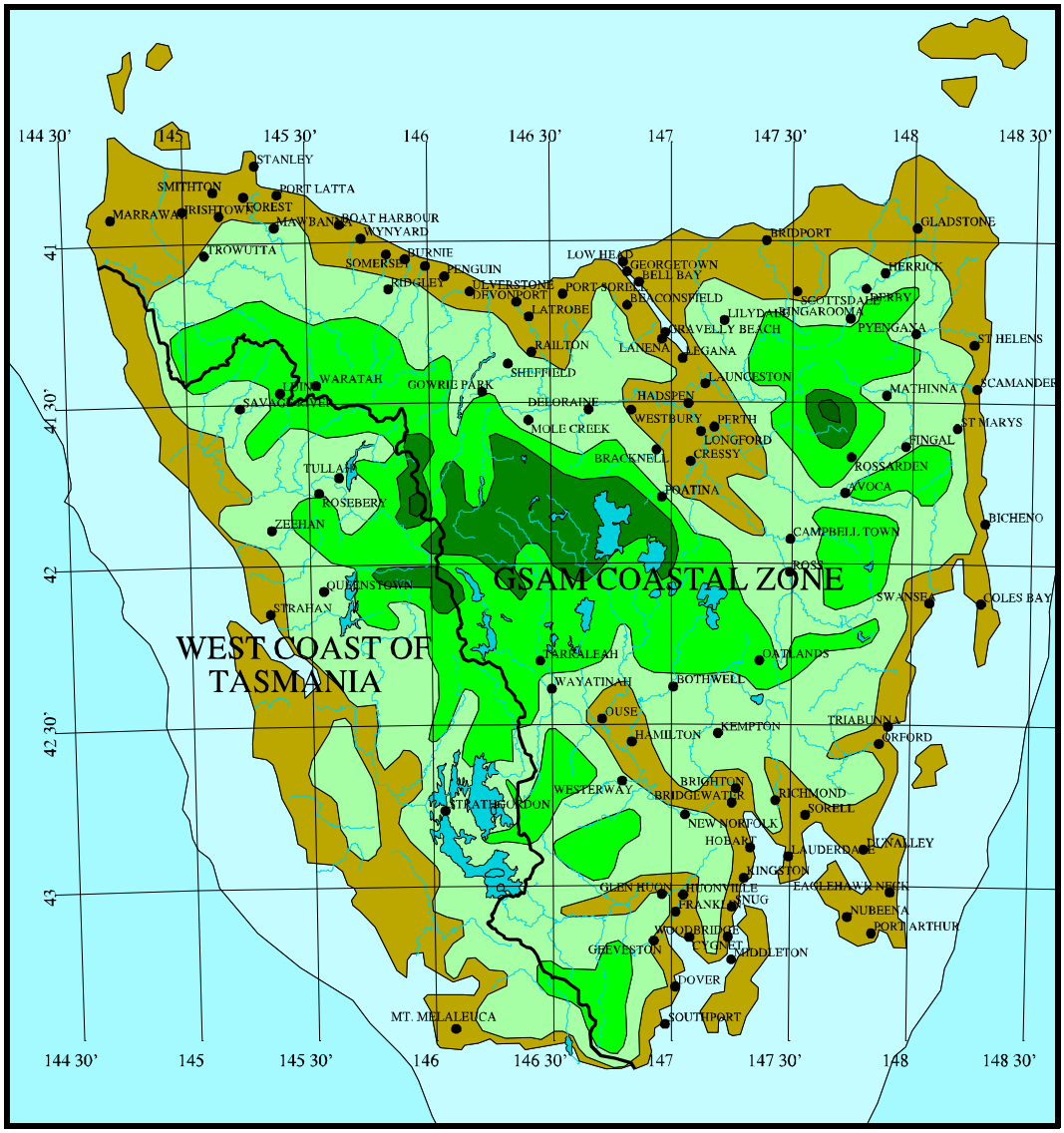


Figure 1.2: Map of Tasmania showing major towns and the Tasmanian GSAM Coastal Zone and the West Coast of Tasmania.

2. OTHER STUDIES OF EXTREME PRECIPITATION IN THE WEST COAST OF TASMANIA

In the 1960s, the Bureau of Meteorology carried out several studies of extreme

precipitation for catchments in Tasmania's west. Unfortunately, no copies of the original reports could be located, either at the Bureau of Meteorology (Head Office and the Tasmanian Regional Office) or at Hydro Tasmania. However, perusal of archived documents revealed that most past studies of extreme precipitation in Tasmania's west involved *in situ* maximisation. The transposition of major storms was not considered viable because of strong orographic influences on the rainfall. For catchments in the southwest, it was not even possible to use *in situ* maximisation because there was no rainfall data for events which had occurred before about 1960. For these catchments, an event which was known to be significant in the northwest and which would also have been significant in the southwest was selected, and the rainfall pattern in the southwest deduced using maps of mean rainfall and **variance** of rainfall. Some other useful information gathered from the documents include storm dates, catchment rainfall depths and **storm dewpoint temperature**s.

The HEC (as Hydro Tasmania was known at the time) has also carried out its own studies of extreme precipitation for some catchments based on a storm which occurred in May 1975. More recently, Hydro Tasmania has applied the CRC-FORGE method (Gamble and McConachy, 1999; Nandakumar *et al.*, 1997) to estimate rainfalls up to 1 in 2000 AEP.

3. DEVELOPMENT OF THE METHOD OF STORM TRANSPOSITION AND MAXIMISATION FOR THE WEST COAST OF TASMANIA

3.1 Overview

The keystone for the development of a method for extreme rainfall estimation is a database containing the most significant rainfall events in a region. From a detailed meteorological analysis of these storms, the inappropriateness of the use of the GSAM in western Tasmania was inferred from the different meteorological influences on extreme events in western Tasmania compared with the Tasmanian GSAM Coastal Zone events.

A database containing **isohyet**al analyses of all major storms in Tasmania's west was established. These analyses can subsequently be used *in situ* or transposed (subject to orographic constraints) over catchments in the west coast of Tasmania.

Moisture maximisation (either *in situ* or with storm transposition) consists of adjusting the storm rainfall upwards assuming maximum moisture inflow into the storm. Moisture availability is represented by the precipitable water which, in turn, is related to the **dewpoint temperature**. The storm dewpoint temperature is an identifying storm characteristic which is also essential for moisture maximisation. Storm dewpoint temperatures for all the major storms analysed are presented.

In addition to estimates of extreme rainfall, the temporal distribution of extreme rainfall at three-hourly intervals is also required by hydrologists to estimate the **Probable Maximum Flood** (PMF). The temporal distributions for analysed storms for which three-hourly data is available have been constructed and combined to form a design temporal distribution of extreme rainfall.

3.2 Storm Database

3.2.1 Selection of sites

The storm search area is defined as the area which includes the west coast region and an overlap zone adjacent to the west coast region as shown in Figure 3.1. All Bureau of Meteorology and Hydro Tasmania daily rainfall and pluviometer sites contained within the search area were used. This totalled 288 sites.

3.2.2 Selection of threshold values

For each site within the search area, threshold values for each of the required 1-day, 2-day and 3-day durations were set based on the rainfall statistics at each site and the dates when rainfalls exceeded these thresholds were identified.

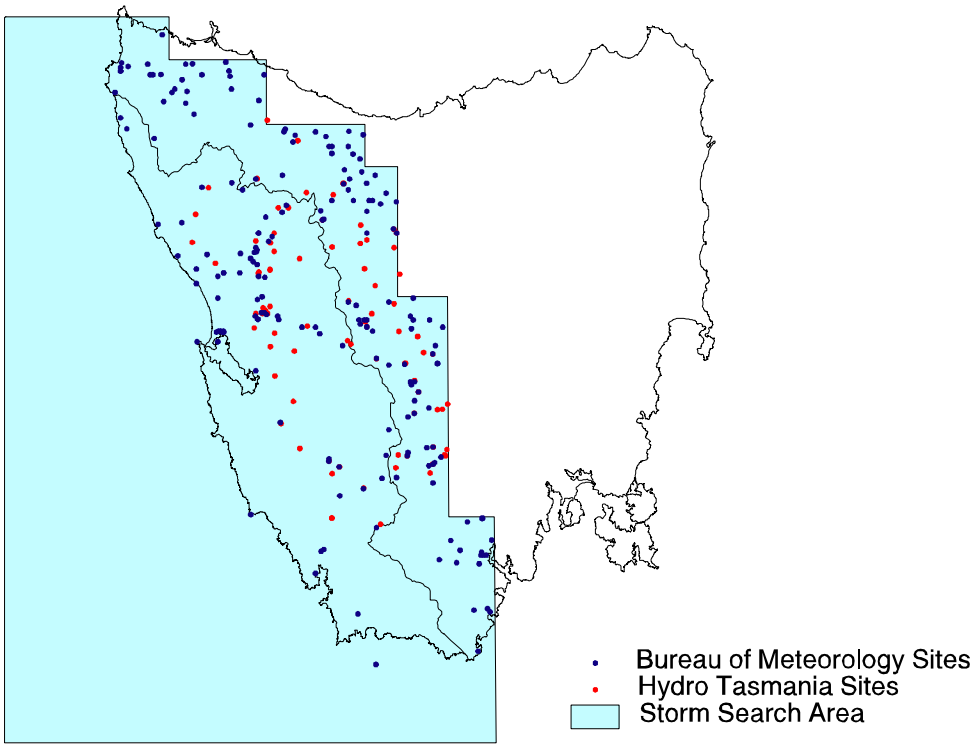


Figure 3.1: Storm search area and Bureau of Meteorology and Hydro Tasmania sites used in the storm search.

The storms included in the GSAM study have at least one station which recorded rainfall with **average recurrence interval** (ARI) of more than 50 years as determined using the **CDIRS** (**I.E. Aust.**, 1998). In this study, for each site within the storm search area, a threshold value corresponding to an ARI of 20 years (which is the next standard ARI lower than 50 years) was chosen.

3.2.3 Mapping of rainfall data and ARI

For each daily rainfall site, the dates of events for which rainfalls exceeded the 20 year ARI at 1-day, 2-day and 3-day durations were identified and rainfall data and ARIs over all of Tasmania were extracted and mapped in order to assess the significance of the rainfall over all of Tasmania. Figures 3.2(a) and (b) and Figures 3.3 (a) and (b) portray mapped rainfall and ARI for two three-day events which occurred in November 1913 and May 1975. These figures also show the differences in data coverage. (The notation '$>x < y$' implies that the rainfall had ARI between x and y years).

Data from pluviometer sites is available in the form of midnight-to-midnight aggregated 24-hourly rainfall totals. These rainfall totals were used to identify the dates of significant rainfall events and 9 am to 9 am aggregated totals subsequently determined to correlate with the time span of the daily rainfall sites. The pluviometer data was then merged with the daily rainfall data and the rainfall over all of Tasmania was mapped.

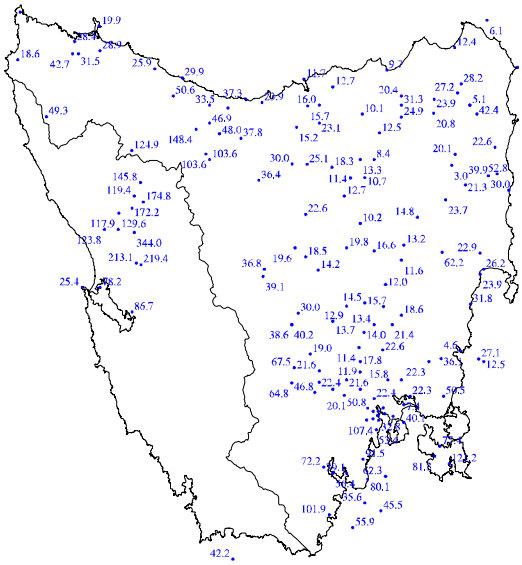


Fig. 3.2(a) Mapped 3-day rainfall for the 12 - 15 November 1913 event.

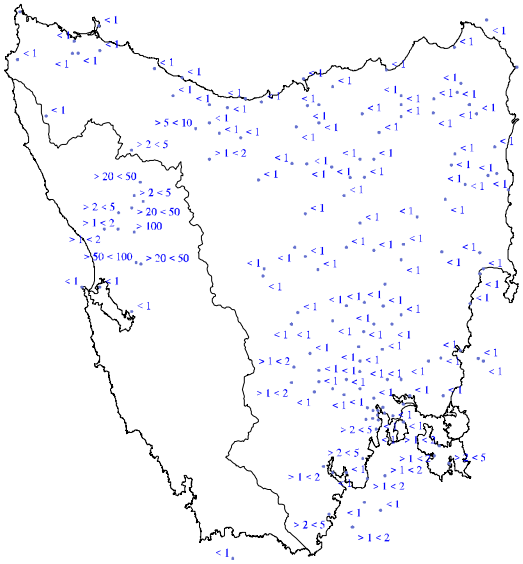


Fig. 3.2(b) Mapped ARI for the 12 - 15 November 1913 event.

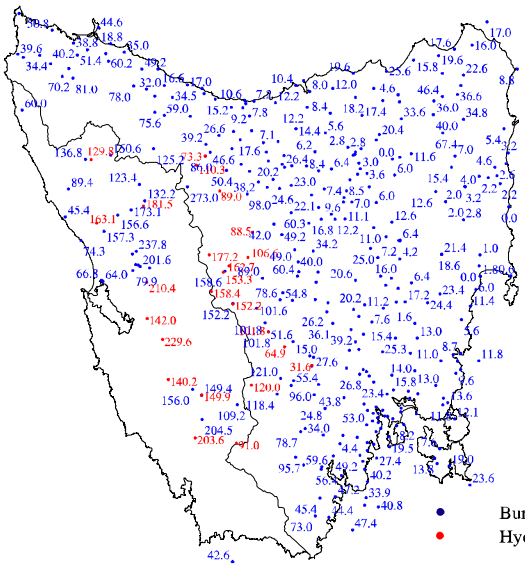


Fig. 3.3(a) Mapped 3-day rainfall for the 16 - 19 May 1975 event.

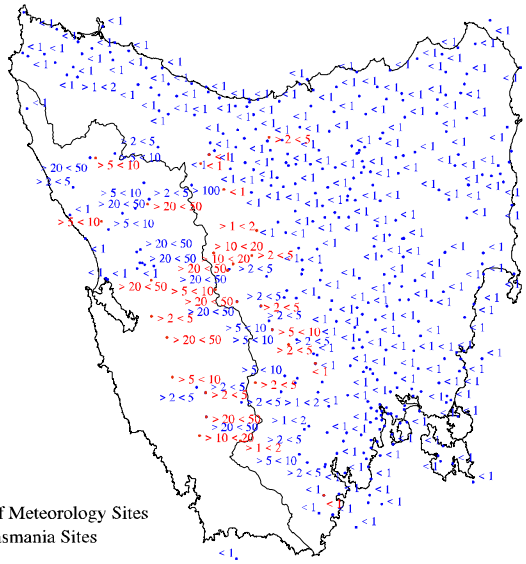


Fig. 3.3(b) Mapped ARI for the 16 - 19 May 1975 event.

3.2.4 Data Quality Control

The rainfall data within the search area was examined for temporal and spatial inconsistencies. In several instances, the rainfall was recorded on the wrong date. In other cases accumulated totals were unmarked and zero rainfall recorded over the period where the rainfall was accumulated. Whenever instances of marked or unmarked accumulations were found, the rainfall was disaggregated using rainfall observations at nearby sites and an estimate of the rainfall at the site was entered.

The highest recorded rainfalls were also checked with the original observers' records obtained from National Archives of Australia, Burwood and Hobart.

3.2.5 Dates of the Most Significant Storms in the West Coast of Tasmania

Initially, approximately 90 independent storm dates were identified. Some of these were found to have been significant only in that portion of the search area within the Tasmanian GSAM Coastal Zone. Others had been significant mostly in the GSAM region but rainfall with ARI of more than 20 years was recorded at one or two sites in the west coast due to **spillover**. Some events were clearly less significant than others, having rainfall with ARI approximately 25 years at only one site in the west coast compared with other events which had rainfalls with ARI between 50 and 100 years at more than one site. After assessing the significance of all the events in the west coast on an areal basis, 29 events remained. These are listed below in Table 3.1.

3.3 Climatology of Large/Extreme Rainfall Events in the West Coast of Tasmania

Tasmania lies in the regime of predominantly westerly flow, the 'roaring forties' of the mariners. The west coast of Tasmania is one of the wettest regions in Australia as far as annual rainfall is concerned (http://www.bom.gov.au/climate/map/anual_rainfall). Most of the rainfall in the west occurs in the cooler winter months with the passage of **front**al systems in the westerlies. In the lee of the mountains that separate the west coast region from the Tasmanian GSAM Coastal Zone there exists a rain shadow effect which results in a rapid decrease of the eastward extent of the rainfall. In the east, the heaviest rainfall occurs in the warmer spring/summer months of the year when low pressure systems in the Tasman Sea may direct an easterly onshore flow across the island (Bureau of Meteorology, 1993). This pattern is similar to the Tasmanian events included in the GSAM Coastal Zone storm database which were generally caused by **cut-off low**s near Tasmania directing easterly or northerly flow over the isle.

From meteorological analysis, it is inferred that large rainfall events in Tasmania's west are caused by the passage of fronts which are sometimes associated with an intense **extratropical cyclone**, with a westerly or southwesterly airstream. The meteorological influences giving rise to large rainfall events in the west differ from those which give rise to large rainfall events in the Tasmanian GSAM Coastal Zone. Therefore the GSAM is inappropriate for use in western Tasmania.

Consistent with the PMP concept, the key meteorological factors which give rise to extreme events are assumed to be the same as those operating in large events. Extreme events represent future events with more opportune combinations of moisture availability and efficiency. (The definitions of 'large' and 'extreme' here are as defined in Nathan and Weinmann (1999); namely, a 'large' event is an event having an AEP between about 1 in 50 and 1 in 100 years, and an 'extreme' event is an event having AEP between about 1 in 2000 years to the AEP of the PMP).

Having gained a thorough understanding of the meteorology of the area, the most outstanding storms on record are selected for further analysis. The set of analysed storms could then be transposed and maximised over catchments in the west coast to yield estimates of extreme rainfall.

3.3.1 Charts Obtained

Mean Sea Level (MSL) pressure analyses were obtained from several days before the onset of significant rainfall at 3-hourly, 12-hourly or 24-hourly intervals depending on their availability. For events which occurred before 1956, it was necessary to hand copy the analysis charts from originals which are kept at National Archives of Australia, Burwood. Analysis charts at 500 hPa and satellite images were also obtained if they were available.

3.3.2 Classification of Events

The synoptic situations of the 29 events identified were studied and storm descriptions discussing the meteorological conditions of each event were prepared.

The events were classified into categories according to the meteorological situation that gave rise to the event, as follows:

F	Frontal system
FW	**Frontal system with waves**
EC	Extratropical cyclone
C	Cut-off low
W	West/west northwesterly flow ahead of a front

Table 3.1 lists the dates of the 29 storms in chronological order along with their classification. Events 1, 5, 8 and 25 were not studied in detail and therefore their classification is not known. Events 1 and 8 were only significant at Maatsuyker Island and there would not have been enough data to carry out isohyetal analyses for these storms. Events 5 and 25 were deemed less significant than several of the other events considering depths at points and over areas up to about 2000 sq. km.

3.3.3 Key Meteorological Influences of large/extreme events in the West Coast of Tasmania

All of the events in Table 3.1 were most significant in regions subject to onshore flow. Common to events 14, 16, 17, 18 and 19 was a strong southerly component to the flow over southern Tasmania directed around a deep cut-off low in the Tasman Sea. An example is shown in Figure 3.4. For these events significant rainfall in western Tasmania was recorded only at Mt. Melaleuca in the far southwest. Unfortunately, these storms all occurred at a time when there were very few stations in the southwest. Assuming that the rainfall in the southwest would have been similar to the rainfall in the southeast, it is unlikely that the significant rainfall would have penetrated further north than about 43°S. All of the other events were significant north of 43°S in the west and occurred with a westerly, west northwesterly or southwesterly airstream.

TABLE 3.1

Dates of significant rainfall events in the west coast of Tasmania

Storm No.	Event start and end dates	Classification
1	23 - 26 December 1911	-
2	5 - 8 September 1912	F/EC
3	17 - 20 May 1913	F/EC
4	12 - 15 November 1913	C
5	8 - 11 July 1914	-
6	11 - 14 April 1915	F/EC
7	24 - 27 April 1916	C
8	7 - 10 July 1916	-
9	28 April - 1 May 1937	F/EC
10	4 - 7 March 1945	F/C
11	15 - 18 June 1947	W/F/FW
12	27 - 30 May 1948	W/F/FW
13	27 - 30 June 1948	W/F/FW
14	12 - 14 April 1951	C
15	23 - 26 June 1952	W/F/EC
16	19 - 22 September 1953	C
17	16 - 19 October 1956	C
18	14 - 17 September 1957	C
19	21 - 24 April 1960	C
20	14 - 17 May 1960	C
21	14 - 17 June 1962	W/F
22	18 - 21 June 1974	W/F
23	16 - 19 May 1975	W/F/FW
24	12 - 15 June 1977	W/F
25	29 June - 2 July 1981	-
26	25 - 28 May 1994	W/F
27	23 - 26 June 1996	F/C
28	26 - 29 December 1998	F/C
29	5 - 8 February 1999	F/C

Several of the events in Table 3.1 were caused by the passage of a sequence of active fronts, sometimes with waves. The presence of waves or wave lows on fronts is indicative of enhanced convection and hence precipitation. Very often, the fronts were located along the **convergence zone** between warm, moist air of **subtropical** origin being advected around a high pressure system over central Australia and a cold southwesterly airstream to the south of southwest Western Australia. Prolonged west/west northwesterly flow ahead the front or fronts transports high dewpoint air over western Tasmania and contributes to heavy rainfall. An example of a typical pattern of this type appears in Figure 3.5. This type of event can only occur in the cooler months of the year. In the warmer seasons, the **subtropical ridge** is situated further south which pushes the west or west northwesterly flow to latitudes well to the south of Tasmania.

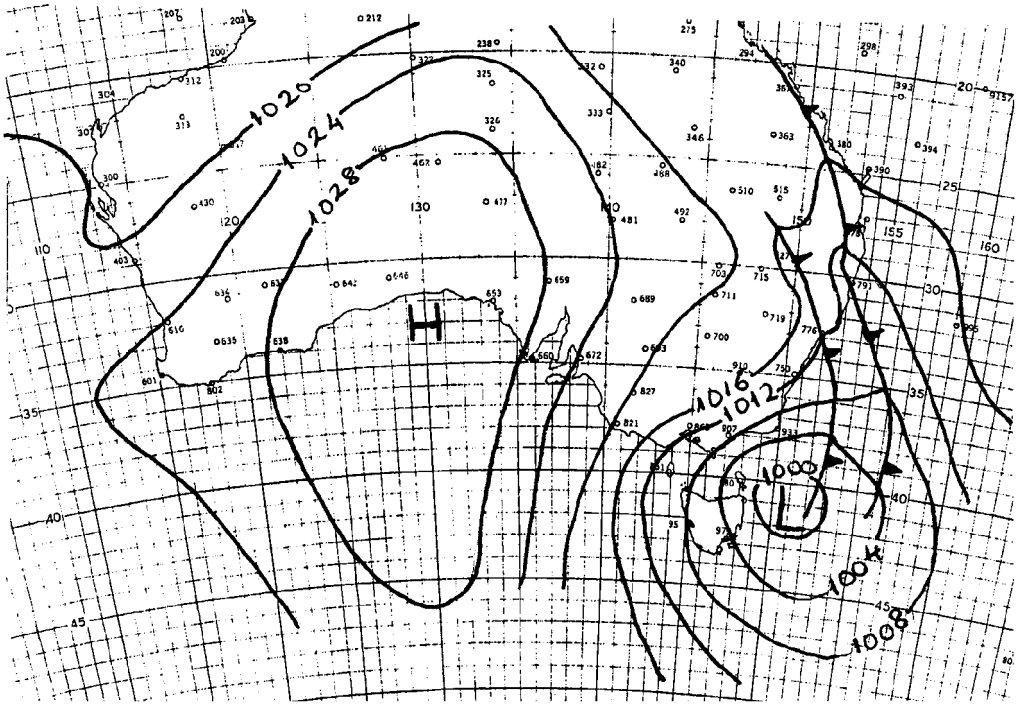


Figure 3.4: Mean sea level pressure analysis for 15 September 1957 (9 pm) showing a cut-off low east of Tasmania directing southerly flow over the isle.

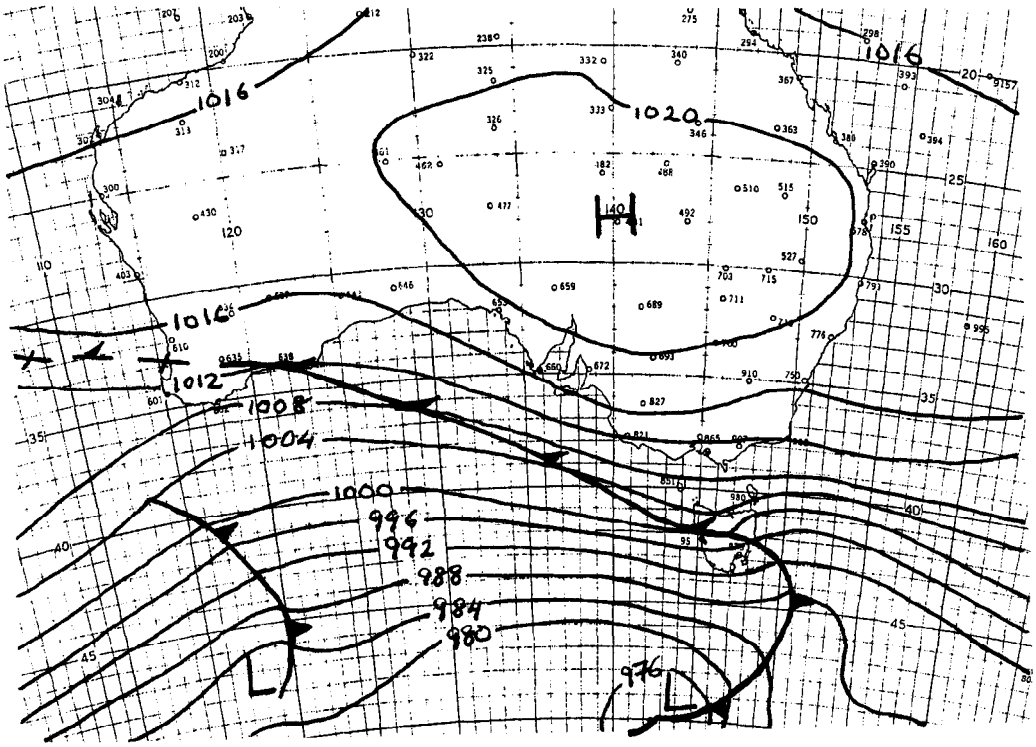


Figure 3.5: Mean sea level pressure analysis for 18 May 1975 (9 am) showing west northwesterly flow and a front crossing Tasmania.

Another typical synoptic pattern which seems to have occurred more often in the earlier events, is a quasi-stationary **trough** with an intense extratropical cyclone in the Tasman Sea maintaining an unstable southwesterly airstream over Tasmania, possibly with fronts over a period of several days. An example of this type of pattern is shown in Figure 3.6.

In some cases, particularly in the warmer months of the year, these extratropical cyclones appear to have been cut-off lows. Generally, the cold season cyclones were not cut-off lows because they were embedded in generally westerly flow, with the subtropical ridge situated further north over central Australia. However there is some ambiguity about the earlier charts because the analyses are based on limited data over the landmasses only.

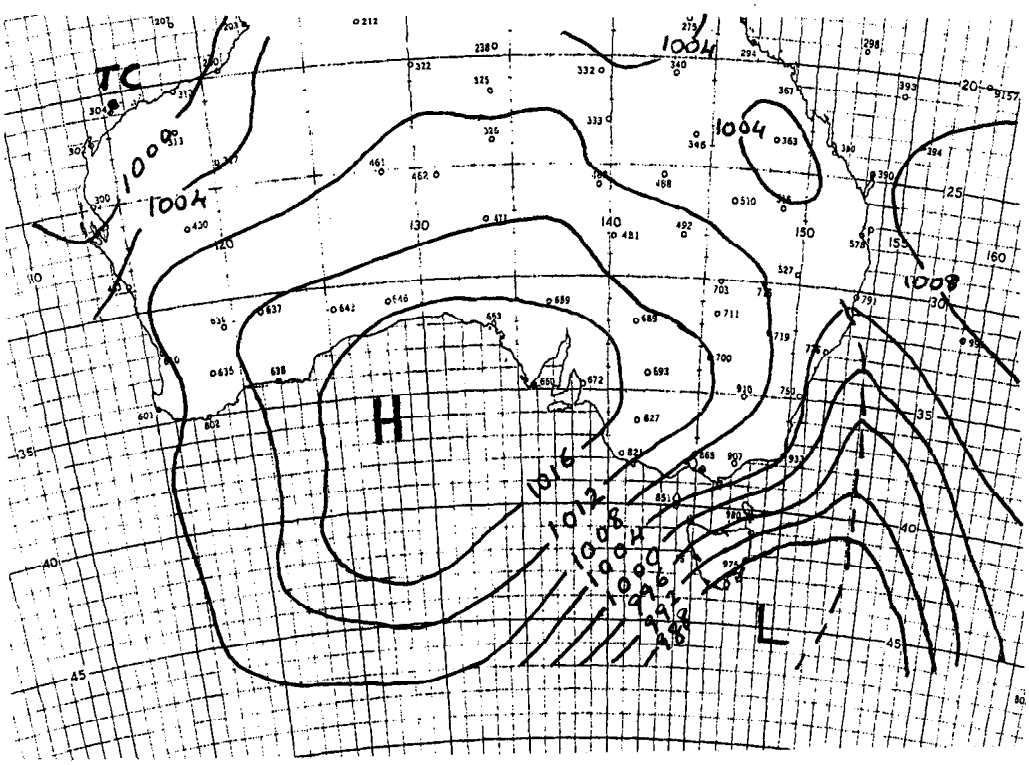


Figure 3.6: Mean sea level pressure analysis for 5 March 1945 (9 am) showing southwesterly flow over Tasmania and a trough in the Tasman Sea.

All of the events for which upper charts are available had a strong upper **jet stream** located in the vicinity of Tasmania. A strong upper jet can assist in maintaining activity of the fronts and/or deepening of a **depression**.

In summary the key meteorological features giving rise to large/extreme events in the west coast of Tasmania are:

West, west northwest or southwesterly flow

and

A slow-moving trough with a deep low (possibly a cut-off low) in the Tasman Sea, sometimes with fronts moving through it, directing an unstable southwesterly airstream over western Tasmania.

or

The passage of a sequence of active fronts tracking across Tasmania from the west;

and

West or west northwesterly flow ahead of a front advecting warm moist air of subtropical origin into the convergence zone between the anticyclone to the north and the cold air from the south.

together with

A polar front jet in the upper levels in the Southern Ocean near the latitude of Tasmania.

The orography also plays a major role in enhancing the rainfall in western Tasmania. Forced lifting of air over higher terrain can release **potential instability**, a consequence of which can be increased rainfall.

This compilation of large events was compared to some less significant events which were identified as part of the storm search and were also studied in some detail. It was found that the factors determining whether the event is significant or not relate to:

- The speed at which a trough is moving, since a slow moving trough prolongs instability over the region and also allows the passage of more fronts.
- The position of the trough or extratropical cyclone in the Tasman Sea such that a southwesterly airstream is directed over western Tasmania.
- The intensity of the extratropical cyclone, since the deeper the low pressure centre is, the more likely it is to cause heavy rainfall.
- The length of time that westerly or west northwesterly flow has persisted ahead of a front since a prolonged strong westerly or west northwesterly airstream allows a longer period of time to transport moist air over the Tasmanian region.
- The strength of an upper jet in the Southern Ocean near the latitude of Tasmania,

since a strong upper jet may maintain activity of the front or fronts and/or deepening of an associated low pressure centre.

3.3.4 Comparison with GSAM Events

The GSAM database includes seven Tasmanian storms. These generally occurred as a result of a depression near Tasmania directing northerly or easterly flow over Tasmania. Figure 3.7 depicts the mean sea level pressure analysis for a GSAM event known as SE2APR60. A deep cut-off low situated in Bass Strait directed warm moist air of subtropical origin over Tasmania. This event caused widespread rainfall in the east with ARI's > 100 years recorded at many sites including some just east of the ranges separating the west coast region from the Tasmanian GSAM Coastal Zone. There are no observations just west of the ranges. However, given that the ranges are relatively significant rising to over 1000 m, it is unlikely that the significant rainfall extended far westwards, though some spillover could have occurred. Further west, near Queenstown, rainfall with ARI less than 2 years was recorded. As the low pressure centre moved eastwards, the low-level winds acquired a more southerly component as in Figure 3.4 causing significant rainfall in the far south. This event is therefore also listed as Event 19 in Table 3.3, although the time-spans over which the event was significant in the east and the southwest overlap but do not coincide.

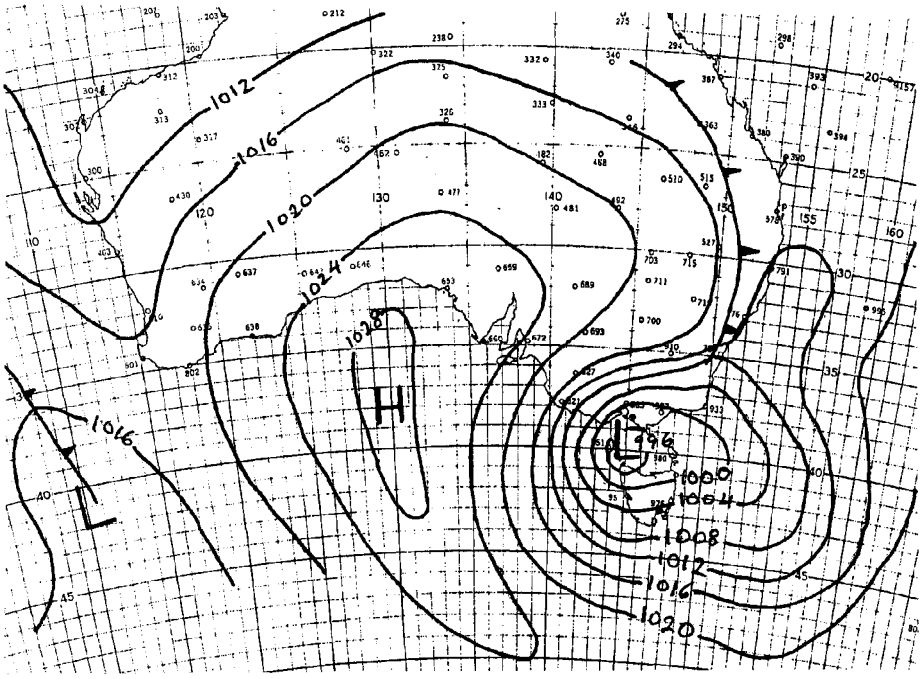


Figure 3.7: Mean sea level pressure analysis for 21 April 1960 (9 am) showing a deep cut-off low over southeastern Australia directing easterly flow over Tasmania.

None of the other Tasmanian GSAM events caused significant rainfall in western Tasmania. The inference is that Tasmania's west coast and GSAM Coastal Zone regions experience large and extreme rainfalls through different mechanisms and the GSAM is therefore **not** an appropriate method for PMP estimation in Tasmania's west.

3.4 Storm Selection

Table 3.1 lists the most outstanding storms on record which affected the west coast of Tasmania. Some of the storms were significant at 1, 2 and 3-day durations, while others were only significant at one duration. In this section, the most significant storms at each duration are selected for further analysis.

Events 14, 16, 17, 18 and 19 all occurred with southerly or southeasterly flow and were significant only south of 43°S limiting their relevance to catchments in the southernmost part of Tasmania. Hydro Tasmania has advised that there are no catchments in that region for which estimates of extreme rainfall would be required, therefore these storms were not selected for further analysis since they are not suitable for transposition further north.

By assessing the significance of the events on an areal basis and at each duration, some of the storms in Table 3.1 were less significant than others. The shortlist of storms which were analysed further appears in Table 3.2 below.

TABLE 3.2

Storms selected for further Analysis

No.	Storm Start and end Dates	Durations Analysed (Days)
2	6 - 8 September 1912	1,2
4	12 - 15 November 1913	1,2,3
7	24 - 27 April 1916	1,2,3
9	28 April - 1 May 1937	1
10	4 - 7 March 1945	2,3
11	15 - 18 June 1947	1,2,3
12	27 - 30 May 1948	3
13	27 - 30 June 1948	2,3
15	23 - 26 June 1952	2,3
21	14 - 17 June 1962	2,3
22	18 - 21 June 1974	2,3
23	16 - 19 May 1975	1,2(2),3
24	14 - 15 June 1977	1
26	25 - 28 May 1994	3
29	6 - 8 February 1999	1,2

Several storms were significant at more than one duration bringing the total number of storms analysed to 31. The May 1975 storm was analysed at two 2-day durations for different overlapping 2-day periods.

3.5 Storm Analysis

3.5.1 Isohyetal Analysis of Major Storms

For each storm that was selected for analysis, rainfall depths from Bureau of Meteorology and HydroTasmania sites were plotted on charts of A0 size. These charts were then overlayed on a topographic map at the same scale and projection and then analysed by hand. The more recent storms have good data coverage, however for the

earlier storms data coverage is very limited, resulting in more subjective analyses. In data-sparse areas, the later storms were used as guidance as to the orographic influences on the rainfall in the region as also were guidelines in WMO (1986). The hand drawn analyses were digitised and transferred onto a regular grid ensuring that the computer contours satisfactorily replicated the manual analyses. Figure 3.8 depicts an analysis for the June 1947 event which had poor data coverage whilst Figure 3.9 depicts the analysis for the May 1994 event which had good data coverage.

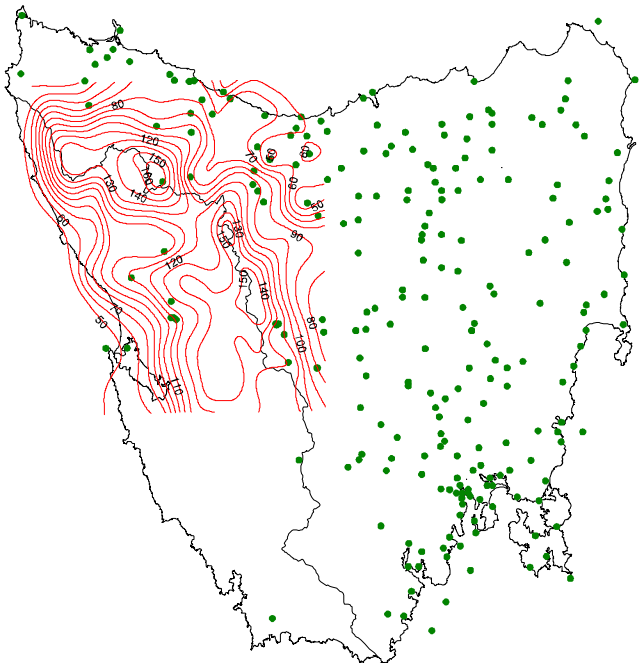


Figure 3.8 Isohyetal analysis for the 15-17 June 1947 event.

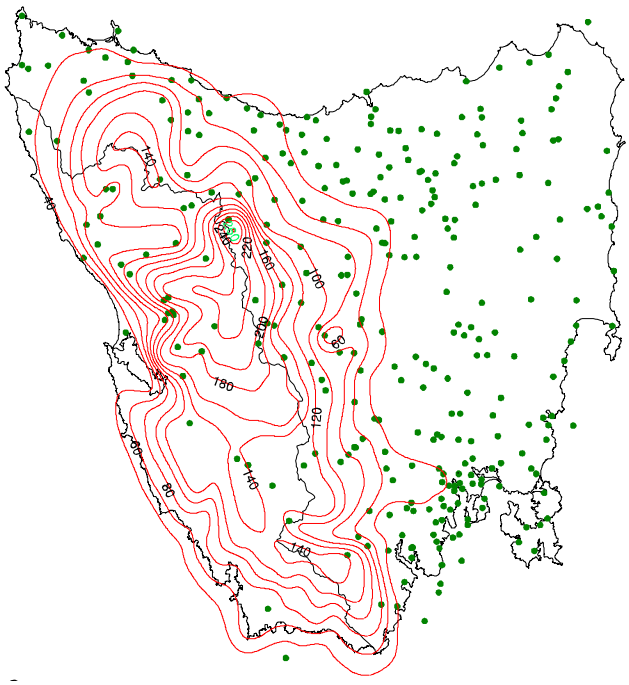


Figure 3.9 Isohyetal analysis for the 25-28 May 1994 event.

The extent to which different analyses for the same storms affect rainfall depths with respect to GSAM storms is discussed in Minty *et al.* (1996). In that study, it was found that rainfall depths for the early storms and those in the Inland Zone in particular tended to be under-estimated due to the smaller rain gauge density compared with later Coastal Zone storms. Consequently small-area adjustments were constructed for Coastal and Inland Zone storms. In western Tasmania, there are still many areas devoid of data even at present, therefore quantifying the effect of rain gauge density on analyses is rather difficult. The effect of data sparsity on the analyses was borne in mind and at least partly accounted for in the analyses, therefore it is not considered necessary to make any further allowances due to lack of data. However, lack of data contributes an additional element of uncertainty to the method. Therefore, estimates of extreme rainfall for catchments in the west coast of Tasmania derived from this method must be treated with caution.

3.5.2 Storm Dewpoint Temperatures and Maximisation Factors

Moisture maximisation involves adjusting the storm rainfall upward based upon the hypothesis of maximum moisture inflow into the storm. Maximised rainfall is the rainfall that would have resulted had the maximum possible moisture for the same time of year been available to the storm.

The dewpoint temperature is used as an indicator of the moisture content of an **air mass**. The storm dewpoint temperature represents the moisture inflow into the storm. The extreme persisting dewpoint temperature represents the maximum moisture that could occur at the same time and place as the storm. Both storm and extreme dewpoint temperatures are required for moisture maximisation.

The extreme persisting dewpoints are obtained using long-term climatological data. For each suitable site, the maximum 24-hour persisting dewpoints for each month of the year are plotted and enveloped. Extreme persisting dewpoints and the corresponding extreme precipitable water values at 1000 hPa (**hectopascal**s) exist in grid form as a set of monthly charts. The extreme persisting dewpoint temperature for the same time of year that the storm occurred is used in moisture maximisation.

The storm dewpoint temperature is most accurately determined using temperature and humidity soundings from radiosonde measurements. However due to the sparseness of the radiosonde observational network, it is rarely possible for soundings representative of a storm to be available. Therefore, storm dewpoint temperatures are more often estimated using surface observations. Fortunately, the assumption of a saturated **pseudo-adiabat**ic lapse rate is closely approximated in extreme storms and surface observations can be used to estimate the storm dewpoint temperature. In western Tasmania no radiosonde observations are available, therefore storm dewpoint temperatures were determined solely from surface observations.

For each storm, time series of surface dewpoint temperature, as well as other meteorological data, were prepared using several sites near the main storm area. The data were extracted from the National Climate Centre database, Australian Region Mean Sea Level (MSL) charts and original observers logbooks obtained from National Archives of Australia. The dewpoint temperature persisting over a period of 6 to 24 hours at several suitable sites along the moisture inflow path were reduced pseudo-

adiabatically to 1000 hPa values (United States Weather Bureau, 1951) if station elevations exceeded 100 m and averaged. Care was taken to ensure that the surface dewpoints were not contaminated by rain, otherwise estimates of storm dewpoints could be too high due to local evaporation.

The estimation of a dewpoint temperature to represent the moisture inflow into the storm from a number of surface observations which are varying over time involves a great deal of judgement. Minty *et al.* (1996) (page 10) discusses the limitations to the accuracies in the determination of storm dewpoint temperatures. Despite exercising due care in their estimation, storm dewpoint temperatures can only be determined to an accuracy of about 2^{o}C.

Storm and extreme persisting dewpoint temperatures can be related to the storm and extreme precipitable water values. The moisture maximisation factor for a catchment at sea level would be the ratio of the extreme precipitable water corresponding to the extreme dew point temperature to the storm precipitable water corresponding to the storm dewpoint temperature. Thus,

$$MF = \frac{EPW}{SPW}$$

where MF is the moisture maximisation factor,
EPW is the Extreme Precipitable Water corresponding to the extreme dewpoint temperature, and
SPW is the Storm Precipitable Water corresponding to the storm dewpoint temperature.

Table 3.3 lists the storm dewpoint temperatures reduced to 1000 hPa and *in situ* maximisation factors at 1000 hPa for the west coast Tasmanian storms analysed. These maximisation factors are based on the assumption that there is no barrier to the moisture inflow at the storm location. Storm dewpoint temperatures are given to one decimal place because this is the accuracy of the dewpoint temperature measurement. It does not imply such accuracy in storm dewpoint temperature.

Although the persisting 6 to 24 hour storm dewpoint temperature is unlikely to persist for longer duration storms, it has been found (WMO, 1986) that if different storm dewpoint temperatures were to be used for every 12-hour period, then different extreme dewpoint temperatures would also have to be used such that the maximisation factor would remain approximately constant. Therefore, in line with general practice, the same storm dewpoint temperatures apply for all periods within the storms.

TABLE 3.3

STORM DEWPOINT TEMPERATURES AND MAXIMISATIONS FACTORS (1000 hPa)

No.	Storm Start and end Dates	Storm Dewpoint Temperature (°C) (1000 hPa)	Maximisation Factor (*in situ*) (1000 hPa)
2	5 - 8 September 1912	8.0	1.6
4	12 - 15 November 1913	9.6	1.9
7	24 - 27 April 1916	10.0	2.0
9	28 April - 1 May 1937	10.0	2.0
10	4 - 7 March 1945	16.1	1.3
11	15 - 18 June 1947	11.5	1.2
12	27 - 30 May 1948	8.9	1.8
13	27 - 30 June 1948	7.1	1.8
15	23 - 26 June 1952	10.1	1.4
21	14 - 17 June 1962	10.3	1.4
22	18 - 21 June 1974	10.2	1.5
23	16 - 19 May 1975	9.3	1.8
26	25 - 28 May 1994	10.0	1.7
29	5 - 8 February 1999	17.4	1.2

3.5.3 Development of Temporal Distributions

For those storms for which pluviometer data are available, temporal distributions for unrestricted 24, 36, 48 and 72 hour durations were constructed for selected stations close to the storm centres. Three-hourly synoptic observations from observers' logbooks were used for some of the early storms for which pluviometer data are not available.

For each duration, average temporal distributions were derived by applying the average variability method (AVM) of Pilgrim, Cordery and French (1969) to the **storm temporal distribution**s. This method of combining the storm temporal distributions achieves AEP-neutrality, whereby the AEP of the design flood is equivalent to the AEP of its causative design rainfall. The distributions were then smoothed using the method described by Nathan (1992) to give **design storm temporal distributions of extreme rainfall**.

This procedure of combining temporal distributions is akin to that used in the development of the GSAM temporal distributions, the difference being that in the GSAM, the temporal distributions pertained to standard areas rather than point locations. For long durations for southeast Australia, Nathan and Weinmann (1999) recommend the use of GSAM unsmoothed temporal distributions for rare events, and GSAM smoothed temporal distributions for extreme events, where 'rare' and 'extreme' are as defined in Nathan and Weinmann (1999). Dr. Rory Nathan (personal communication) recommends a similar approach with respect to long duration events in western Tasmania, whereby unsmoothed west coast of Tasmania temporal distributions are to be used for rare design rainfalls, while smoothed west coast of Tasmania temporal distributions are to be used for extreme design rainfalls. Figures 3.10(a), 3.11(a), 3.12(a) and 3.13(a) depict incremental storm temporal distributions for durations of 24, 36, 48 and 72 hours as well as the unsmoothed and smoothed temporal distributions at three hourly intervals. In Figures 3.10(b), 3.11(b), 3.12(b) and 3.13(b), cumulative

temporal distributions are portrayed. In Figures 3.12(a) and (b), two 48 hour distributions for the 1975 storm are shown for each site. These pertain to two different overlapping 48 hour time periods which are considered equally significant.

Figures 3.14(a) and (b) depict unsmoothed and smoothed design incremental and cumulative temporal distributions of extreme rainfall for 24, 36, 48 and 72 hour durations. Appendices A and B contain the tabulated data for Figures 3.14(a) and (b).

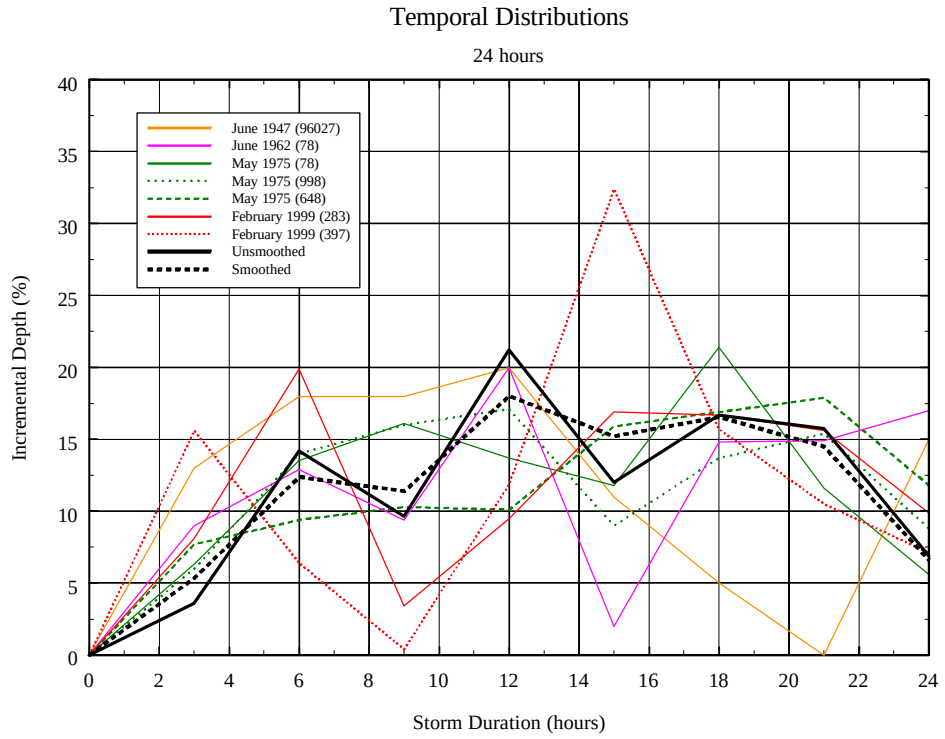
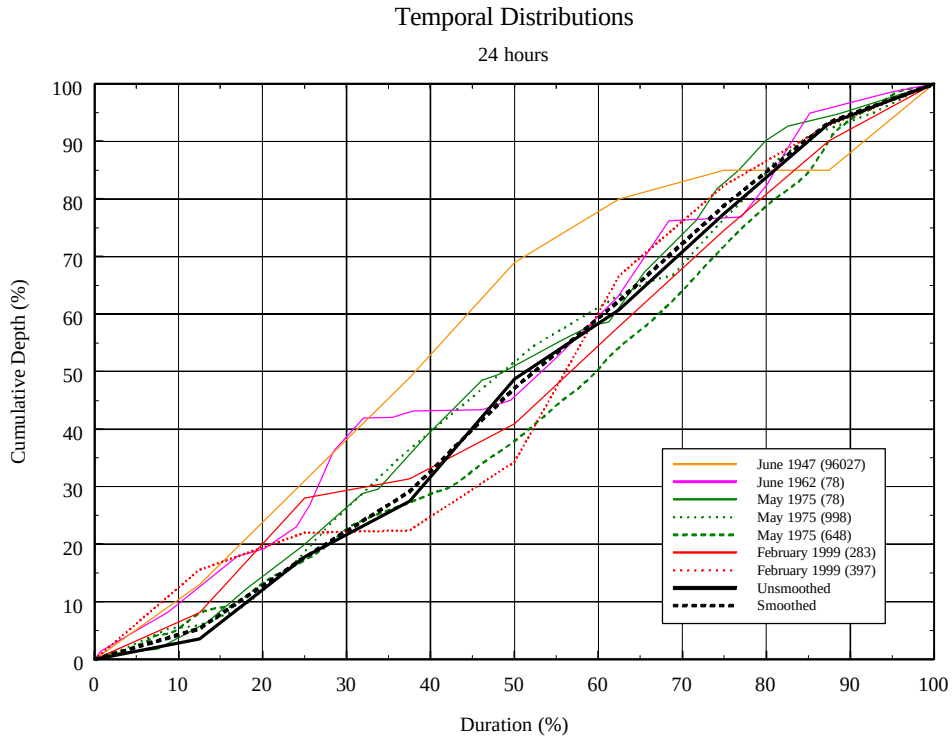
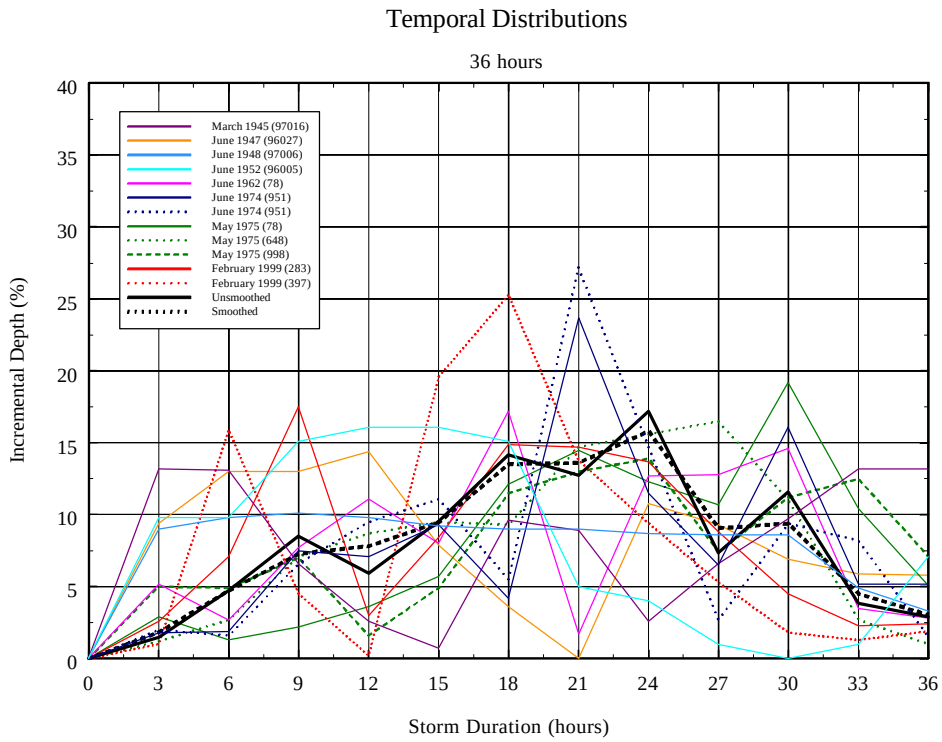


Figure 3.10(a): Storm, smoothed and unsmoothed incremental temporal distributions for a duration of 24 hours. (The figures in brackets in the legend denote the site numbers of the rainfall
stations which were used to derive the temporal distributions. Five digit numbers



denote Bureau of Meteorology sites while the remainder denote Hydro Tasmania sites).

Figure 3.10(b): Storm, smoothed and unsmoothed cumulative temporal distributions for a duration of 24 hours.



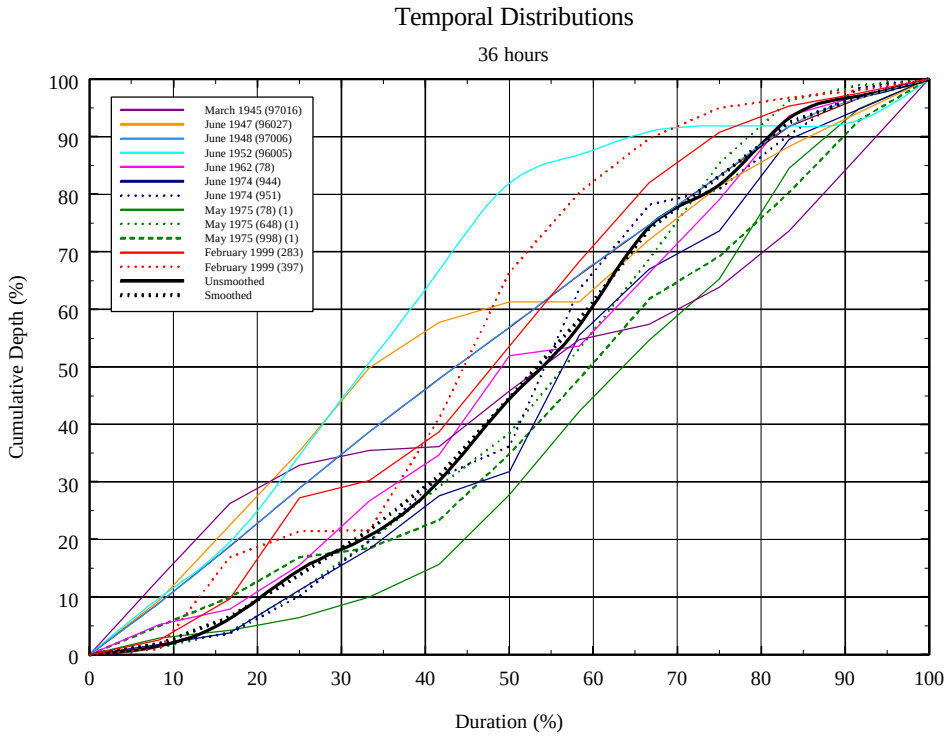
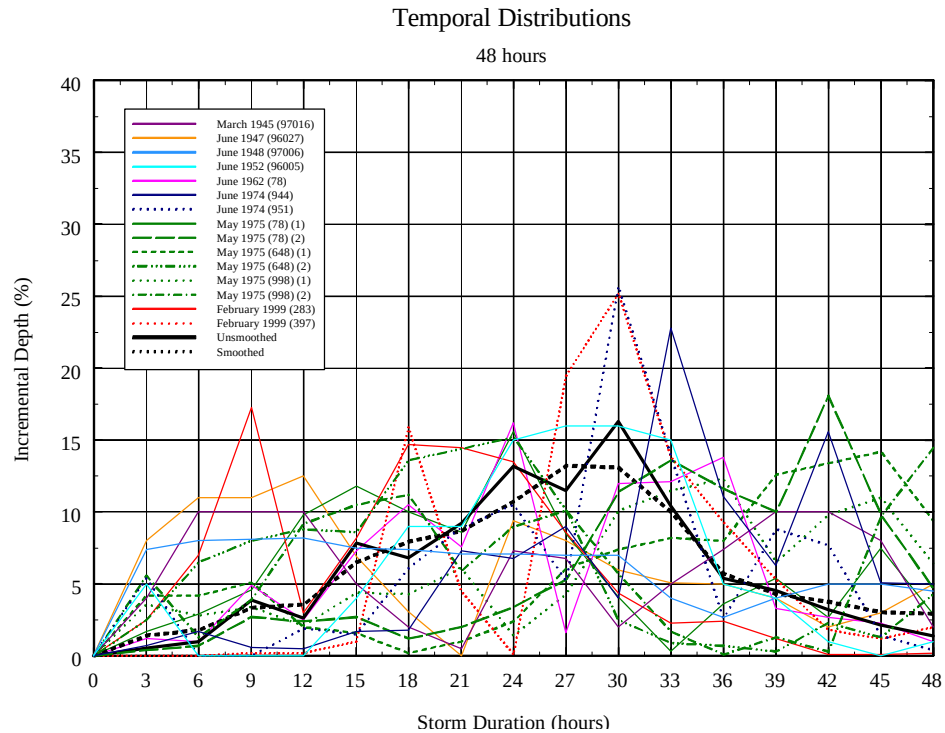


Figure 3.11(a): Storm, smoothed and unsmoothed incremental temporal distributions for a duration of 36 hours.

Figure 3.11(b): Storm, smoothed and unsmoothed cumulative temporal distributions for a duration



of 36 hours.

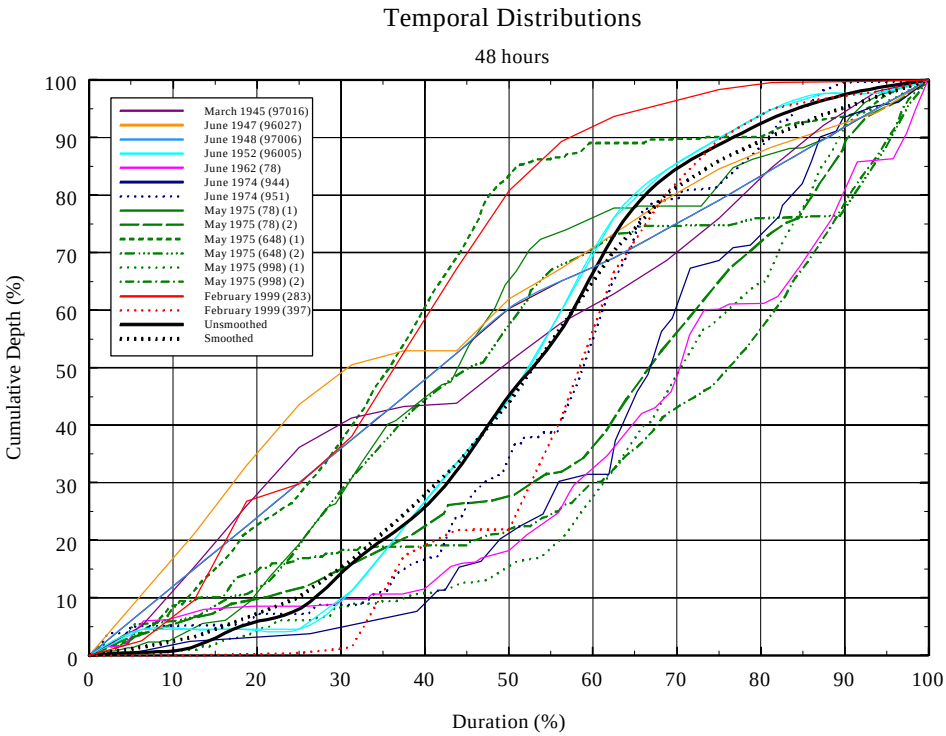
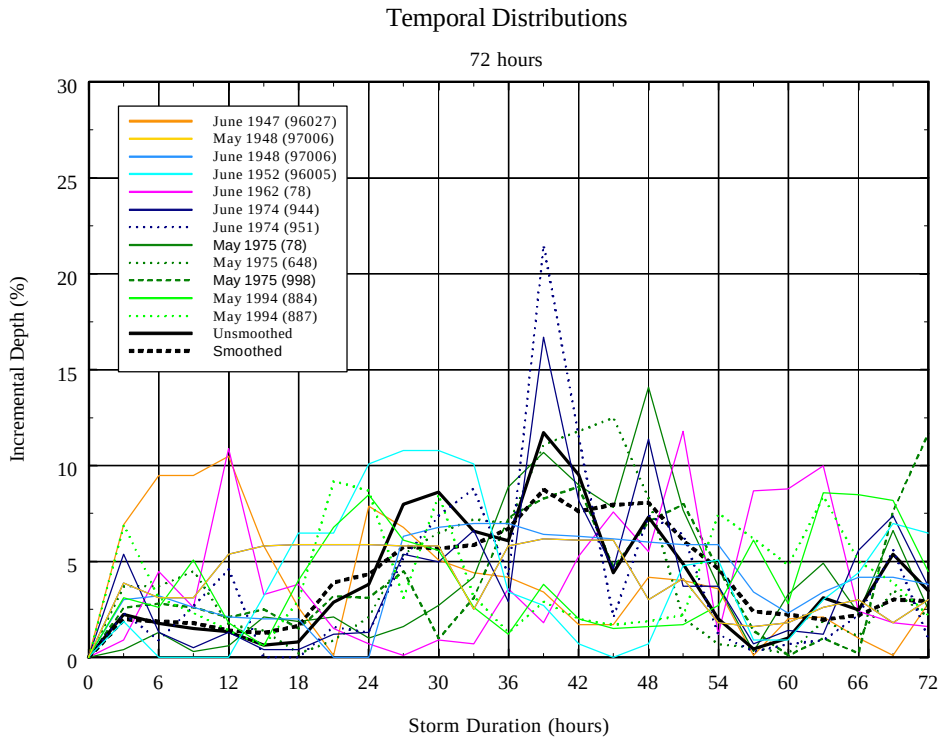


Figure 3.12(a): Storm, smoothed and unsmoothed incremental temporal distributions for a duration of 48 hours.

Figure 3.12(b): Storm, smoothed and unsmoothed cumulative temporal distributions for a duration of 48 hours.



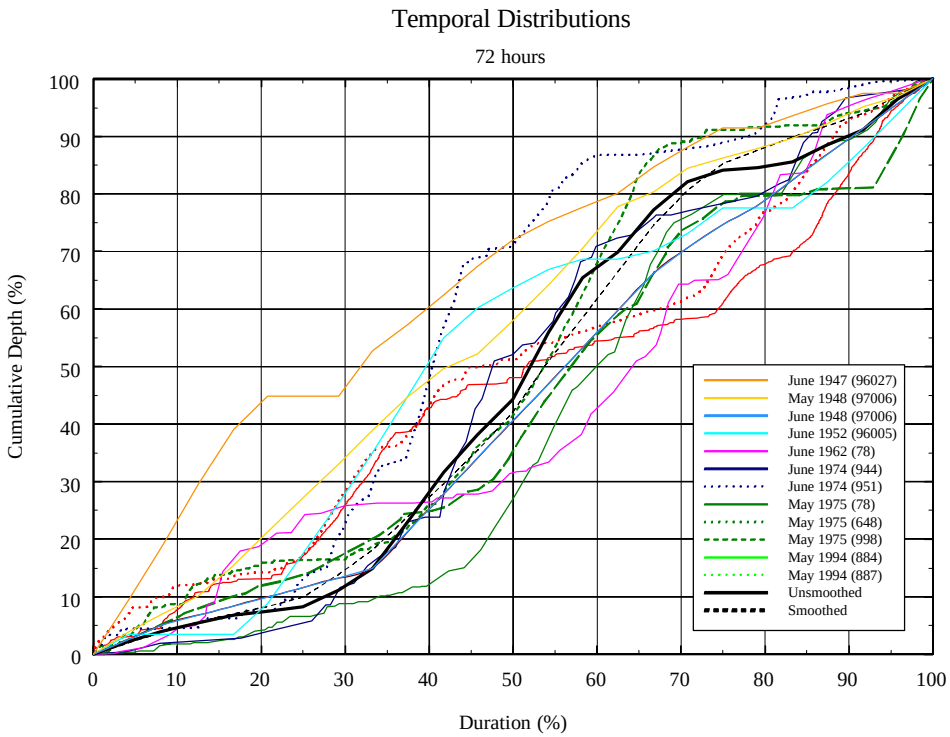


Figure 3.13(a): Storm, smoothed and unsmoothed incremental temporal distributions for a duration of 72 hours.

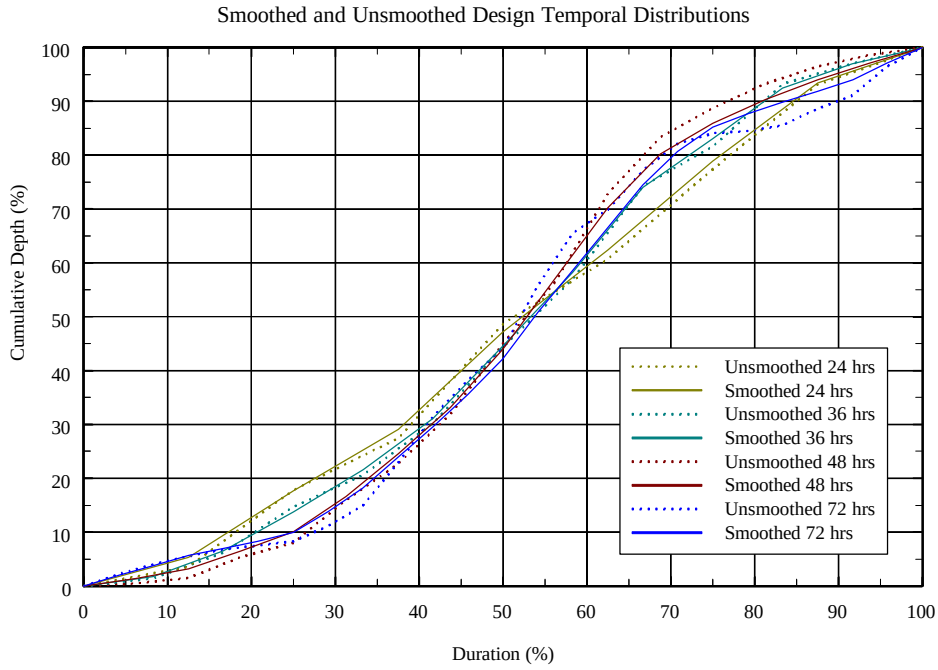
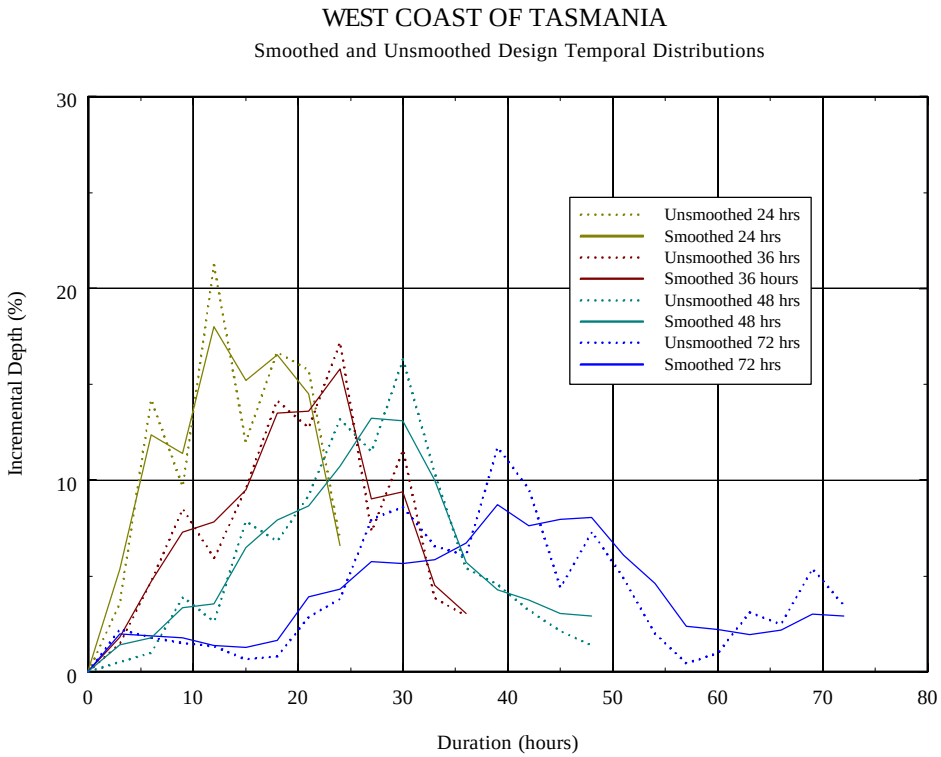


Figure 3.13(b): Storm, smoothed and unsmoothed incremental temporal distributions for a duration of 72 hours.

Figure 3.14(a): Smoothed and unsmoothed incremental design temporal distributions for durations of 24, 36, 48 and 72 hours.

Figure 3.14(b): Smoothed and unsmoothed cumulative design temporal distributions for durations of 24, 36, 48 and 72 hours.



4. APPLICATION OF THE METHOD OF STORM TRANSPOSITION AND MAXIMISATION TO CATCHMENTS IN THE WEST COAST OF TASMANIA

Application of the method of storm transposition and maximisation to catchments in the west coast of Tasmania involves selecting a storm from Table 3.2 and transposing the isohyets from the original location where the storm occurred to a target location. Expert judgement on the suitability of transposition of storms and the placement of isohyets is required since the storm precipitation patterns can strongly reflect the orography where they occurred. For each duration, several storms may need to be transposed in order to determine which would give the maximum rainfall over a particular catchment.

For each storm, the catchment rainfall is then maximised using the maximisation factors listed in Table 3.3 adjusted for barrier differences between the storm and catchment locations and differences in extreme persisting dewpoints between the location of the inflow to the storm where it originally occurred and that at the target location.

Application of moisture maximisation assumes that the moisture inflow into the storm can be increased without altering the storm dynamics. Excessively high maximisation factors can result if storm dewpoints determined from surface observations are under-estimated. The use of such high maximisation factors would imply a large increase in moisture inflow into the storm which could alter the storm dynamics. Common practice is to set a limit on the maximisation factor. A limit of 1.8 was imposed on maximisation factors for GSAM storms. This limit is also chosen for west coast of Tasmania extreme rainfalls. Table 3.3 shows three storms which had maximisation factors in excess of 1.8 at 1000 hPa although different maximisation factors may result when barrier effects are accounted for. Further details as to the reasons for imposing a limit on the maximisation factors obtained in the GSAM storms are expounded in Minty *et al.*, 1996 (pp. 20-21).

In the past, the rainfall was sometimes also maximised for potential wind speed and direction, but in general there was insufficient information available to make this practical. Wind speed and direction are now considered to be part of the overall storm mechanism.

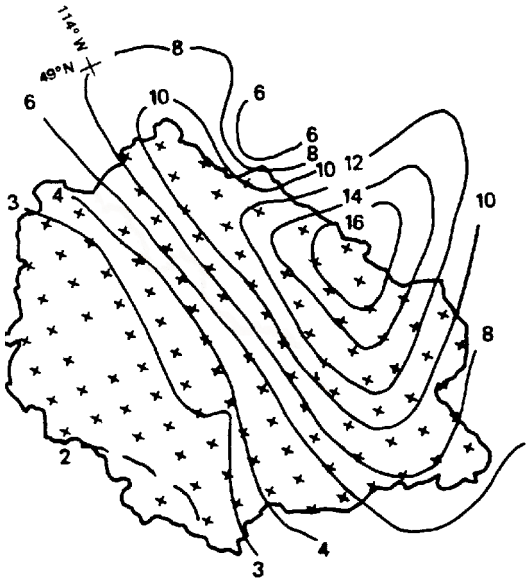
In orographic regions, Weisner (1970) and Wang (1986) advocate the use of the rainfall frequency intensity field to adjust for the differing topographic influences of the rainfall between the storm and target locations. This method is to be applied to studies of extreme rainfall for catchments in western Tasmania.

The following example is taken from Wang (1986) and describes how the rainfall frequency intensity field can be used in transposing a storm from Montana to Cheesman basin. Figure 4.1(a) shows isohyets of a storm over Montana transposed to Cheesman basin. Figures 4.1(b) and 4.1(c) show the grids of 100-year 24-hour rainfall over Montana and Cheesman catchment respectively. (In Figure 4.1(b) the Cheesman catchment outline has been shown to locate the grid points where computations are required). The transposed storm rainfall at each grid point (Figure 4.1(d) is given by multiplying the grid from (a) by the ratio of the 100-year 24-hour rainfall grid over Cheesman to the 100-year 24-hour rainfall grid over Montana.

In Australia, the rainfall frequency intensity field is available in the form of CDIRS (Computerised Database IFD (Intensity Frequency Duration) Rainfall System). Thus,

$$R_c = R_s \times \frac{IFD_c}{IFD_s}$$

where R_c denotes the rainfall grid over the target catchment
R_s denotes the rainfall grid over the storm location
IFD_c is the rainfall frequency intensity grid over the target catchment
IFD_s is the rainfall frequency intensity grid over the storm location.



a): 1964 Montana storm isohyets (inches) transposed to Cheesman basin.

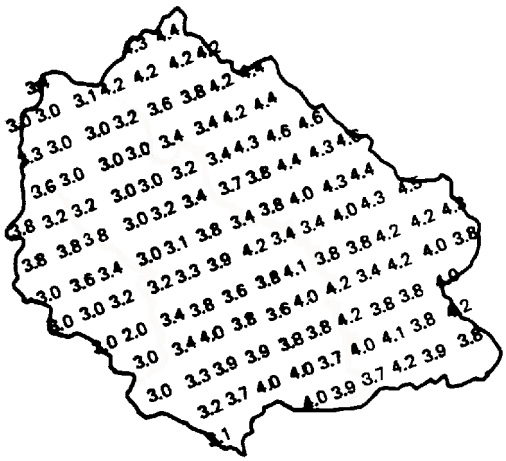
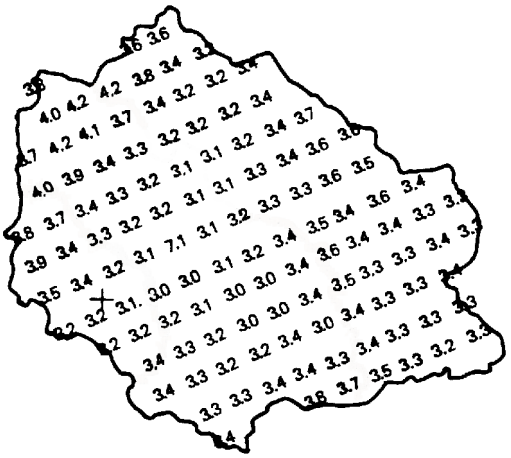


Fig. 4.1(b): Montana 100-year 24-hour rainfall (inches).



Fig, 4.1(c): Cheesman 100-year 24-hour rainfall (inches).

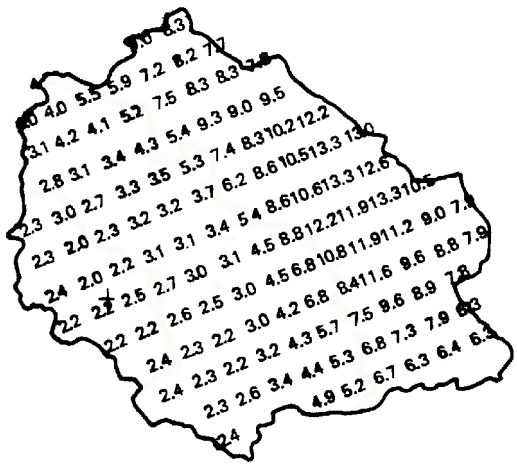


Fig. 4.1(d): Grid of rainfall depth (inches) of Montana storm transposed over Cheesman basin multiplied by the ratio of the grids of figures 4.1(c) to

(b).

It has been decided to use the 48-hour 50-year intensity field because:

(i) 50 years is about the mean of the range of ARIs for west coast Tasmanian storms, and

(ii) 48 hours is about the middle of the duration range for the storms.

This method has the advantage that the IFD field adjusts for the differences in the orographic influences on the rainfall between the location where the storm occurred and the transposed location. However, care must still be taken to ensure that the initial displacement of isohyets is realistic, therefore there is still a degree of subjectivity involved in transposing the storms. Given the relatively significant orography in western Tasmania, it may not be possible to displace the storms very far from where they originally occurred.

An adjustment needs to be factored in to yield extreme rainfalls for unrestricted 24, 48 and 72 hour durations since the storm analyses are based on 9 am to 9 am (restricted) rainfalls. On average, rainfalls for unrestricted durations are higher than rainfalls for restricted durations. Several investigations have been made into deriving correction factors for converting restricted to unrestricted annual rainfall series. The most recent recommends a factor of 1.17 for climates prone to frontal systems (Dwyer and Reed, 1995). This factor could also be used with estimates of extreme rainfall in western Tasmania.

Estimates from the GSDM for durations up to three hours and maximised unrestricted storm depths for the transposed storms are plotted on a graph and final extreme rainfall values are determined by **envelopment**. The design spatial distribution of the design extreme storm is given by the rainfall frequency intensity field. This achieves AEP-neutrality as desired by Nathan and Weinmann (1999). Design temporal distributions of extreme rainfall are given in Figures 3.14(a) and (b).

Finally, it must be pointed out that, owing to the limited rainfall data available in western Tasmania, estimates of extreme rainfall derived from this method should be treated with caution.

5. SEASONAL VARIATION OF ESTIMATES OF EXTREME RAINFALL

The storm search procedure described in section 3.2 has been conducted with a view to establishing a procedure for determining estimates of extreme rainfall without consideration of any seasonal variation. Of the storms analysed in Table 3.2, only three occurred in the months November to March. More than half occurred in May/June as a result of the passage of a sequence of fronts preceded by west northwesterly flow. However, a slow-moving trough in the Tasman Sea with a deep low, whether it be a cut-off low or an intense extratropical cyclone, has the same potential for giving rise to extreme events in Tasmania's west and could occur at any time of year. Therefore, this method may be used to estimate extreme rainfall in western Tasmania throughout the year.

6. PROBABILITY OF ESTIMATES OF EXTREME RAINFALL IN THE WEST COAST OF TASMANIA

The PMP concept, as defined in Section 1, effectively involves zero probability of exceedance. However, estimates made by the various PMP methodologies have a non-zero probability of exceedance. For example, '*in situ* maximisation' method estimates for the Fortescue River catchment in Western Australia were exceeded by rainfall from tropical cyclone Joan in 1975 (Kennedy, 1982). The maximised rainfall from the Dapto 1984 storm (Shepherd and Colquhoun, 1985) near Wollongong in New South Wales exceeded the 'method of adjusted US data' PMP estimates used at the time. Probabilities of exceedance can therefore be associated with the methodology used to estimate the PMP, not the concept of PMP itself.

For some catchments estimates of PMP depth have been made using a variety of methods, but the associated probabilities may vary considerably. Using deterministic meteorological methods of estimating PMP rather than statistical methods means that the assignment of AEPs to the PMP estimates is not straightforward. However, guidance can be given on the comparative probabilities of exceedance by PMP depths estimated by the different methods.

Kennedy and Hart (1984) provided notional estimates of AEP for various PMP methods assuming that the PMP is the result of the joint probability of storm efficiency and moisture content. They also showed why generalised estimates such as those derived by the GSDM for up to 6 hours could, in some cases, exceed the *in situ* maximisation method estimates for 24 hours for some catchments. Pearce (1994) reviewed Kennedy and Hart's (1984) estimates following similar reasoning but allowed for sampling of events due to the density and length of record of the rain gauge network. Pearse and Laurenson (1997) developed a joint probability approach to determine the probability distribution of convergence rainfall in the Sydney area. More recently, Nathan *et al.*, (1999) produced estimates of AEPs within the GSAM zone by generating a frequency curve of ratios of observed GSAM storm depths to the estimated PMP depths. Laurenson and Kuczera (1999) conducted a review of these methods of estimating the AEP of the PMP and recommended that Kennedy and Hart's (1984) figures for generalised estimates be applied to PMP estimates from all current generalised methods in Australia until further research is completed. Nathan and Weinmann (1999) endorse Laurenson and Kuczera's (1999) conclusions.

Most of the above investigations into the AEP of the PMP have focussed on generalised methods of PMP estimation. However, Kennedy and Hart (1984) also provide guidance towards determining estimates of AEP for the *in situ* maximisation and transposition and maximisation methods. They estimate the AEP for *in situ* maximisation estimates to be around 10^{-3}. With transposition, the probability is reduced by the ratio of the catchment to transposition areas. Therefore, given that the west coast of Tasmania has an area of approximately 18 500 km^2, for a catchment area of 1 000 km^2, the AEP of estimates of extreme rainfall using this method would be of the order of 10^{-4}. However, there is considerable uncertainty in this estimate. Due to lack of data in western Tasmania, the AEP of estimates of extreme rainfall may be higher. Laurenson and Kuczera (1999)

suggested that the AEP of the PMP values be interpreted as follows:

- ‘ Recommended AEP values plus or minus two orders of magnitude of AEP be regarded as notional upper and lower limits for the true AEPs;

- ‘Recommended AEP values plus or minus one order of magnitude of AEP be regarded as confidence limits with about 75% subjective probability that the true AEP lies within the limits; and

- ‘The recommended AEP values be regarded as the current best estimates of the AEPs.’

Although Laurenson and Kuczera’s (1999) recommendations are presented in the context of generalised methods of PMP estimation, they are also relevant for the *in situ* maximisation and the storm transposition and maximisation methods.

7. APPLICABILITY OF DATA FROM OTHER REGIONS

The west coast of Tasmania covers a relatively small area and has limited rainfall data, particularly for the years prior to the 1960s. Lack of data limits the sampling of large events in the region. However, the sample size could be increased if data from other regions prone to the same meteorological influences as those that give rise to large/extreme events in Tasmania's west were used. This would increase the likelihood of an outlier being included in the sample and estimates with a lower AEP could be possible.

Regions in Australia that might be subject to the same key influences as those conducive to large/extreme events in the west coast of Tasmania are the southwest of Western Australia and the southern part of the South Australian/Victorian border. However, finding storms in these regions bearing the same meteorological features as those in western Tasmania is beyond the scope of this work.

New Zealand might be a promising region to look for events similar to the west coast of Tasmania storm data set. Tomlinson and Thompson (1992) describe the top 10 storms in the North Island and the top 10 in the South Island.

In the North Island, extreme events are usually caused by the proximate slow passage of a tropical depression in summer. This type of event is not expected ever to occur over Tasmania. However, there was one event (of the 10 described in detail) which was caused by the passage of active fronts similarly to some of the west Tasmanian extreme events. There may be other events in the New Zealand North Island storm dataset which were similar.

The top 10 South Island storms all occurred with the passage of fronts through a trough in the Tasman Sea west of New Zealand. Some of the events were associated with slow moving fronts which sometimes developed waves which enhanced the rainfall. These contrast with the Tasmanian events where the fronts were more mobile.

However, there are some other South Island events which occurred due to the passage of a sequence of fronts moving through a slow-moving trough in the Tasman Sea. Often the fronts occurred in the convergence zone between a warm moist northwesterly airstream and a trough with a cooler airstream to the west. These bear some resemblance to some of those Tasmanian storms which occurred as a result of west or west northwesterly flow ahead of a cold front. The main difference is that the South Island fronts were preceded by warm moist north westerlies which results in air flow originating from lower latitudes than over Tasmania. Also, in Tasmania this type of event occurs in the cooler seasons when the subtropical ridge lies over central Australia. In New Zealand this type of event can also occur in the warmer seasons when dew point temperatures are higher which would increase the likelihood of the occurrence of a more significant event.

The orography in New Zealand exerts a much stronger influence on the rainfall than in western Tasmania, however the New Zealand Meteorological Service has separated out the **convergence precipitation** (which is the total storm rainfall less the orographic component of the rainfall) of all the storms analysed. This is the portion of the total storm rainfall which would be transposed to western Tasmania.

There are therefore several positive lines of investigation that could be pursued if it is considered necessary to supplement the west coast of Tasmania storm data set. However, searching for storms in other regions would require looking for storms with similar synoptic patterns as those that gave rise to large/extreme events in Tasmania's west. These synoptic patterns would not necessarily be conducive to large/extreme events in the regions in which they occurred. Searching for storms in other areas would therefore take a considerable amount of time. This may need to be done some time in the future if it is considered that development of a generalised methodology is necessary. At this point in time, however, due to time constraints, it was decided to develop a method for estimating extreme rainfalls using only west coast Tasmanian storms.

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10. GLOSSARY

Air mass - An extensive body of air having approximately horizontally homogeneous temperature and moisture characteristics.

Annual Exceedance Probability - The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year.

ARI - Average Recurrence Interval. The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration.

CDIRS - Computerised Design IFD Rainfall System. A gridded dataset of the IFD design rainfall published in *Australian Rainfall and Runoff* (I.E. Aust., 1987) and an automated procedure for the construction of IFD curves.

Convergence zone - Area into which wind trajectories converge.

Convergence precipitation - Precipitation due to any atmospheric process unaffected by terrain.

Cut-off low - A low pressure centre that is 'cut off' or detached from the prevailing westerly flow.

Depression - An area of low pressure.

Design storm temporal distributions of extreme rainfall - The hypothetical time order in which incremental amounts of the extreme storm fall.

Dewpoint temperature - The temperature to which air must be cooled at constant pressure for dew to form.

Envelopment - A process for selecting the largest value from any set of data and drawing a smooth curve.

Extratropical cyclone - A low pressure frontal system not of tropical origin found in the **middle** and **high latitudes**.

Flood frequency techniques - Statistical techniques that use data from historical or past floods.

Front - Interface between two air masses having different densities and temperatures.

Frontal system with waves - A frontal system with wavelike deformations caused by the formation of cyclones on a front.

Generalised methods of PMP estimation - Methods which utilise the rainfalls recorded over a large region by separating the portion of rainfall arising from 'site-specific' influences from that portion arising from regional influences. Such methods provide regional consistency of PMP estimation.

GSAM - Generalised Southeast Australia Method of PMP estimation. A generalised method for estimating longer-duration PMP in southeast Australia.

GSDM - Generalised Short Duration Method of PMP estimation. A generalised method for estimating small-area, short-duration PMP in Australia.

GTSM - Generalised Tropical Storm Method of PMP estimation. A generalised method for estimating longer-duration PMP in those parts of Australia affected by tropical storms.

hectopascal (hPa) - Unit of atmospheric pressure, standard atmospheric pressure being 1013.2 hPa.

High latitudes - Regions located approximately 60 to 90 degrees latitude North and South.

I.E. Aust. - The Institution of Engineers, Australia.

IFD - Intensity-Frequency-Duration of rainfall. Frequency analyses of rainfall expressed as rainfall intensities (in mm/hr) maintained over a specified duration (in hr), and recurring on average once every *n* years (an ARI of *n* years).

Isohyet - Line of equal rainfall depth for a given duration.

Jet stream - Region of strong winds in the upper atmosphere located in the tropical and mid-latitude regions.

Maximisation or **Moisture Maximisation** - '*the process of adjusting observed precipitation amounts upwards based upon the hypothesis of increased moisture inflow to the storm*' (WMO, 1986). The increase is generally to theoretical values which could be reached if the moisture content of the air had been at the maximum recorded for that location and time of year, but the other meteorological conditions affecting the storm had remained unchanged.

Maximisation Factor - The factor by which storm rainfall amounts are multiplied to simulate maximised storm moisture content, defined as:

$$\frac{\text{Extreme Precipitable Water (at storm location and time of year)}}{\text{Storm Precipitable Water}}$$

Middle Latitudes - Regions located approximately between 35 and 65 degrees latitude North and South.

Paleohydrologic techniques - The study of geomorphic, sedimentologic or botanical evidence of past large floods.

Potential Instability - The stability of a layer after the entire layer has been lifted to saturation. A layer can be lifted as a result of the passage of a front or if it is forced over a mountain. If, after lifting, the layer is stable then the layer is *potentially stable*. If, after lifting, the layer is unstable, then the layer is *potentially unstable*.

Probable Maximum Flood - The flood produced when runoff from the PMP is routed through the catchment.

Probable Maximum Precipitation - '*the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends.'* (WMO, 1986).

Pseudo-adiabat - Line on a thermodynamic diagram showing the pressure and temperature changes undergone by saturated air rising in the atmosphere, without ice-crystal formation and without exchange of heat with its environment other than that involved in assuming that the liquid water, formed by condensation, drops out. It is the heat exchange associated with condensation that forces the term *pseudo.*

Spillover - '*That part of orographically induced precipitation which is transported by the wind in a direction which has a horizontal component so that it reaches the ground in the nominal rain shadow on the lee side of a ridge*'. (WMO, 1986).

Standard deviation - A measure of dispersion or deviation from the mean of a frequency distribution, equal to the square root of the mean of the squares of the deviations from the arithmetic mean of the distribution.

Storm dewpoint temperature - The 1000 hPa dewpoint temperature that is representative of the rain-producing air mass of the storm.

Storm temporal distribution - The variation of the rainfall with time as a percentage of the total storm rainfall.

Storm transposition - Moving the characteristics of a storm from its place of occurrence to another location under study to represent a possible future storm.

Subtropics/Subtropical - Region between the **tropical** and **mid-latitude** regions, approximately between 35 and 40 degrees North and South latitude.

Subtropical ridge - Region of high pressure situated between the **tropical** and **mid-latitude** regions.

Tropical - Area between the subtropical ridges in the northern and southern hemispheres generally under the influence of easterly flow.

Trough - A region of relatively low atmospheric pressure.

Variance - square of the **standard deviation**.

WMO - World Meteorological Organization.

APPENDIX A

WEST COAST OF TASMANIA

Unsmoothed Design Temporal Distributions

TABLE A.1

Unsmoothed Temporal Distribution for a 24-hour Duration

Time h	Time %	Increment %	Cumulative %
3	12.50	3.59	3.59
6	25.00	14.21	17.80
9	37.50	9.67	27.47
12	50.00	21.24	48.71
15	62.50	12.01	60.72
18	75.00	16.67	77.39
21	87.50	15.74	93.13
24	100.00	6.87	100.00

TABLE A.2

Unsmoothed Temporal Distribution for a 36-hour Duration

Time h	Time %	Increment %	Cumulative %
3	8.33	1.47	1.47
6	16.67	4.72	6.19
9	25.00	8.51	14.70
12	33.33	5.95	20.65
15	41.67	9.56	30.21
18	50.00	14.16	44.37
21	58.33	12.73	57.10
24	66.67	17.20	74.30
27	75.00	7.34	81.64
30	83.33	11.59	93.23
33	91.67	3.85	97.08
36	100.00	2.92	100.00

TABLE A.3

Unsmoothed Temporal Distribution for a 48-hour Duration

Time h	Time %	Increment %	Cumulative %
3	8.33	0.52	0.52
6	6.25	1.01	1.53
9	12.50	3.89	5.42
12	18.75	2.63	8.05
15	25.00	7.86	15.91
18	31.25	6.81	22.72
21	43.75	9.21	31.93
24	50.00	13.18	45.11
27	56.25	11.50	56.61
30	62.50	16.31	72.92
33	68.75	10.40	83.32
36	75.00	5.41	88.73
39	81.25	4.56	93.29
42	87.50	3.21	96.50
45	93.75	2.12	98.62
48	100.00	1.38	100.00

TABLE A.4

Unsmoothed Temporal Distribution for a 72-hour Duration

Time h	Time %	Increment %	Cumulative %
3	4.17	2.23	2.23
6	8.33	1.78	4.01
9	12.50	1.51	5.52
12	16.67	1.34	6.86
15	20.83	0.66	7.52
18	25.00	0.81	8.33
21	29.17	2.86	11.19
24	33.33	3.81	15.00
27	37.50	8.00	23.00
30	41.67	8.61	31.61
33	45.83	6.57	38.18
36	50.00	6.08	44.26
39	54.17	11.72	55.98
42	58.33	9.53	65.51
45	62.50	4.40	69.91
48	66.67	7.31	77.22
51	70.83	4.88	82.10
54	75.00	2.00	84.10
57	79.17	0.44	84.54
60	83.33	1.00	85.54
63	87.50	3.11	88.65
66	91.67	2.48	91.13
69	95.83	5.39	96.52
72	100.00	3.48	100.00

APPENDIX B

WEST COAST OF TASMANIA

Smoothed Design Temporal Distributions

TABLE B.1

Smoothed Temporal Distribution for a 24-hour Duration

Time h	Time %	Increment %	Cumulative %
3	12.50	5.36	5.36
6	25.00	12.37	17.73
9	37.50	11.39	29.12
12	50.00	18.02	47.14
15	62.50	15.21	62.35
18	75.00	16.54	78.89
21	87.50	14.50	93.39
24	100.00	6.61	100.00

TABLE B.2

Smoothed Temporal Distribution for a 36-hour Duration

Time h	Time %	Increment %	Cumulative %
3	8.33	1.82	1.82
6	16.67	4.72	6.54
9	25.00	7.28	13.82
12	33.33	7.81	21.63
15	41.67	9.48	31.11
18	50.00	13.50	44.61
21	58.33	13.61	58.22
24	66.67	15.81	74.03
27	75.00	9.04	83.07
30	83.33	9.38	92.45
33	91.67	4.51	96.96
36	100.00	3.04	100.00

TABLE B.3

Smoothed Temporal Distribution for a 48-hour Duration

Time h	Time %	Increment %	Cumulative %
3	6.25	1.41	1.41
6	12.50	1.79	3.20
9	18.75	3.34	6.54
12	25.00	3.56	10.10
15	31.25	6.50	16.60
18	37.50	7.94	24.54
21	43.75	8.67	33.21
24	50.00	10.73	43.94
27	56.25	13.22	57.16
30	62.50	13.09	70.25
33	68.75	10.00	80.25
36	75.00	5.73	85.98
39	81.25	4.30	90.28
42	87.50	3.76	94.04
45	93.75	3.04	97.08
48	100.00	2.92	100.00

TABLE B.3

Smoothed Temporal Distribution for a 72-hour Duration

Time h	Time %	Increment %	Cumulative %
3	4.17	1.99	1.99
6	8.33	1.87	3.86
9	12.50	1.79	5.65
12	16.67	1.39	7.04
15	20.83	1.27	8.31
18	25.00	1.64	9.95
21	29.17	3.91	13.86
24	33.33	4.33	18.19
27	37.50	5.77	23.96
30	41.67	5.67	29.63
33	45.83	5.86	35.49
36	50.00	6.72	42.21
39	54.17	8.74	50.95
42	58.33	7.61	58.56
45	62.50	7.96	66.52
48	66.67	8.05	74.57
51	70.83	6.10	80.67
54	75.00	4.62	85.29
57	79.17	2.38	87.67
60	83.33	2.23	89.90
63	87.50	1.97	91.87
66	91.67	2.19	94.06
69	95.83	3.02	97.08
72	100.00	2.92	100.00

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