Bivariate analysis of intense rainfall on the island of Madeira and its relationship with alluvium flood events

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Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Abstract

Intense rainfall~~s~~ and alluvium flooding are familiar occurrences on Madeira, however, the understanding of how intense rainfall relates to alluvium flooding is limited. This thesis seeks to classify the extremity of intense rainfall events measured from the Funchal rain gauge station and analyse their relationship with the alluvium flooding record on the Portuguese island of Madeira. Other studies consider other hydrological factors and use a univariate or categorised approach to rainfall data. This study focuses on extreme rainfall and its relationship with alluvium flood events using the copula approach as a way of arriving at possibly more exact return periods values. This thesis uses the annual maximum series (AMS) technique to classify hourly and daily time-series rainfall as extreme rainfall over a 34-year and 80-year period respectively. By using bivariate copula analysis, rainfall immediately before or/and after the annual maximum is also studied. Each intense rainfall event's joint and conditional return periods are calculated and their relationship with alluvium flood events are analysed, including the late February 2010 event. The results of this study conclude that the copula approach may be useful and adequate to understand the relationship between rainfalls and alluvium events. It showed that the rainfall events that are coupled with alluvium flood events tend to have higher return periods than those that are not and that the late February 2010 event was exceptional. This work assists in understanding how intense rainfall events relate to alluvium flood events, and the adequacy of copulas in hydrological studies.

Keywords

Island of Madeira; Extreme rainfall; Alluvium; Bivariate analysis; Copula; Return period.

Resumo

Precipitações intensas e cheias causando aluviões são ocorrências frequentes na Ilha da Madeira. Porém a compreensão de como tais precipitações se relacionam com aquelas aluviões é limitada. A presente tese pretende caracterizar a excecionalidade das precipitações intensas registadas no posto udográfico do Funchal e analisar como tal excecionalidade se relaciona com a ocorrência de aluviões naquela zona. Contrariamente a outros estudos que recorreram a métodos uni-variados ou categorizados para analisar as precipitações intensas, a presente dissertação utilizou exclusivamente séries de máximos anuais de precipitações horárias e diárias durante 34 e 80 anos, respetivamente. Mediante o recurso a cópulas bivariadas, também se analisou a precipitações que imediatamente os precederam ou lhes sucederam. Cada evento foi caraterizado por quatro períodos de retorno, dois conjuntos e dois condicionais. Seguidamente analisou-se se a tal acontecimento se podia associar uma aluvião, com ênfase para a aluvião que teve lugar a 20 de fevereiro de 2010. Os resultados do estudo efetuado indicam que as cópulas podem ser uma ferramenta importante na compreensão da relação entre precipitações intensas e aluviões na Ilha da Madeira. Indicam ainda que as precipitações a que se associaram aluviões tendem a ter períodos de retorno superiores aos das precipitações de que não resultaram aluviões e que o acontecimento de 20 de fevereiro de 2010 foi realmente excecional. O estudo efetuado contribui, assim, para uma melhor compreensão da relação entre precipitações intensas e aluviões na Ilha da madeira, evidenciando a adequação do recurso a cópulas em problemas de índole hidrológica.

Palavras Chave

Ilha da Madeira; Chuva extrema; Aluviões; Análise bivariada; Copula; Períodos de Retorno.

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1 Introduction

Throughout history, societies have given utmost importance to the comprehension of hydrological systems and events. The study of intense rainfall has been one of these necessary understandings for human civilisation. These extreme hydrological events have so shaped human cultures that great archetypal stories have been written based on these. Stories such as the destruction of Atlantis in Greek mythology, Manu from the Hindu Puranas and Noah's flood from the Bible. These examples show how significant destruction and death caused by extreme rainfall, floods and alluviums have inspired different myths and stories in different cultures.

Extreme rainfall is an important point in hydrology. Most of the world's ecosystems are adapted and calibrated to regular rainfall events, and so is human society. Extreme rainfall events are generally characterised as such because they are rare or have implications that are also not commonly caused by regular rainfall, like death, destruction, etc. Such is the case on the Portuguese island of Madeira. Throughout the recorded history of Madeira, extreme rainfall events have been connected to disastrous occurrences such as alluvium flood events. This thesis seeks to study extreme rainfall events and relate them to recorded alluvium flood events, all in the Funchal area (located on the island's southern slope) and its vicinity. The hourly and daily rainfall depth data used in this thesis was measured at Funchal rain gauge and the record of alluvium flood events was collected by Sepúlveda (2011). This study has been done with the prime objective of understanding the exceptionality of such extreme events and their previous and following conditions, also aiming to help with the choices in the allocation of societal funds for the preservation of Madeira and the safety of its people.

For this analysis, it was necessary to identify the extreme rainfall events to be considered. For the hourly and daily rainfall data, the annual maximum series (AMS) technique was applied. This means the annual maximum hourly and daily rainfall is classified as that hydrological year's extreme rainfall event. According to the U.S. Geological Survey (2016), a hydrological year (or water year) is "the 12-month period October 1, for any given year through September 30, of the following year." By combining the hourly and daily rainfall data with this definition of extreme rainfall event the hourly and daily annual maximum series were obtained. By analysing rainfall data before and after each annual maximum several other series, that came to be called "cumulative series" (further explained in chapter *5 Datasets and modelling approach*) were coupled with the annual maxima. With the use of statistical methods such marginal distribution fitting and bivariate copula analysis, univariate and bivariate statistical models were developed and applied. From these models, an analysis was made of the relationship between rainfall events and their coupled alluvium events, based on univariate and bivariate return periods. In this work, the annual maximum rainfalls coupled with the rainfalls that precede or/and followed the maxima (prior or/and posterior rainfalls) will form the bivariate copulas and will be classified as coupled rainfall events. Therefore, this thesis will also test the adequacy of the bivariate copula approach in dealing with series of extreme rainfall.

The most important literature relating to this study is the work done by Lopes *et al.,* (2020), Fragoso, *et al.* (2012) and Levizzani, *et al.* (2013). Those authors studied various hydrological and climatological factors that could be related to and could have caused the alluvium floods in Madeira with a focus on the late February 2010 event (from 18 to 20/02/2010). A description of that disastrous event can be found in Table 3 presented in subchapter *3.3 Alluvium data*. Conversely to the previously mentioned studies, this thesis uses a multivariate approach to the analysis of the rainfall data series, whilst those studies merely used a univariate or categorised approach. The bivariate copula approach will provide a deeper understanding of return periods and permit different perspectives to be taken, namely that of joint and conditional return periods of rainfall. The multivariate approach also permits for an analysis of the rainfall prior and/or posterior to the annual maximum and how it relates to the annual maximum rainfall. Thus, it was admitted that for one same occurrence there could be different consequences, depending on the previous or antecedent humidity conditions of the hydrological basin on a given date.

Finally, to properly understand this thesis, there must first be an explanation of some of the terms used throughout it. In this work, an “alluvium flood event” is the phenomenon characterised by the flooding of an area with the consequence of displacing clay, silt and sand and other debris. However, other terms have also been used to mean the same thing. Terms like “alluvium event(s)” or “alluvium(s)” or “alluvium flooding” were used and are not to be confused with the mere deposit of clay, silt or sand left by floods, which is also commonly referred to as alluvium. In this thesis, an alluvium flood event involves the process of the flood, the movement of solid material (debris) and the deposits that are left thereafter.

2 Copulas and extreme events literature review

2.1 Introduction

In this chapter, a summary explanation and commentary of the literature that pertains to this thesis will be given. The publications of other researchers will be reviewed and a background on the various themes and concepts that this thesis utilises and discusses will be given. The three main purposes of this chapter are to explain to the reader how and why particular publications were important for the composition of this thesis; to understand how the work done in this thesis fits in with and further expands the understanding of how intense rainfall relates to alluvium events, specifically in the island of Madeira; to serve as a foundation and building block for other students to be able to learn and build upon this thesis' methods and findings in what relates to the relationship between intense rainfall, alluviums and copulas.

Firstly, a review of Copula theory, which began with Sklar (1959), and its usage in the academic world is given in subchapter *2.2 Copula review*. Most copula theory applications have occurred in the last twenty years due to the considerable computational requirements of the corresponding models. With the recent rise of computational capacities, researchers have been able to apply this statistical theory to many areas. The largest use of copulas in a particular field has been in quantitative finance. Other fields that have largely used copulas are medicine, reliability engineering, signal processing and hydrology. Considering that the subject of this thesis is extreme rainfalls and alluvium events, the academic interaction that copulas and hydrology have had will be reviewed. A greater understanding of the advantages and practical uses of copulas will arise with a greater understanding of its literature. Thus, the reasons for the use of copulas in this thesis will become more apparent when the reader has a more robust and complete view of the existing academic literature that exists.

Furthermore, a review of the hydrological theoretical framework will also is done in subchapter *2.3 Extreme rainfall and alluvium review*. This also is instrumental because it gives a context and a lens through which this thesis' methodology and the results can be understood. For example, the many methods that other authors choose to organise their data, or which data they think is important for a study of rainfall and alluvium events, what statistical methods were utilised to analyse the data and what conclusions were reached will form the basis of what themes and questions this thesis can expand.

2.2 Copula review

2.2.1 Copula theory

The copula academic landscape can be divided into two general areas of publication. The first is the mathematical type papers and the second is the application type papers. The first area focuses almost solely on the definition of copula theory and copula families. They are useful for people that want to understand the intricacies of copulas and present the most “cutting edge” theories. These papers sometimes also focus on the use of programming to create copula models. In this thesis, there were a few published papers and books that were used to understand and explain copula theory and its mathematical definitions. As stated before, the first was Sklar (1959), who lays down the foundations of copula theory. One of the most cited works for the definition and comprehension of copulas is Nelsen's (2007) *An introduction to copulas*. This book contains the fundamental formulations of copulas and has a thorough view and explanative perspective of its concepts. It was an integral part of the writing of Chapter *4 Models and mathematical definitions*. Another paper that was important to the writing of this thesis was Embrechts' (2009) *Copulas: A Personal View*. This short paper explains in simpler terms the basics of the copula. Maybe the most important and most utilised work in this thesis was Hofert, *et al.,* (2019). This very contemporary publication presents much of the copula definitions in clear ways that are easily applicable for computational work, namely the R programming language. It also contains definitions of more complicated copula models.

Many publications focus on a type of copula and thus only present definitions for the family of copulas used in the publication. Therefore, it was necessary to read many books and papers to gather into one place, this thesis, the various copula family definitions, whether Elliptical, Archimedean, Survival or Mixed copulas. Hofert *et al.* (2019) and Chen and Guo (2019) define many of the families used in this thesis. Also, some papers, even papers of the second general area of application, application type papers, formulate many of the more basic copula families. However, this thesis uses more complex copulas that result from copula transformations. Such copulas are not thoroughly defined in these books. For example, Hofert *et al.* (2019) explain with some detail mixed copulas and Chen and Guo (2019) merely touch on the subject. Therefore, the paper written by Yamaka *et al.* (2021) was necessary for a stronger understanding of mixed copulas. As is apparent, the more complex the copula theory, the more recent the publications are. Some of the copula theory used in this thesis, such as copula transformations, are at the forefront of statistical and copula innovation. This thesis seeks to aggregate the basic formulation of the variety of copula. It was not, however, the purpose of this thesis to do a thorough walk through every theoretical formulation of copulas. As stated before, much of this was done by Nelsen (2007).

As previously mentioned, some papers that are focused on a particular scientific or engineering application also present copula definitions, in particular, the different copula family definitions the authors of those papers used. The literature for the second general area of is not reviewed in this thesis work, specifically, hydrological applications.

2.2.2 Hydrology and copulas

The most significant and complete work on the subject of copulas and hydrology is Chen and Guo's (2019) book *Copulas and its application in hydrology and water resources*. This is a foundational book for the use of copulas in hydrology. It defines copula theory and its mathematical formulations. Furthermore, it explains copula application to various hydrological phenomena. Most of which are flood and drought events. To the author's best knowledge, little has been published directly studying rainfall using copulas. A notable academic paper that studies rainfall with recourse to copulas was written by Zhang and Singh (2007). Here, bivariate Archimedean copula analysis is applied to understand dependency between characteristic rainfall variables: duration, intensity and depth. This paper shows how these copula results concur with the already known hydrological theory. The two previous publications were cited thoroughly in this thesis. Most of the work in the hydrological field with the use of copulas has been in the areas of flood and drought analysis and its characterisation. For example, Kao and Govindaraju (2010); Xu *et al.* (2015); Ayantobo *et al.* (2019); Pontes Filho *et al.* (2019) and Espinosa *et al.* (2019) have used copulas for the study of droughts. Examples of published papers on the study of floods were written by Grimaldi and Serinaldi (2006) and Karmakar and Simonovic (2009). The paper written by Tahroudi *et al.* (2020) is an example of a paper that covers rainfall, flood and drought topics by studying groundwater level deficiency in relation to rainfall deficiency.

After the descriptions of copulas in chapter *4 Models and mathematical definitions*, is the explanation of the hydrological notion of return periods. Though return periods are widely used in hydrology, bivariate return periods that are calculated from copulas are rare. Chen and Guo (2019) define bivariate joint return periods. However, the understanding and definitions used in this thesis were solely extracted from Espinosa *et al.,* (2019) since its joint return period definition coincides with one from Chen and Guo (2019), but also formulates bivariate conditional return periods.

2.3 Extreme rainfall and alluvium review

2.3.1 Alluviums and extreme rainfall

The study of alluviums and extreme rainfall has been the object of analysis from different fields of knowledge, and thus, much research has taken place and many papers have been published on these topics. Because of the vast number of causes, consequences, types and behaviours of said events, their research can be easily tailored to each field. For example, extreme rainfall events can be studied from a climatological perspective by Guhathakurta *et al.* (2011); from an agricultural perspective by Martınez-Casasnovas *et al.* (2002); for risk assessment for ecosystems and societies by Mason *et al.* (1999) and others. Likewise, the study of alluviums and alluvium events can have many applications and thus many interested parties from different fields of knowledge devoting time to research and publish on alluviums. For example, from a geological and petrological perspective by Lumsden *et al.* (2016); from a fluvial geomorphological viewpoint by James (1999); from a geotechnical perspective by Campolunghi *et al.* (2007) and more.

Another characteristic of the intense rainfall and alluvium literature is that, as far as this author can tell, much of the research is focused on specific spatial locations. Though this can vary in scale, it is understood that some of the causes and implications of such events can vary rapidly from city to city, country to country and continent to continent. Sometimes, because of the complexity and variety of these events, not all variables are known. The relationship between rainfall and alluviums, and their causes and consequences are not entirely known and thus, there is no complete equation that can define such hydrological and geological events. Therefore, much of the work on these topics is done with statistical inferences within spatial boundaries where less variability between any possibly unknown variables that impact the study can be assumed. A commonly used spatial scale for these events is the city scale (Peck *et al.,* 2012). Another scale is the relative one of a geographical feature, for example, a specific river (Johan *et al.,* 1990) or a type of feature, for example, dip-slip faults (Cole Jr and Lade, 1984). Another scale is the region scale, for example, the work written by Fowler and Kilsby (2003) or Manton *et al.* (2001). Larger scale or global studies can also be performed. These studies tend to be focused on understanding the general view of worldwide tendencies for such events, whilst research done in the previous scales can be more focused on the local event type, geographical or geological peculiarities, local risk assessment, or other notable and newsworthy occurrences that caused or were caused by the event, such as those studied in this thesis.

2.3.2 Alluviums and hydrology in the island of Madeira

As already stated, this thesis studies extreme hydrological events on the mountainous Portuguese island of Madeira and, in particular, in the small city of Funchal and its immediate vicinity. Therefore, the scale of this study is the city scale. Chapter *7 Discussion and conclusion* deliberates if some or any of the results achieved in this thesis can be applied to other regions of the island or other places on the globe.

With the notion that the variables that impact extreme rainfalls and alluviums and their theoretical underpinnings can change with the type of study conducted on them and the scale and location of the study, a better understanding of the literature specifically focusing on extreme rainfall and alluviums on the island of Madeira is needed. Lopes *et al.,* (2020) analysed heavy rainfall in the Funchal area. They argue “intense precipitations are effectively the main triggering factor of mass movements, which is why their statistical characteristics and local contrasts are analysed”. This thesis also considers that argument when analysing alluviums and seeks to understand the relationship between intense rainfall and the movement of mass by way of an alluvium event. The previously mentioned paper focuses on the spatial understanding of the mass movements and their relationship with the terrain in the Funchal area. Thus, it takes into consideration the study area’s different terrain slopes, drainage systems, type and occupation of soil and precipitation. The research from Lopes *et al*, 2020, does not however take a vast quantitative statistical approach to the study of precipitation/rainfall. For each of three different categories of precipitation, (i) maximum hourly precipitation, (ii) maximum precipitation at 12h and (iii) 95 percentile of daily precipitation, the authors simply adopted five classes based on the amount of precipitation: 1—very low, 2—low, 3—medium, 4—high, 5—very high. Nothing in such an approach ensures that it accounts for the heavy rainfall variability along time during and before the mass movement events. This thesis takes a more detailed quantitative look at the rainfall measurements and on how to characterise and understand any related alluvium events. This way, there is no need to create classifications for degrees of rainfall. As stated before, this thesis does not consider physiographic features in its analysis. It only intends to look for possible statistical relationships between hourly or daily extreme rainfalls and alluvium flood events.

Central to the conception of this thesis was the intent to further understand the deadly 2010’s late February heavy rainfall and alluvium event in Madeira. To this author’s knowledge, there are two main publications that deal with this subject. The first, written by Fragoso, *et al.* (2012) sought to understand the exceptionality of this rainfall event and understand the flash floods that then occurred. They took a holistic approach to the subject and studied the various possible contributing factors to the alluvium events. They analysed that winter’s rainfall and the rainfall during the late February time frame. They also took into account the temporal and spatial evolution of the heavy rainfall event. Furthermore, they also considered atmospheric data in their models and conclusions. The result of their findings was that the 2009/2010 winter negative phase of the North Atlantic Oscillation “was responsible for the record rainy season observed” and that heavy rainfall was observed throughout the event. The paper from

Fragoso *et al.* (2012) concluded that the rainfall for the February 2010 event was exceptional. This thesis seeks to delve deeper into the relationship between the rainfall event and alluvium events in Madeira, including the late February 2010 event. The univariate statistical approach that Fragoso *et al.* (2012) utilised may not fully explicate this relationship and the exceptionality of the rainfall event including giving an accurate value of its return period. A copula approach, as implemented in this thesis, can account for the non-linearity of the rainfall event, highlighting parts of the rainfall event with some joint or conditional premises. For example, what is the probability of the previous n days of rainfall being greater Pv (mm) given that the rainfall on the day of the flash flood was Pu (mm)? Or vice-versa.

The second publication focusing on the theme of the late 2010 February heavy rainfall and flash floods in the island of Madeira was written by Levizzani, *et al.* (2013). Their focus was on understanding the precipitation that caused the flash floods through satellite passive microwave sounders. By using different techniques, the authors-estimated the precipitation and classified cloud types. The purpose of their publication wasn't so much studying the exceptionality of such or defining it and its evolution. Their research was turned towards the investigation of "the skills of the precipitation estimation and cloud classification algorithm 183-WSL for an accurate cloud and rainfall monitoring of such a limited area event" which is fulfilled in their conclusion: this "study is successful as a proof of concept that a high-resolution satellite rainfall estimation algorithm can be used to monitor a very localized precipitation event leading to floods in an island environment". This thesis does not intend to holistically study a particular event or solely prove the exceptionality of the late February 2010 event. As stated before, it focuses on the usage of copulas to model extreme rainfall events. And it also uses copulas as statistical tools to understand the exceptionality and relationship between rainfall and alluvium events.

3 Data

3.1 Introduction

There were two main sets of data that were the main object of study and were used to create the models. The rainfall data and the alluvium data, namely, dates and affected areas. In this chapter, an explanation of their origin and composition is given. Furthermore, this thesis' definition and methodological approach of extreme rainfall will also be given.

3.2 Rainfall data

The first main dataset used is the daily and hourly rainfall at Funchal rain-gage. The daily data was composed of daily rainfalls (in mm) from the 1st of October of 1937 to the 30th of September 2017, whereas the hourly referred to hourly measurements (also in millimetres) from the 1st of October 1980 to the 30th of September 2014. These rainfall datasets, as used for this thesis, were complete, i.e., didn't present gaps in the measurements. These datasets were obtained separately. The daily rainfalls comprehended both measurements and data resulting from the filling-gap procedure developed by Espinosa *et al.*, (2021), whereas the hourly rainfalls referred only to measurements provided by the IPMA – Instituto Português do Mar e da Atmosfera, I. P.

From this first main dataset, a study was done to define the most extreme rainfall event of every available hydrological year. The definition arrived at was the annual maximum series (AMS). The series of annual maximum rainfall in a given period (for this thesis, hours or days) is composed by the maximum rainfall in each (hydrological) year in that period, that is to say, it is an annual maximum series, AMS. To ensure the randomness of the series thus achieved under the specific hydrological constraints that prevail in Portugal, the year refers to the period from October 1 to September 30 of the following year.

Therefore, for each hydrological year of the hourly and daily rainfall dataset, the maximum rainfall that occurred in the respective hour or day was selected. These values form the hourly and daily AMS. These time-series are presented in Table 1, along with their occurrence dates.

3.3 Alluvium data

The second main set of data is related to recorded alluviums from 1601 to 2010 and was collected from Sepúlveda (2011). For each alluvium event, this author provides some characteristics of the weather conditions and the location of the occurrence. This data can be found in Annex I in its author's original format.

Criteria were defined with the objective of associating extreme rainfall events represented in the hourly AMS and the historical alluviums systematised by Sepúlveda (2011). The purpose of this was to connect the two main datasets for the interests of this thesis, namely, studying the association of alluviums and extreme rainfall vents on the island of Madeira.

An important methodological note is that all the extreme rainfall events were initially defined by the AMS and analysed with the objective of Copula study, and not only the ones that are here defined to be related to alluviums. This means attribution of return periods was made for all the extreme rainfall events independently of if they were associated with alluviums or not.

Table 1 – Daily and hourly annual maximum series (AMS) in mm and corresponding date of occurrence and hydrological year. From 1937/1938 to 2016/2017, for daily rainfall, and from 1980/1981 to 2013/2014, for hourly rainfall.

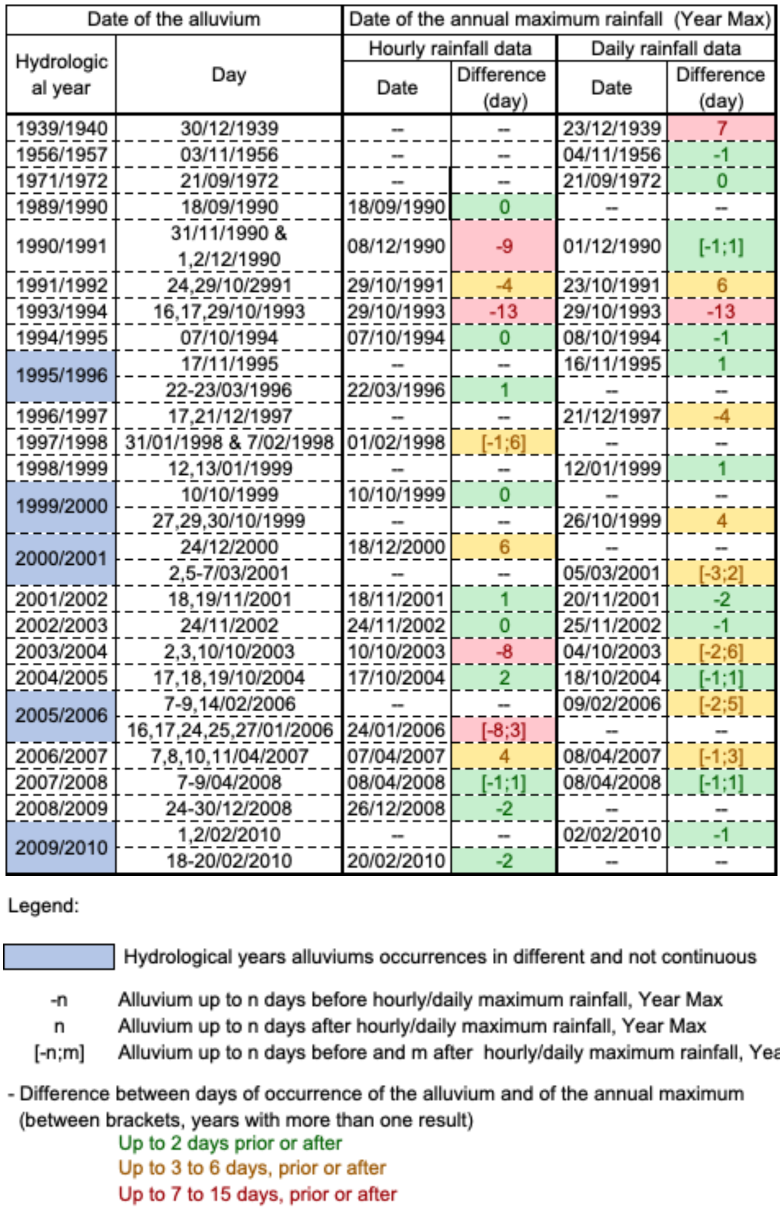
Hydrological year	Daily rainfall - AMS		Hourly rainfall - AMS		Hydrological year	Daily rainfall - AMS		Hourly rainfall - AMS	
	Date of occurrence	Rainfall (mm)	Date of occurrence	Rainfall (mm)		Date of occurrence	Rainfall (mm)	Date of occurrence	Rainfall (mm)
1937/1938	19/10/1937	61.2	-	-	1977/1978	20/12/1977	55.7	-	-
1938/1939	23/09/1939	28.2	-	-	1978/1979	06/11/1978	76.6	-	-
1939/1940	23/12/1939	60.5	-	-	1979/1980	14/04/1980	34.6	-	-
1940/1941	12/02/1941	107.0	-	-	1980/1981	04/10/1980	26.6	11/11/1980	11.4
1941/1942	06/11/1941	67.7	-	-	1981/1982	16/09/1982	42.1	21/11/1981	16.2
1942/1943	06/10/1942	56.0	-	-	1982/1983	06/03/1983	19.9	23/09/1983	10.9
1943/1944	09/02/1944	43.8	-	-	1983/1984	22/09/1984	73.2	21/09/1984	22.0
1944/1945	11/11/1944	38.2	-	-	1984/1985	06/01/1985	55.5	06/01/1985	24.7
1945/1946	13/12/1945	59.1	-	-	1985/1986	23/10/1985	47.5	23/10/1985	28.6
1946/1947	24/01/1947	51.0	-	-	1986/1987	23/01/1987	90.2	22/01/1987	18.5
1947/1948	23/02/1948	41.0	-	-	1987/1988	25/10/1987	91.7	24/10/1987	14.4
1948/1949	23/11/1948	30.2	-	-	1988/1989	27/09/1989	97.7	26/09/1989	29.4
1949/1950	03/11/1949	66.8	-	-	1989/1990	26/10/1989	82.8	18/09/1990	37.7
1950/1951	02/06/1951	27.5	-	-	1990/1991	01/12/1990	71.6	08/12/1990	31.0
1951/1952	31/03/1952	48.4	-	-	1991/1992	23/10/1991	56.1	29/10/1991	25.4
1952/1953	19/11/1952	111.9	-	-	1992/1993	09/05/1993	42.4	09/05/1993	18.6
1953/1954	09/10/1953	115.6	-	-	1993/1994	29/10/1993	88.9	29/10/1993	29.8
1954/1955	02/01/1955	27.3	-	-	1994/1995	08/10/1994	53.0	07/10/1994	10.9
1955/1956	12/01/1956	97.6	-	-	1995/1996	16/11/1995	94.7	22/03/1996	32.5
1956/1957	04/11/1956	131.2	-	-	1996/1997	01/02/1997	39.8	19/03/1997	15.9
1957/1958	09/12/1957	38.0	-	-	1997/1998	21/12/1997	68.1	01/02/1998	28.7
1958/1959	24/01/1959	52.6	-	-	1998/1999	12/01/1999	53.1	05/11/1998	11.9
1959/1960	21/03/1960	47.4	-	-	1999/2000	26/10/1999	50.6	10/10/1999	26.5
1960/1961	22/10/1960	20.4	-	-	2000/2001	05/03/2001	53.1	18/12/2000	20.4
1961/1962	22/09/1962	49.1	-	-	2001/2002	20/11/2001	86.1	18/11/2001	20.6
1962/1963	31/01/1963	62.7	-	-	2002/2003	25/11/2002	78.2	24/11/2002	29.9
1963/1964	21/06/1964	57.8	-	-	2003/2004	04/10/2003	36.0	10/10/2003	18.4
1964/1965	01/06/1965	44.3	-	-	2004/2005	18/10/2004	61.7	17/10/2004	21.4
1965/1966	26/10/1965	54.1	-	-	2005/2006	09/02/2006	44.2	24/01/2006	15.5
1966/1967	31/10/1966	68.7	-	-	2006/2007	08/04/2007	62.9	07/04/2007	22.1
1967/1968	21/11/1967	64.9	-	-	2007/2008	08/04/2008	110.9	08/04/2008	41.4
1968/1969	04/01/1969	84.4	-	-	2008/2009	27/02/2009	82.3	26/12/2008	17.2
1969/1970	26/03/1970	45.8	-	-	2009/2010	02/02/2010	111.0	20/02/2010	51.2
1970/1971	29/12/1970	52.3	-	-	2010/2011	26/11/2010	155.1	25/11/2010	37.3
1971/1972	21/09/1972	72.6	-	-	2011/2012	24/10/2011	30.0	23/10/2011	10.2
1972/1973	23/10/1972	38.0	-	-	2012/2013	25/11/2012	67.3	25/11/2012	21.5
1973/1974	27/05/1974	71.4	-	-	2013/2014	16/09/2014	33.1	18/10/2013	21.7
1974/1975	27/02/1975	47.0	-	-	2014/2015	29/11/2014	37.8	-	-
1975/1976	15/12/1975	37.6	-	-	2015/2016	22/04/2016	85.5	-	-
1976/1977	27/12/1976	84.9	-	-	2016/2017	26/04/2017	62.8	-	-

The criteria of selection for the purposes of association were **temporal**, **spatial** and **substantive**. As further discussed in Chapter *5 Datasets and modelling approach* regarding the annual maximum hourly rainfall, the temporal criterion couples the extreme rainfall-alluvium event if the annual maximum rainfall occurred within the previous 6 days of the identified alluviums. As for the annual maximum daily rainfall, the **temporal criterion** generally considers a time interval of 6 days, but in this case either before or after the alluvium event. Depending on the type of daily analysis the temporal criterion of association might differ slightly. This will be further discussed in section *6.2.2 Bivariate return periods or-and comparison for daily rainfall*.

The **spatial criterion** indicates that the alluvium must have occurred specifically in Funchal or was said to have impacted the southern slope of the island or all over the island. Finally, the **substantive criterion** was defined as having caused either floods or landslides or damaging impacts to civil infrastructure and human life.

Table 2 presents how the temporal criterion was utilised, based on the AMS of both hourly and daily rainfall. It shows the date and hydrological year of the alluvium events and their related extreme rainfall events and, for each alluvium event, the difference in days between the same and the corresponding annual maximum. As stated before, only the rainfall and alluvium events that are separated by a maximum of 6 days (either before – negative values, or after – positive values) will be regarded as temporally related.

Table 2 – Differences in days between possible temporally related alluvium events and annual maximum rainfalls.



Date of the alluvium		Date of the annual maximum rainfall (Year Max)			
		Hourly rainfall data		Daily rainfall data	
Hydrological year	Day	Date	Difference (day)	Date	Difference (day)
1939/1940	30/12/1939	–	–	23/12/1939	7
1956/1957	03/11/1956	–	–	04/11/1956	-1
1971/1972	21/09/1972	–	–	21/09/1972	0
1989/1990	18/09/1990	18/09/1990	0	–	–
1990/1991	31/11/1990 & 1,2/12/1990	08/12/1990	-9	01/12/1990	[-1;1]
1991/1992	24,29/10/2991	29/10/1991	-4	23/10/1991	6
1993/1994	16,17,29/10/1993	29/10/1993	-13	29/10/1993	-13
1994/1995	07/10/1994	07/10/1994	0	08/10/1994	-1
1995/1996	17/11/1995	–	–	16/11/1995	1
	22-23/03/1996	22/03/1996	1	–	–
1996/1997	17,21/12/1997	–	–	21/12/1997	-4
1997/1998	31/01/1998 & 7/02/1998	01/02/1998	[-1;6]	–	–
1998/1999	12,13/01/1999	–	–	12/01/1999	1
1999/2000	10/10/1999	10/10/1999	0	–	–
	27,29,30/10/1999	–	–	26/10/1999	4
2000/2001	24/12/2000	18/12/2000	6	–	–
	2,5-7/03/2001	–	–	05/03/2001	[-3;2]
2001/2002	18,19/11/2001	18/11/2001	1	20/11/2001	-2
2002/2003	24/11/2002	24/11/2002	0	25/11/2002	-1
2003/2004	2,3,10/10/2003	10/10/2003	-8	04/10/2003	[-2;6]
2004/2005	17,18,19/10/2004	17/10/2004	2	18/10/2004	[-1;1]
2005/2006	7-9,14/02/2006	–	–	09/02/2006	[-2;5]
	16,17,24,25,27/01/2006	24/01/2006	[-8;3]	–	–
2006/2007	7,8,10,11/04/2007	07/04/2007	4	08/04/2007	[-1;3]
2007/2008	7-9/04/2008	08/04/2008	[-1;1]	08/04/2008	[-1;1]
2008/2009	24-30/12/2008	26/12/2008	-2	–	–
2009/2010	1,2/02/2010	–	–	02/02/2010	-1
	18-20/02/2010	20/02/2010	-2	–	–

Legend:

🟦 Hydrological years alluviums occurrences in different and not continuous

-n	Alluvium up to n days before hourly/daily maximum rainfall, Year Max
n	Alluvium up to n days after hourly/daily maximum rainfall, Year Max
[-n;m]	Alluvium up to n days before and m after hourly/daily maximum rainfall, Yea

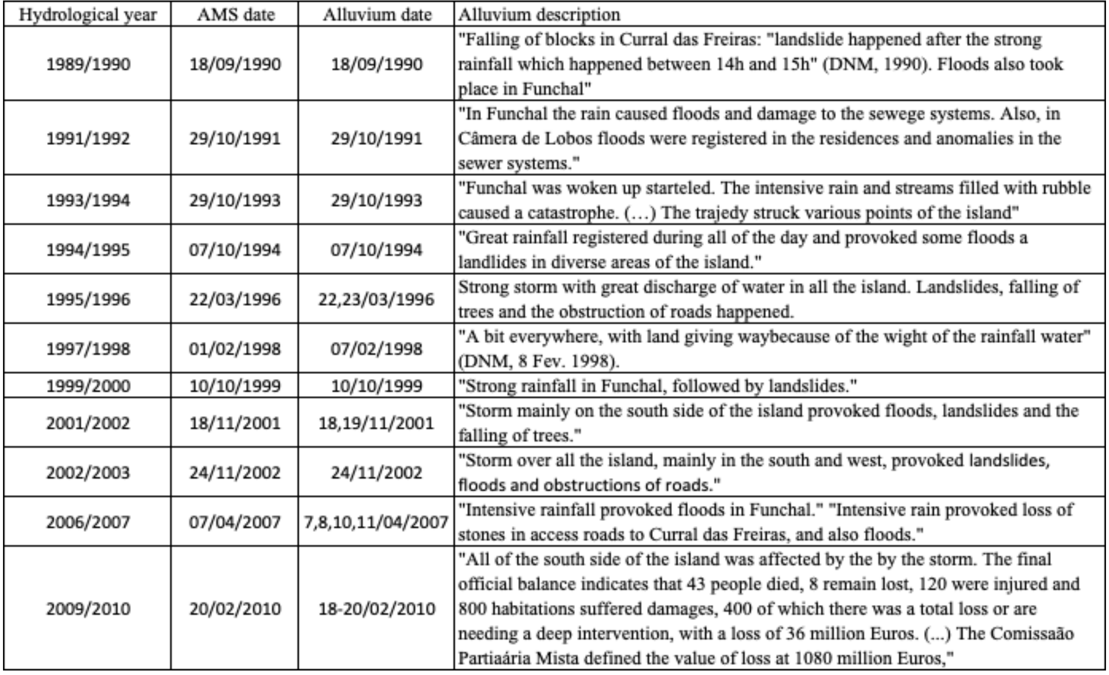
- Difference between days of occurrence of the alluvium and of the annual maximum (between brackets, years with more than one result)

Up to 2 days prior or after
Up to 3 to 6 days, prior or after
Up to 7 to 15 days, prior or after

Of the events in Table 2 that were found to have a temporal relationship, the ones that also had a spatial and substantive association with extreme rainfalls were regarded as fully related/associated.

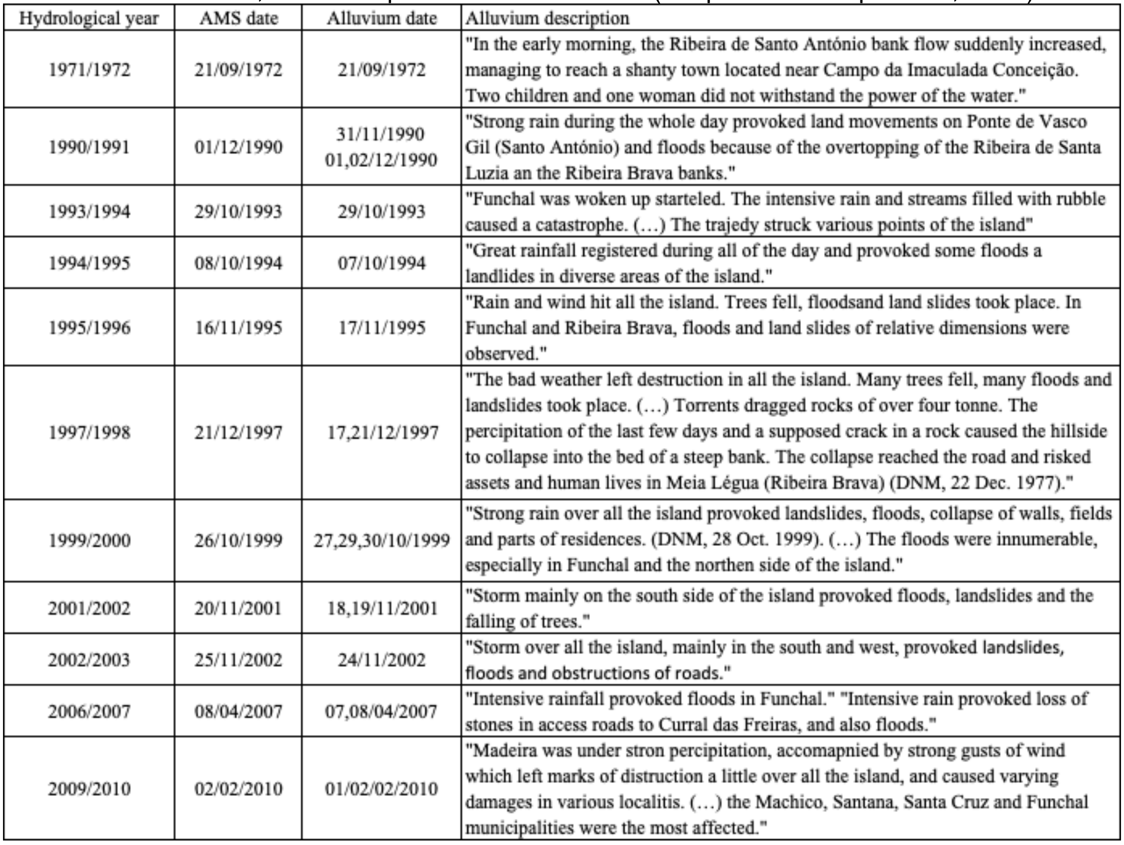
Table 3 presents the fully related (meeting all the three criteria) alluviums and rainfall events for hourly rainfall measurements, while Table 4 contains the same information but for the annual daily rainfalls. Some of the related events appear in both tables because the hourly and daily annual maxima occur on the same date or only a few days apart, and thus, are associated with the same alluvium event.

Table 3 – Hydrological year of associated alluvium, dates of the maximum hourly rainfall and of the alluvium. Then, the description of each alluvium (adapted from Sepúlveda, 2011).



Hydrological year	AMS date	Alluvium date	Alluvium description
1989/1990	18/09/1990	18/09/1990	"Falling of blocks in Curral das Freiras: "landslide happened after the strong rainfall which happened between 14h and 15h" (DNM, 1990). Floods also took place in Funchal"
1991/1992	29/10/1991	29/10/1991	"In Funchal the rain caused floods and damage to the sewege systems. Also, in Câmera de Lobos floods were registered in the residences and anomalies in the sewer systems."
1993/1994	29/10/1993	29/10/1993	"Funchal was woken up starteled. The intensive rain and streams filled with rubble caused a catastrophe. (…) The trajedy struck various points of the island"
1994/1995	07/10/1994	07/10/1994	"Great rainfall registered during all of the day and provoked some floods a landlides in diverse areas of the island."
1995/1996	22/03/1996	22,23/03/1996	Strong storm with great discharge of water in all the island. Landslides, falling of trees and the obstruction of roads happened.
1997/1998	01/02/1998	07/02/1998	"A bit everywhere, with land giving waybecause of the wight of the rainfall water" (DNM, 8 Fev. 1998).
1999/2000	10/10/1999	10/10/1999	"Strong rainfall in Funchal, followed by landslides."
2001/2002	18/11/2001	18,19/11/2001	"Storm mainly on the south side of the island provoked floods, landslides and the falling of trees."
2002/2003	24/11/2002	24/11/2002	"Storm over all the island, mainly in the south and west, provoked landslides, floods and obstructions of roads."
2006/2007	07/04/2007	7,8,10,11/04/2007	"Intensive rainfall provoked floods in Funchal." "Intensive rain provoked loss of stones in access roads to Curral das Freiras, and also floods."
2009/2010	20/02/2010	18-20/02/2010	"All of the south side of the island was affected by the by the storm. The final official balance indicates that 43 people died, 8 remain lost, 120 were injured and 800 habitations suffered damages, 400 of which there was a total loss or are needing a deep intervention, with a loss of 36 million Euros. (...) The Comissão Partiaária Mista defined the value of loss at 1080 million Euros,"

Table 4 – Hydrological year of associated alluvium, dates of the maximum daily rainfall and of the alluvium. Then, the description of each alluvium (adapted from Sepúlveda, 2011).



Hydrological year	AMS date	Alluvium date	Alluvium description
1971/1972	21/09/1972	21/09/1972	"In the early morning, the Ribeira de Santo António bank flow suddenly increased, managing to reach a shanty town located near Campo da Imaculada Conceição. Two children and one woman did not withstand the power of the water."
1990/1991	01/12/1990	31/11/1990 01,02/12/1990	"Strong rain during the whole day provoked land movements on Ponte de Vasco Gil (Santo António) and floods because of the overtopping of the Ribeira de Santa Luzia an the Ribeira Brava banks."
1993/1994	29/10/1993	29/10/1993	"Funchal was woken up starteled. The intensive rain and streams filled with rubble caused a catastrophe. (…) The trajedy struck various points of the island"
1994/1995	08/10/1994	07/10/1994	"Great rainfall registered during all of the day and provoked some floods a landlides in diverse areas of the island."
1995/1996	16/11/1995	17/11/1995	"Rain and wind hit all the island. Trees fell, floodsand land slides took place. In Funchal and Ribeira Brava, floods and land slides of relative dimensions were observed."
1997/1998	21/12/1997	17,21/12/1997	"The bad weather left destruction in all the island. Many trees fell, many floods and landslides took place. (…) Torrents dragged rocks of over four tonne. The percipitation of the last few days and a supposed crack in a rock caused the hillside to collapse into the bed of a steep bank. The collapse reached the road and risked assets and human lives in Meia Légua (Ribeira Brava) (DNM, 22 Dec. 1977)."
1999/2000	26/10/1999	27,29,30/10/1999	"Strong rain over all the island provoked landslides, floods, collapse of walls, fields and parts of residences. (DNM, 28 Oct. 1999). (…) The floods were innumerable, especially in Funchal and the northen side of the island."
2001/2002	20/11/2001	18,19/11/2001	"Storm mainly on the south side of the island provoked floods, landslides and the falling of trees."
2002/2003	25/11/2002	24/11/2002	"Storm over all the island, mainly in the south and west, provoked landslides, floods and obstructions of roads."
2006/2007	08/04/2007	07,08/04/2007	"Intensive rainfall provoked floods in Funchal." "Intensive rain provoked loss of stones in access roads to Curral das Freiras, and also floods."
2009/2010	02/02/2010	01/02/02/2010	"Madeira was under stron percipitation, accomapnied by strong gusts of wind which left marks of distruction a little over all the island, and caused varying damages in various localitis. (…) the Machico, Santana, Santa Cruz and Funchal municipalities were the most affected."

4. Models and Mathematical Definitions

4.1 Introduction

In this chapter, the theoretical ideas behind all the statistical processes used in this thesis are presented. Furthermore, the mathematical formulations that underpin these processes are also provided. This chapter is essential to understand the following chapters and all the methodology and results presented in this thesis.

4.2 Marginal distributions

4.2.1 Introduction

Marginal distribution is the name given to univariate statistical distributions. In this thesis, marginal distributions are continuous and will be applied to model the rainfall random series for bivariate statistical analysis based on copulas. The following items define and comment on the various statistical distributions used in this thesis. In these formulations, $f(x)$ is the probability density function in the x coordinate, x is the value of a given random variable X with mean, standard deviation and the variance represented by μ, σ, and σ^2, respectively.

4.2.2 Normal distribution

Also referred to as Gaussian distribution, the Normal distribution is a symmetrical distribution and is the best known statistical distribution (Altman and Bland, 1995). It is used in most areas where statistical methods are used to describe empirical distributions. It is in fact the default distribution used in most statistical analyses. As indicated by Taylor (2020), Equation (4.2.1) is the mathematical formulation for the probability density function for the Normal distribution.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{4.2.1}$$

4.2.3 Log-normal distribution

Sometimes referred to as Galton distribution. The log-normal distribution is a non-symmetric distribution that is derived from the Normal distribution. Its relationship with the Normal distribution is as follows: if the natural logarithm of a random variable composes a normal distribution, then the random variable is log-normally distributed, this is, $Y = \ln(X)$, in which, Y is the dependent variable and X is the log-normally distributed random variable. Equation (4.2.2) formalises the probability density function for the log-normal distribution (Weisstein, 2021b).

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln(x)-\mu)^2}{2\sigma^2}} \tag{4.2.2}$$

4.2.4 Exponential distribution

The Exponential distribution (the continuous counterpart to the geometric distribution) is a version of the Gamma distribution where the Gamma distribution's shape and scale parameters are 1 and 1/λ respectively. The Exponential distribution is also closely related to the Poisson distribution, in which the Exponential distribution of the time between occurrences of successive events with the continuous flow of time (Poisson point process). Equation (4.2.3) is the mathematical formulation for the probability density function for the Exponential distribution, where for all negative values of x, $f(x)$ is equal to zero and λ is the rate parameter of the distribution.

$$f(x) = \lambda e^{-(\lambda x)} \tag{4.2.3}$$

4.2.5 Gamma distribution

The Gamma distribution is another common statistical distribution. It is used for positive continuous variables and is non-symmetrical. It is closely related to the Erlang distribution, Chi-square distribution and as mentioned previously, the Exponential distribution. Equation (4.2.4) is the mathematical formulation for the probability density function for the Gamma distribution where $\alpha = \mu^2/\sigma^2$and $\beta = \mu/\sigma^2$ are respectively the shape and rate (inverse of scale) parameters and for all negative values of x, $f(x)$ is equal to zero.

$$f(x) = \frac{\beta^{\alpha}}{\Gamma(\alpha)} x^{\alpha-1} e^{-\beta x} \tag{4.2.4}$$

4.2.6 Weibull distribution

The Weibull distribution is a non-symmetric continuous distribution. As suggested by Martz (2003), it is extensively used in reliability engineering because such distribution is a generalisation of the Exponential distribution in that it includes non-constant failure rate functions. The Weibull distribution can be transformed into both the Exponential distribution by equalling its shape parameter to 1 and the Rayleigh distribution by equalling its shape parameter to 2 and its scale parameter to $\sigma\sqrt{2}$ (Naghettini, 2007). Equation (4.2.5) is the mathematical formulation for the probability density function for the Weibull distribution, in which k and λ are respectively the shape and scale parameters and x is always positive. All negative values □ of are null.

$$f(x) = \frac{k}{\lambda} (x/\lambda)^{\alpha-1} e^{-(x/\lambda)^{k}} \tag{4.2.5}$$

4.2.7 Cauchy distribution

Also referred to as Lorentz or Breit-Wigner distribution, the Cauchy distribution is continuous and is symmetric around its location parameter. It is related to the Normal distribution in that it is the ratio between two random variables that are normally distributed. One of its rare attributes is that it has no mean or variance. It must be noted, however, that the location parameter is equal to the median and mode of the distribution. Equation (4.2.6) is the mathematical formulation for the probability density function for the Cauchy distribution, in which m and b (width at half maximum) are respectively the location and scale parameters (Weisstein, 2021a).

$$f(x) = \frac{1}{\pi} \frac{b}{(x-m)^2 + b^2} \tag{4.2.6}$$

4.2.8 Logistic distribution

The Logistic distribution is continuous and non-symmetric. In statistical theory, its cumulative distribution is the logistic function of logistic regression. Though similar in shape to the Normal distribution, it has a higher kurtosis, this is, wider tails, which means it better models the likelihood of extreme events. As indicated by Kissell and Poserina (2017), Equation (4.2.7) is the mathematical formulation for the probability density function for the Logistic distribution, in which $s = \sqrt{3\sigma^2}/\pi$ is the scale parameter.

$$f(x) = \frac{e^{-\frac{x-\mu}{s}}}{s\left(1 + e^{-\frac{x-\mu}{s}}\right)^2} \tag{4.2.7}$$

4.3 Fitting methods

4.3.1 Introduction

In line with Delignette-Muller and Dutang (2015), fitting methods are operations that fit a vector of random data (a series) with a statistical distribution by adjusting that distribution's parameters. The outputs of these methods are, for each distribution that is fitted to the data, their parameters. The estimated values of the parameters are the ones that best calibrate the distribution to model the vector of data. Therefore, for each series of data, there will be multiple fitted distributions with their respective estimated parameters. This will then allow for non-exceedance probabilities to be calculated.

For the purpose of calculating univariate return periods and utilising the copula approach for bivariate return periods the following four fitting/estimation methods presented in the next items were considered: Maximum Likelihood Estimation (MLE), Moment Matching Estimation (MME), Moment Goodness-of-fit Estimation (MGE) and Quantile Matching Estimation (QME). They are now mathematically defined and commented on as follows.

4.3.2 Maximum Likelihood Estimation

As its name states, MLE "determines values for the parameters of a model… such that they maximise the likelihood" that model best fits the observed data (Brooks-Bartlett, 2018). As Delignette-Muller and Dutang (2015) indicate, the mathematical function that is to be maximised is defined in Equation (4.3.1), where $L(\theta)$ is the likelihood function, θ are the distribution parameters and x_i are the observations of a random variable *X*.

$$L(\theta) = \prod_{i=1}^{n} f(x_i|\theta) \tag{4.3.1}$$

4.3.3 Moment Matching Estimation

This fitting method identifies the sample's moments and seeks to equal the theoretical distribution's moments. Such moments are the expected value, variance skewness and kurtosis.

According to Bowman and Shenton (2014), a mathematical understanding of this concept can be expressed in Equation (4.3.2), where $E(X^k)$ is the kth moment of a random variable X with sample size n.

$$\mu_i \equiv E(X^k) \; approximised \; by \; \frac{1}{n}\sum_{i=1}^{n} X_i^k \tag{4.3.2}$$

4.3.4 Goodness-of-fit Estimation

In light of D'Agostino and Stephens' (1986) work, *Goodness-of-Fit Techniques*, the method examines "how well a sample of data agrees with a given distribution as its population." (D'Agostino and Stephens, 1986, pp.1). On the same page, they go on to state this fitting method seeks to measure "in some way the conformity of the sample data (a set of x -values) to the hypothesized distribution, or, equivalently, its discrepancy from it." In this thesis, three goodness-of-fit statistics were utilised to test the fitting of the distributions to the samples. In the following formulations F is the cumulative distribution function, F_n is the empirical distribution function and *n* is the number of "observations of a continuous variable X" (Delignette-Muller and Dutang, 2015, pp.10).

The first is the Kolmogorov-Smirnov statistic (KS) as indicated by D'Agostino and Stephens (1986). The mathematical formulation is written in Equation (4.3.3), where D is the KS statistic.

$$D = sup_X|F_n(x) - F(x)| \tag{4.3.3}$$

D'Agostino and Stephens (1986) define the second test is the Cramér-von Mises statistic (CvM). The mathematical formulation is expressed in Equation (4.3.4), where Q is the CvM statistic. Delignette-Muller and Dutang (2015).

$$Q = n\int_{-\infty}^{+\infty} (F_n(x) - F(x))^2 dx \tag{4.3.4}$$

The third and final goodness-of-fit statistic used in this thesis is the Anderson and Darling (1954) statistic (AD). It is mathematically defined as the (4.3.5) equation, where A^2 is the AD statistic. Delignette-Muller and Dutang (2015).

$$A^2 = n\int_{-\infty}^{+\infty} \frac{(F_n(x) - F(x))^2}{F(x)(1 - \square(x))} dx \tag{4.3.5}$$

Both the Cramér-von Mises and Anderson-Darling statistic can be derived from a more general mathematical formula, where Cramér-von Mises sets $\psi(x)$ as $\psi(x) = 1$ and Anderson-Darling sets $\psi(x)$ as $\psi(x) = [F(x)(1 - F(x))]^{-1}$. In this formulation, "$\psi(x)$ is a suitable function which gives weights to the squared difference $\{F_n(x) - F(x)\}^2$." (D'Agostino and Stephens, 1986, pp.100). Thus, the more general equation is expressed as Equation (4.3.6).

$$n \int_{-\infty}^{+\infty} \{F_n(x) - F(x)\}^2 \psi(x) dF(x) \tag{4.3.6}$$

4.3.5 Quantile Matching Estimation

This method seeks to fit parametric distributions "by matching theoretical quantiles of the parametric distributions (for specified probabilities) against the empirical quantiles" (Delignette-Muller and Dutang, 2015, pp.17). In this thesis, for a given fitting, two quantiles were chosen as the matching points for quantile estimation. The mathematical formulation is defined in Equation (4.3.7), where k is the sequence from 1 to the number of parameters that are to be estimated, θ are the distribution parameters, "and Q_{n,p_k} the empirical quantiles calculated from data for specified probabilities p_k" (Delignette-Muller and Dutang, 2015, pp.17).

$$F^{-1}(p_k|\theta) = Q_{n,p_{\square}} \tag{4.3.7}$$

4.4 Selection Criteria

4.4.1 Introduction

Three criteria were used to evaluate the relative quality of the fitting of marginal distributions to the various data series with the purpose of then selecting the best-fitted distribution. The three criteria were, as discussed in the next items: Log-Likelihood Function (LLF), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC).

Thus, of the fitted distributions for every series of data, the best distribution was selected and used to calculate univariate return periods and the copulas.

4.4.2 Log-Likelihood Function

In line with Stover (2021), LLF is a test that allows for a relative comparison of the quality of fitted statistical distributions. This comparison then allows for the selection of the distribution that best fits each data series. LLF represented by F(θ) is equal to "the natural logarithm of the likelihood function L(θ)", this is, $F(\theta) = \ln(F(\theta))$. The greater the value of F(θ) the higher quality the distribution fitting is. Equation (4.4.1) defines LLF.

$$F(\theta) = \sum_{i=1}^{n} \ln(f_i(x_i|\,\theta)) \tag{4.4.1}$$

4.4.3 Akaike Information Criterion

As argued by Moffatt (2020), AIC is a criterion that evaluates the relative quality of fitting of statistical distributions. Once evaluated, the distribution with the highest relative quality of fitting is the one that presents the lowest AIC value. Bellow, is Equation (4.4.2) which is the calculation of the AIC value, where K is the number of estimated free parameters, n is the number of observations, and RSS is the residual sum of squares.

$$AIC = \mathrm{n}\ln(RSS) + 2K \tag{4.4.2}$$

4.4.4 Bayesian Information Criterion

Similar to AIC, BIC, also referred to as Schwarz Information Criterion (SIC) Schwarz (1978), too calculates the relative quality of fitting of statistical distributions. For the selection of the best-fitted distribution, the lower the BIC value the better the fit. Equation (4.4.3) shows the calculation of the BIC value, where k is the number of estimated free parameters, n is the sample size and RSS is the residual sum of squares.

$$BIC = n\ln(\frac{RSS}{n}) + \mathrm{k}\ln(\mathrm{n}) \tag{4.4.3}$$

Since BIC is a comparison between relative values, the difference between two BIC values can show how much better one model fitting is compared to the other. This is summarised in Table 5.

Table 5 – Difference in BIC and evidence for a better fit.

Difference in BIC	**Evidence for better fit**
0 to 2	Not worth more than a bare mention
2 to 6	Positive
6 to 10	Strong
>10	Very strong

Source: adapted from *Kass and Raftery (1995)*

4.5 Copulas

4.5.1 Introduction

The main mathematical and statistical multivariate formulation used to model joint probabilities, which will be subsequently used to obtain substantive hydrological information, is the *Copula*. Similarly to marginal distributions, copulas can be distinguished and understood by some fundamental elements. For example, the existence of dispersion or degree of scatter along the correlation path and the right and left tail in combination with the uniformity and symmetry of the scatter.

The following explanations detail the mathematical formulations of the multi-dimensional and more specifically bivariate Copula and their univariate marginals.

In this thesis, copulas were applied to model the association among annual maximum rainfall and rainfall in prior and posterior time intervals relative to the annual maximum.

4.5.2 Concept of bivariate distributions and the copula

As the word bivariate indicates, the distribution is formed with two variables. According to Zhang and Singh (2007, pp.95), for two random dependent or independent variables X and Y, a "joint probability distribution, H, can be expressed" in the following formulation – Equation (4.5.1).

$$H(x,y) = P(X \leq x, Y \leq y) = \int_{-\infty}^{x}\int_{-\infty}^{y} h(u,v)\,du\,dv \tag{4.5.1}$$

The copula is a concept that derives its theory from this joint distribution notion. A mathematical definition will now be given, which will then be proceeded with further details of the copula. As indicated by Embrechts (2009), the bivariate copula can be argued as the following:

For two random variables X and Y, with their respective continuous cumulative distribution functions H_1 and H_2there is a joint cumulative distribution function H, *with* $U_1 = H_1(X)$ and $U_2 = H_2(Y)$ uniformly distributed random variables in $\mathbf{I} \in [0,1]$.

For these premises, copula C in **I**^{2} is the cumulative distribution function of a random vector $(U_1, U_2)^T$ and is expressed in equations (4.5.2) and (4.5.3):

$$H(x,y) = P(X \leq x, Y \leq y) = P(U_1 \leq H_1(x), U_2 \leq H_2(y)) \tag{4.5.2}$$

then,

$$H(x,y) = C(H_1(x), H_2(y)) = C(u,v) \tag{4.5.3}$$

Furthermore, the copula density function $c(u,v)$ can be defined by the joint probability density function h_{XY}, (Zeng *et al.*, 2014):

$$c(u,v) = \frac{\partial^2 C(u,v)}{\partial u\,\partial v} = \frac{\partial^2 C(H_1(x), H_2(y))}{\partial H_1(x)\partial H_2(y)} = \frac{h_{XY}(x,y)}{h_X(x)h_Y(\square)} \tag{4.5.4}$$

4.5.3 Concept of bivariate copula

As argued by Sklar (1959), the definition of an nth dimensioned Copula is "any continuous and non-decreasing function C_n, defined on $[0, 1]^n$, satisfying the following conditions: (i) $C_n(0, \ldots, 0) = 0$, and (ii) $C_n(1, \ldots, 1, \alpha, 1, \ldots, 1) = \alpha$." (in Sklar, 2004, pp.2).

For this thesis' purpose, a two-dimensional representative case is necessary for a more intricate understanding of the bivariate copula definition. Nelsen (2007) gives us this example:

Let C be a 2-copula or 2-subcopula with domain **I**^{2}, or synonymously, "an arbitrary two-dimensional copula function" Chen and Guo (2019, pp.14), since "a two-dimensional copula (…) is a 2-subcopula C whose domain is **I**^{2}", where C maintains the properties previously defined by Sklar (1959) for an n^th dimensioned Copula. Since C is two dimensioned, $C \equiv C(u,v)$ with u and v in **I** (Nelsen, 2007, pp.8), "the unit square $\mathbf{I}^2$ is the product of $\mathbf{I}\times\mathbf{I}$, where $\mathbf{I} \in [0,1]$." (Nelsen, 2007, pp.6). Five fundamental definitions of the copula are expressed equations (4.5.5) to (4.5.10), for every u and v in **I**,

$$C(u,0) = 0 \tag{4.5.5}$$

and

$$C(0,v) = 0 \tag{4.5.6}$$

thus,

$$C(u,0) = C(0,v) = 0 \tag{4.5.7}$$

Furthermore,

$$C(u,1) = u \tag{4.5.8}$$

and

$$C(1,v) = v \tag{4.5.9}$$

Then, "for every u_1, u_2, v_1, v_2 in **I** such that $u_1 \leq u_2$ and $v_1 \leq v_2$" (Nelsen, 2006, pp.8),

$$C(u_2,v_2) - C(u_2,v_1) - C(u_1,v_2) + C(u_1,v_1) \geq 0 \tag{4.5.10}$$

4.5.4 Joint distribution and probabilistic summation problems

To better understand the copula concept, a more intuitive illustration will now be given of how, with its introduction by Sklar (1959), marginal distributions can be separated "from the dependency structure of a given multivariate distribution." (Espinosa *et al.*, 2019).

Copulas are mathematical models that are defined by their correlation parameters and are produced by two or more marginal distributions. Copulas produce a joint distribution, except for conditional copulas (Zhang and Singh, 2007).

Considering Jordan's (2020) online course: *Introduction to Copulas*, when composing joint distributions, a problem arises when we want to perform an *or* joint distribution. The probability of an occurrence is always from 0 to 1, however, when we are performing *or* joint distributions the summation of probabilities can exceed 1. This is a statistical impossibility. The solution proposed in copula modelling is to transform the probability using a generator function from 0 to 1 to a number from 0 to infinity. Then, after the construction of the joint distribution, the inverse transformation can occur. Consequently, the probability space will return to 0 to 1. And we will be able to perform all the probabilistic and statistical laws with no problems. For example:

Let A and B be independent, mutually exclusive random variables,

where,

$$P(A) = 0.9$$

and

$$P(B) = 0.8$$

The probability of the union/sum of A and B is,

$$P(A) + P(B) = 0.9 + 0.8 = 1.7$$

However, this is a statistical impossibility. To begin to solve this issue, the Independent copula will now be presented, since it is the easiest to understand.

4.5.5 Copula families

4.5.5.1 Independence copula and generating function definition

Continuing with Jordan's (2020) description, to solve this issue, the copula proposes a series of transformations and inverse transformations to solve the joint distribution and dependency problems. The most basic copula is the Independence copula. Let us begin by understanding the transformation operations that occur in the copula theory. It must be noted that for the purposes of simple exemplification, only probabilities were utilised. However, copulas are in practice always applied to two or more distributions.

For a $P(A) \in [0,1]$ and a $P(B) \in [0,1]$, a transformation occurs so that $P(A) \in [0,\infty[$ and $P(B) \in [0,\infty[$. This way, when the union/sum of the two variables is performed, $P(A) + P(B) \in [0,\infty[$ maintains true. This means that the inverse transformation is applicable. The result of this is $P(A) + P(B) \in [0,1]$.

Continuing the example with the same definitions of A and B and their respective probability. If we apply a negative natural logarithm transformation as the generator function we will be able to sum the two probabilities and arrive at a probabilistically possible outcome, this is, $P(A) + P(B) \in [0,1]$. On that account,

$$-\ln\big(P(A)\big) = -\ln\,(0.9) \approx 0.105$$

and

$$-\ln\big(P(B)\big) = -\ln\,(0.8) \approx 0.223$$

then,

$$-\ln\big(P(A)\big) + \big(-\ln\big(P(B)\big)\big) \approx 0.105 + 0.223 = 0.328$$

By applying the inverse of the negative natural logarithm transformation, we arrive at,

$$e^{-\ln(P(A))+(-\ln(P(B)))} \approx e^{-0.328} \approx 0.72$$

This is the definition of the Independent copula. (This is one of the many Archimedean Copulas that will be described in the following sub-chapters.) $C(A,B) = P(A)\times P(B)$. In this case $P(A)\times P(B) = 0.72$. This definition is similarly applied to distributions. For example, in Equation (4.5.11),

Let X and Y be two independent random variables,

$$C[H(x),H(y)] = H(x)\times H(y) \tag{4.5.11}$$

However, joint distributions can currently be obtained from multiple independent distributions (being that all the distributions must be the same type, only varying in parameters) without the application of copula. The main purpose of copulas is to obtain the joint distribution of multiple marginal distributions of any kind and parameter. For the other copulas that involve dependent marginal distributions, a correlation parameter is integrated with the generating function. For all copula families, the standard notation and mathematical definition that establishes the copula and the transformative generating functions previously explained are the following:

With *n* number of random variables $X_1,\dots,X_n$, their respective *n* continuous cumulative distribution functions $H_1\dots H_n$ there is a joint distribution function H. For this premise, there is a unique copula function C, expressed in equations (4.5.12) and (4.5.13), with domain $\mathbf{I}^n$ (Embrechts, 2009).

For $x = (x_1,\dots,x_n)^T \in \mathbb{R}^n$,

$$H(x_1,\dots,x_n) = C(H_1(x_1),\dots,H_n(x_n)) \tag{4.5.12}$$

Therefore, for $u = (u_1,\dots,u_n)^T \in \mathbf{I}^n$,

$$C(u_1,\dots,u_n) = H(H_1^{-1}(u_1),\dots,H_n^{-1}(u_n)) \tag{4.5.13}$$

Henceforth, we will analyse other copula families that are used in this thesis and their different generating functions and transformations.

4.5.5.2 Gaussian copula

The Gaussian copula is the copula counterpart of the multivariate Gaussian distribution and is derived from a similar formulation. As opposed to the standard multivariate Gaussian distribution, the Gaussian Copula can analyse non-linear dependencies between various random variables (Zeng *et al.,* 2013). This copula is part of the wider Elliptical copula family type. The Elliptical type is “the most widely used copulas in practice” (Hofert, *et al.,* 2019, pp.81), and are called elliptical because of their elliptical dependency form. It is characterised by an expanding cloud, moderate tails and two diagonal symmetry axes. Seeing as we will now be working with bivariate copulas the notation is transferred from an n^th^ dimensioned copula $C(u_1,\dots,u_n)$ to a two-dimensional copula $C^{Ga}(u,v)$. As indicated by Zeng *et al.,* (2013), if Φ is the cumulative distribution function of a univariate Normal distribution and Ψ is the bivariate Normal distribution, the bivariate Gaussian copula's formulation with parameter $\rho \in [-1,1]$ is expressed as (4.5.14).

$$C^{Ga}(u,v) = \Psi\big(\Phi^{-1}(u),\Phi^{-1}(v)\big) = \frac{1}{2\pi\sqrt{1-\rho^2}} \int_{-\infty}^{\Phi^{-1}(u)} \int_{-\infty}^{\Phi^{-1}(v)} e^{-\frac{s^2-2\rho st+t^2}{2(1-\rho^2)}} dsdt \tag{4.5.14}$$

4.5.5.3 Student's t copula

Similar to the Gaussian copula, the Student's t copula, or simply the t copula, is a derivation of the multivariate t distributions. This is the second copula family of the Elliptical family type used in this thesis. It is characterised by the absence of tails and has a strong spread in centre sections. As evidenced by Demarta and McNeil (2007), the t copula C^t formulation, where $\mathbf{t}$ is the bivariate distribution with marginal cumulative distribution functions t_1 and t_2, P is the correlation matrix and t_v is the univariate distribution function with θ degrees of freedom is written in Equation (4.5.15).

$$C^t_{\theta,P}(u,v) = t_{\theta,P}\left({t_1}^{-1}(u), {t_2}^{-1}(v)\right) = \int_{-\infty}^{t_\theta^{-1}(u)} \int_{-\infty}^{t_\theta^{-1}(v)} \frac{\Gamma(\frac{\theta+2}{2})}{\Gamma(\frac{v}{2})\sqrt{(\pi\theta)^2|P|}}(1+\frac{x'^{P^{-1}}x}{\theta})^{-\frac{\theta+2}{2}}dx \tag{4.5.15}$$

It is also noted that as $\theta \rightarrow \infty$ the copula functions like a Gaussian Copula (Pakdaman, 2011).

4.5.5.4 Clayton copula

The Clayton copula is part of the larger one-parameter Archimedean copula family. The larger one-parameter Archimedean family type also includes other one-parameter copula families such as the Gumbel, Frank and Joe copulas. They are also “popular choices for dependence models because of their simplicity and generation properties” (Chen and Guo, 2019, pp.15).

The Clayton (1978) copula has a very heavy concentration in the left tail with an expanding cloud. The copula C^C with the single parameter $\theta \in]0,+\infty[$ is defined in Equation (4.5.16).

$$C^C_\theta(u,v) = (u^{-\theta} + v^{-\theta} - 1)^{-\theta^{-1}} \tag{4.5.16}$$

As demonstrated in subchapter *4.5.4 Joint distribution and probabilistic summation problems*, for Archimedean copulas the generator function and its pseudo-inverse conducts the transformation of the probabilities.

Clayton’s generator function ϕ^C is monotone and defined in Equation (4.5.17).

$$\phi^C(t) = t^{-\theta} - 1 \tag{4.5.17}$$

4.5.5.5 Gumbel and Tawn copula

The Gumbel copula is the second one-parameter Archimedean copula used in this thesis. It has a similar left tail similar to the Gaussian copula, but its right tail is heavier. According to Chen and Guo (2019), the Gumbel copula has already “been widely used in the hydrological analysis of bivariate extreme value.” (Chen and Guo, 2019, pp.15). The copula C^G with the parameter $\theta \in [-1,+\infty[$ is defined in Equation (4.5.18).

$$C^G_\theta(u,v) = e^{-((-\ln(u))^\theta + (-\ln(v))^\theta)^{\theta^{-1}}} \tag{4.5.18}$$

And its generator function ϕ^G is expressed in Equation (4.5.19).

$$\phi^G(t) = (-\ln(t))^\theta \tag{4.5.19}$$

This thesis used another type of copula called the Tawn copula which is “an extension of the Gumbel copula with three parameters” (Cheng, Du and Ji, 2020, pp.5). This copula was introduced by

Tawn (1988). The formulation for the Tawn copula □C^{Ta} for the parameters $\theta \in [1, +\infty[$, δ_1 and $\delta_2 \in [0,1]$ and where $t = \frac{\log(v)}{\log(uv)}$ is expressed in Equation (4.5.20).

$$C^{Ta}_{\theta,\delta_1,\delta_2}(u,v) = (1-\delta_1)t - (1-\delta_2)(1-t) + \left(\left(\delta_1(1-t)\right)^{\theta} + (\delta_2 t)^{\theta}\right)^{\theta^{-1}} \tag{4.5.20}$$

4.5.5.6 Frank copula

As opposed to other one-parameter Archimedean bivariate copulas, the Frank bivariate copula is the only necessarily radially symmetric copula (Hofert *et al.,* 2019). It is characterised by its uniform cloud and absence of tails which creates a weak correlation. It has a lighter tail than the Gumbel copula. The Frank copula C^F with the parameter $\theta \in]-\infty, +\infty[$ (Chen and Guo, 2019) is defined by Equation (4.5.21).

$$C^F_\theta(u,v) = \frac{1}{\theta}\log\left(1 + \frac{(e^{\theta u}-1)(e^{\theta v}-1)}{e^{\theta}-1}\right) \tag{4.5.21}$$

Just as with the Clayton copula, for $\theta \in [0, +\infty[$ the generating function is completely monotone (Hofert *et al.*, 2019). Nonetheless, its generating function ϕ^F for $\theta \in]-\infty, +\infty[$ is defined in Equation (4.5.22).

$$\phi^F(t) = \ln\left(\frac{e^{\theta t}-1}{e^{\theta}-1}\right) \tag{4.5.22}$$

4.5.5.7 Joe copula

The fourth and final one-parameter Archimedean copula used in this thesis is the Joe copula, initially presented by Joe (1993). As indicated by Chen and Guo (2019), the copula C^J with the parameter $\theta \in [1, +\infty[$ has its mathematical formulation defined in Equation (4.5.23).

$$C^J_\theta(u,v) = 1 - \left((1-u)^{\theta} + (1+v)^{\theta} - (1-u)^{\theta}(1+v)^{\theta}\right)^{\theta^{-1}} \tag{4.5.23}$$

And its generating function ϕ^J can be defined in Equation (4.5.24).

$$\phi^J(t) = -\ln\left(1 - (1-t)^{\theta}\right) \tag{4.5.24}$$

4.5.6 Copula transformations

4.5.6.1 Mixed multi-parameter copula

The mixing of two or more copulas is possible and “the dependence structures captured by mixed copulas are not changed, even though the data is transformed into several types” (Yamaka, *et al.,* 2021, pp.4). Furthermore, according to these authors, the mixed copula is more adaptable to data and certain dependency structures than the one-parameter non-mixed copula. As indicated by (Hofert *et al.*, 2019) the following formulation defines the mixed copula C_{mix}.

For any *m* ≥ 2, let $C_1, \dots, C_m$ be nth dimensioned copulas. Then, let w be a mixing vector where $w = (w_1, \dots, w_m)$ and applied respectively to the m copulas. Additionally, $\sum_{i=1}^{m} w_i = 1$, in which $\forall i \in \{1, \dots, m\}, w_i \geq 0$ and act as a weight for the respective C_i in $C_1, \dots, C_m$. The mixing of *m* nth dimensioned copulas, this is, with marginal distributions $\boldsymbol{u}$ in $\mathbf{I}^n$, is defined by Equation (4.5.25).

$$C_{mix} = mix_w(C_1, \dots, C_m)(\boldsymbol{u}) = \sum_{i=1}^{m} w_i C_i(\boldsymbol{u}) \tag{4.5.25}$$

Yamaka *et al.*, (2021) give us the rendering of a mixed copula that originates from two nth dimensioned copulas with the parameterisation θ_1 and θ_2 which are two generic parameters for their respective copulas C_{θ_1} and $\square_{\theta_2}$. For the mixing of two copulas, he suggests the use of a single weighting variable w instead of a vector, where the weight w is applied to the first copula, then $1 - w$ is applied to the second copula. Therefore, his formulation is expressed in Equation (4.5.26).

$$C_{mix}(\boldsymbol{u}|\theta_1, \theta_2) = wC_{\theta_1}(\boldsymbol{u}|\theta_1) + (1 - w)C_{\theta_2}(\boldsymbol{u}|\theta_2) \tag{4.5.26}$$

Nonetheless, an equivalent definition for the mixing of two copulas can be with (Hofert *et al.*, 2019) notation. As a result, $w = (w_1, w_2)$ is the mixing vector and in addition the θ_1 and θ_2 parameterisation notation is kept from Yamaka *et al.* (2021) since it exemplifies how the mixing of two one-parameter copulas produces one two-parameter copula. Now, the mixing of the two copulas results in Equation (4.5.27).

$$C_{mix}(\boldsymbol{u}|\theta_1, \theta_2) = mix_w(C_1, C_2)(\boldsymbol{u}|\theta_1, \theta_2) = w_1 C_{\theta_1}(\boldsymbol{u}|\theta_1) + w_2 C_{\theta_2}(\boldsymbol{u}|\theta_2) \tag{4.5.27}$$

In this thesis, four mixed copulas were utilised. All are the outcome of the mixing of two one-parameter Archimedean copulas. This is thus translated into four two-parameter Archimedean copulas. These four mixed copulas are the result of the mixing of previously defined one-parameter copulas. Hence no further mathematical formulation is needed at this point.

The first is the Clayton-Gumbel copula (also called BB1 copula by the VineCopula package for Rstudio.) The second is the Joe-Gumbel copula (also referred to as BB6 copula by the VineCopula package for Rstudio.) The third is the Joe-Clayton copula (also named BB7 copula by the VineCopula package for Rstudio.) The fourth and final copula is the Joe-Frank copula (also labelled BB8 copula by the VineCopula package for Rstudio.)

4.5.6.2 Survival and rotated copula

The survival copula is the natural extension of the survival function and the multivariate survival function. As Hofert *et al.* (2019) indicate, if H is an *n*-dimensional distribution function, such that $H(\boldsymbol{x}) =$

$P(\boldsymbol{X} \leq \boldsymbol{x})$, with $\boldsymbol{x}$ in $\mathbb{R}^n$. Then, $\overline{H}$ is the corresponding multivariate survival function, such that $\overline{H}(\boldsymbol{x}) = P(\boldsymbol{X} > \boldsymbol{x})$, with $\boldsymbol{x}$ also in $\mathbb{R}^n$.

In keeping with standard copula notation, Hofert *et al.* (2019) continue the explanation of the survival copula with the following definitions: For a $\overline{H}$ multivariate survival function with *n* dimensions and their respective marginal distribution functions $\overline{F_1}, \ldots, \overline{F_n}$ there is a survival copula $\bar{C}$ with *n* dimensions and $\boldsymbol{x}$ in $\mathbb{R}^n$ its expression is found in Equation (4.5.28).

$$\overline{H}(\boldsymbol{x}) = \bar{C}(\overline{F_1}(x_1), \ldots, \overline{F_n}(x_n)) \tag{4.5.28}$$

Hofert *et al.* (2019) also state that a bivariate survival copula can be derived from a specific copula C with u and v in **I**, formulated in Equation (4.5.29).

$$\bar{C}(u, v) = u + v - 1 + C(1 - u, 1 - v) \tag{4.5.29}$$

Another way that statisticians have found to transforming existing copulas and allow for the best flexibility in fitting data is to rotate them to any degree. For example, the Clayton copula has a very heavy left tail, but in some circumstances, a heavy right-tailed copula is what is needed, thus the Clayton copula 180° can be rotated. For some copula families, there is no advantage in rotating copulas 180° because they are completely symmetrical or almost symmetrical. For example, the Frank Student t and Gaussian copula families. The rotation of the copulas is also used to capture negative dependencies. However, this is similar to the idea of the survival copula and in fact, it is a generalisation of the survival copula (Hofert *et al.,* 2019). The general copula rotation definition is given by Equation (4.5.30).

$$rot_r(C) \sim ((1 - r_1)U_1 + r_1(1 - U_1), \ldots, (1 - r_d)U_d + r_d(1 - U_d)) \tag{4.5.30}$$

Here, C is an nth dimensioned copula, $\boldsymbol{U} \sim C$ and **r** is in $\mathbf{I}^n$. As Hofert *et al.*, (2019, pp.118) argue, “the survival copula $\bar{C}$ of C is nothing else if not $rot_r(C)$.”

4.5.7 Kendall’s tau and copula selection criteria

Kendall’s tau, represented by τ, is a measure of rank correlation whereby it is regularly Kendall’s rank correlation coefficient (Kendall, 1938). Like other correlation coefficients, the more similar the observations are by rank the closer the coefficient is to 1. Conversely, the more in disagreement the two rankings the closer it is to -1. And if the two random variables are independent, $\tau \approx 0$. Therefore, τ is always in $[-1,1]$. As indicated by Nelsen (2001) for two random variables with n observations the formulation for τ is defined in Equation (4.5.31).

$$\tau = \frac{number\ of\ concordant\ paires - (number\ or\ discordant\ pairs}{\frac{n(n-1)}{2}} \tag{4.5.31}$$

In probabilistic terms, Hofert *et al.*, (2019) define the notion of concordance and Kendall's tau by considering two points (x, y) and (x', y') in $\mathbb{R}^2$. "There points are said to be concordant if $(x_1 - x_1{}')(x_2 - x_2{}') > 0$ (so if the slope of the line through the two points is positive) and to be discordant if $(x_1 - x_1')(x_2 - x_2') < 0$" (Hofert *et al.*, 2019, pp.52). Through this argumentation, and parallel to the previous formulation, Kendall's tau, τ, can also be defined in Equation (4.5.32).

$$\tau = P\big((X_1 - X_1')(X_2 - X_2') > 0\big) - P(((X_1 - X_1')(X_2 - X_2') < 0) \qquad (4.5.32)$$

In this thesis, τ is the coefficient used to understand the correlation between any two variables used in the copulas. As argued by Hofert *et al.* (2019), a summary of this nature, of a copula, is bounded to induce a loss of information. However, it is standard practice to use this rank correlation coefficient in the use of copulas (Chen and Guo, 2019). Furthermore, Kendall's tau can also be used to estimate the parameters of copulas through nonparametric estimation techniques.

In this work, similarly to the marginal distributions, the selection of the best fitting bivariate copula for any given two variables was through the Log-likelihood Function (LLF), Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). The formulation for these criteria has already been presented in the sub-chapter Selection criteria.

4.6 Return periods

4.6.1 Introduction

Return periods (T) are statistical measures of time that estimates the average time interval for an event to occur again. The inverse of the return period is the probability of an event exceeding the frequency of a single occurrence in the time unit of the return period. For example, if the return period of an event is 5 months, then the probability it occurs more than one time in one month is $0.2 = 1/5$. For this thesis, and in line with standard practice in hydrology and the characterising of rainfalls, the return period will always be in the time unit: years. Since this thesis is dealing essentially with annual maximum events, T will always have to be greater than one year: $T \geq 1\ year$.

In line with Espinosa *et al.*, (2019), the univariate and bivariate return periods according to the copula approach will be formulated and described in the next items.

4.6.2 Univariate return periods

Univariate return periods characterise the average time for an event to occur again. For a random variable X that characterises time series data of an event, for example, annual maximum rainfall, and its univariate cumulative distribution function F, Equation (4.6.1) defines the return period of the events in study.

$$T = \frac{E(L)}{P(X \geq x)} = \frac{E(L)}{1 - F(x)} \qquad (4.6.1)$$

Here, $E(L)$ is the expected inter-arrival period. In this thesis $E(L) = 1$ year because annual maximum events will be analysed.

4.6.3 Bivariate return periods

In line with Espinosa *et al.* (2019), the bivariate constitution of the analysis proposed within this thesis manifests bivariate results. Thus, the probabilities used for bivariate return periods all come from the results of the bivariate copulas which are all bivariate joint distributions. Two types of joint return periods can be calculated, these are the union (or) and the intersection (and) types. Which are both calculated from joint copulas. For two random variables X and Y and their respective cumulative distribution functions F_X and F_Y, their joint distribution H_{XY} and the copula C, the definition for joint, union return period $T_{X\ or\ Y}$ is written in Equation (4.6.2).

$$T_{X\ or\ Y} = \frac{E(L)}{P(X \geq \square\ or\ Y \geq y)} = \frac{E(L)}{1 - H_{XY}(x, y)} = \frac{E(L)}{1 - C(F_X(x), F_Y(y))} \tag{4.6.2}$$

The definition for joint, intersection return period $T_{X\ and\ Y}$ is defined in Equation (4.6.3).

$$T_{X\ and\ Y} = \frac{E(L)}{P(X \geq X, Y \geq Y)} = \frac{E(L)}{1 - F_X(X) - F_Y(Y) + C(F_X(x), F_Y(y))} \tag{4.6.3}$$

Furthermore, from a joint copula, the conditional return periods can also be calculated. For the same generic variables stated before, a conditional return period can be understood and calculated as X given Y $(X|Y)$ or Y given X $(Y|X)$. The definition for conditional return period or X given Y, $T_{X|Y}$ can be written in Equation (4.6.4) in relation to the univariate return period T_Y.

$$T_{X|Y} = \frac{T_Y}{P(X \geq x, Y \geq y)} \tag{4.6.4}$$

The definition for conditional return period or Y given X, $T_{Y|X}$ can be written in relation to the univariate return period T_X and is given by Equation (4.6.5).

$$T_{Y|X} = \frac{T_X}{P(X \geq x, Y \geq y)} \tag{4.6.5}$$

5 Datasets and modelling approach

5.1 Introduction

With the objective of studying rainfall and alluvium association and their return periods, a statistical approach was implemented. A hypothesis was drawn up that states that an alluvium event is associated with the rainfall event before or adjacent to it. The difficulty in this hypothesis is in how to understand the rainfall events and their related statistical characteristics (such as exceptionality given by the return periods) that impact the triggering of alluvium flood events. Thus, instead of analysing the extreme rainfall events as univariate statistical models, the in-time internal relationship of said rainfall events was addressed. In the aforementioned hypothesis, it is also defined that a simple usage of an annual maximum series, AMS, is insufficient for a good understanding of the exceptionality of a rainfall event, because annual maximum rainfall with a given duration may not account for the rainfall conditions during which the alluvium event occurred. Since alluviums are related to rainfall that occurs along time, a more meticulous understanding of the rainfall event before the alluvium and its change in time is necessary. In this definition, each rainfall event is identified by an annual maximum rainfall and by an associated cumulative rainfall prior and/or posterior to that maximum.

From this qualitative and hydrological definition, two clear variables standout for analysis. The first is the AMS and the second is its associated before or/and after cumulative rainfall series. To identify the relationship between the AMS and a cumulative series, a bivariate statistical model was used. Furthermore, this bivariate model must also have the ability to enjoin the two variables into one distribution so that in the qualitative hydrological sense the two variables can be looked at as one coupled rainfall event that can then potentially be associated with an alluvium flood event. For this purpose, the bivariate copula model was used. The bivariate copula is in essence a bivariate distribution from which joint or conditional probabilities can be calculated and allows for an understanding of a possible non-linear relationship between two variables. Therefore, using the AMS values as the defining characteristic of the rainfall event and as variable number 1, the cumulative rainfall prior and/or posterior to each annual maximum is defined as variable number 2 of the bivariate analysis.

5.2 Rainfall datasets

To build the cumulative rainfall series associated with the annual maximum three different scenarios were considered: (i) cumulative rainfall in hours or days before the annual maximum, (ii) the same for hours or days after the annual maximum and (iii) a mix of the two previous scenarios, i.e., cumulative rainfall in hours or days before and after each annual maximum. For each of the three previous scenarios, six hourly and six daily series were defined. For the cumulative hourly rainfall before each annual maximum, the first series is the sum of the AMS and the rainfall in one hour before the annual maximum. The second series is the sum of the AMS and the rainfall in one and two hours before the annual maximum. The third series is the sum of the AMS and the rainfall in one, two and three hours before the annual maximum. The other three series of the cumulative hourly rainfall before are the continuation of this process, i.e., are the sum of the AMS and the rainfall up to four, five and six hours before. For the different sets of cumulative daily rainfall before each annual maximum, the logic is equivalent, however, replacing the sum of the cumulative rainfall in one to six previous hours by one to six previous days. The other two sets of cumulative hourly/daily rainfall are made from the summation of rainfall after the annual maximum and cumulative hourly/daily before and after (surrounding) the annual maximum. The cumulative hourly/daily rainfall after also has 6 series, but for the rainfall in subsequent hours and days to the annual maximum. The cumulative hourly/daily rainfall before and after is the sum of each of the corresponding series of the other two types. For example, the first hourly rainfall before and after series would be the sum of the AMS hourly rainfall with the rainfall 1 hour before and 1 hour after such AMS value. The same applies to the cumulative of days after and days before. Figure 1 depicts how the cumulative rainfall series were built. It should be stressed that when working at the hourly level, the AMS series relates to hourly rainfalls (Δt = 1h), while at the daily level relates to daily rainfalls (Δt = 1day).

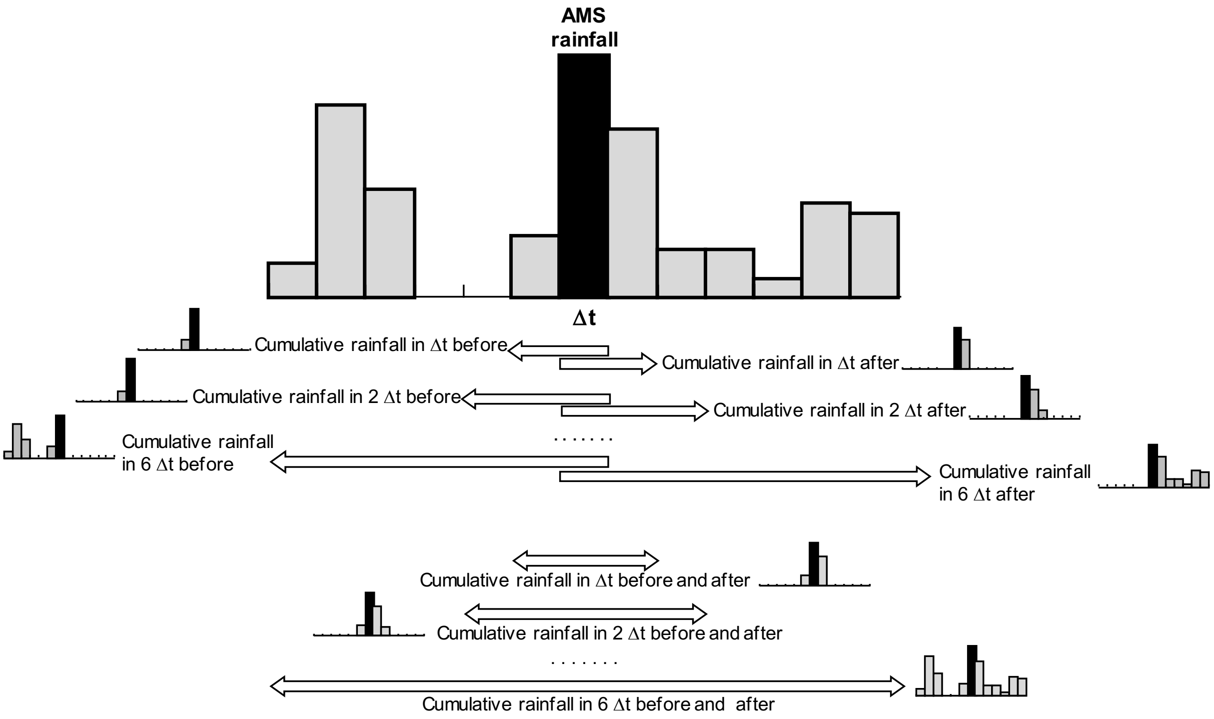


Figure 1 – Schematic representation of the procedure of creating coupled AMS rainfalls and cumulative rainfalls in contiguous time steps with duration Δt (Δt is equal to one hour or one day in association with hourly AMS or daily AMS, respectively).

The understanding of these datasets can also be described in terms of mathematical formulation. Let X_0 designate the annual maximum series and X_n^B the cumulative hourly or daily rainfall before the yearly maximum, where the superscript “B” indicates that the cumulative series is composed of hourly or daily rainfall measurements before the annual maximum and the subscript “n” refers to the number of hours or days considered before the annual maximum. The cumulative hourly or daily rainfall series after each yearly maximum uses an equivalent representation, i.e., X_n^A, where “A” indicates that the cumulative series is composed of hourly or daily rainfall measurements after the annual maximum and the subscript “n” refers to the number of hours or days considered after the annual maximum. Finally, the cumulative rainfall for n hours/days surrounding the yearly maximum was designated as X_n^{BA}.

Mathematically these series can be defined by the equations (5.2.1) to (5.2.3), where the index i refers to the rainfalls in consecutive time steps i Δt(s), with Δt equal to 1 hour or 1 day, respectively for hourly and daily AMS series, a mathematical rendering of the schematic represented in Figure 1.

$$X_n^B = X_0 + \sum_{i=1}^{n} Prior/Before\ rainfall_i \tag{5.2.1}$$

$$X_n^A = X_0 + \sum_{i=1}^{n} Posterior/After\ rainfall_i \tag{5.2.2}$$

$$X_n^{BA} = \square_0 + \sum_{i=1}^{n} Prior/Before\ rainfall_i + Posterior/After\ rainfall_i \tag{5.2.3}$$

Table 6 presents the series of X_0, X_n^B, X_n^A and X_n^{BA} for the hourly rainfall data for the thirty-four hydrological years. For the AMS values (X_0) and the date and hour of their measurement. The daily rainfall data's equivalent table is presented in Annex II.

Table 6 - Hourly rainfall, from 1980/1981 to 2013/2014 (34 years). Δt = 1 h. Date of the hourly maximum rainfall and values X_0, X_n^B, X_n^A and X_n^{BA} (mm).

Date of X_0	Hour of X_0	X_0	X^B_1	X^B_2	X^B_3	X^B_4	X^B_5	X^B_6	X^A_1	X^A_2	X^A_3	X^A_4	X^A_5	X^A_6	X^{BA}_1	X^{BA}_2	X^{BA}_3	X^{BA}_4	X^{BA}_5	X^{BA}_6
11/11/1980	08:00	11.4	13.1	13.1	13.4	13.4	13.4	13.4	19.0	19.0	19.2	19.2	20.0	20.0	20.7	20.7	21.2	21.2	22.0	22.0
21/11/1981	12:00	16.2	22.3	24.4	25.5	25.5	25.5	25.5	20.5	22.1	22.2	22.2	22.2	22.2	26.6	30.3	31.5	31.5	31.5	31.5
23/09/1983	20:00	10.9	14.6	14.6	14.6	14.6	14.6	14.6	11.6	11.7	11.7	11.7	11.7	11.7	15.3	15.4	15.4	15.4	15.4	15.4
21/09/1984	23:00	22.0	22.0	22.0	22.0	22.0	22.0	22.0	28.5	31.7	34.7	34.7	35.5	46.7	28.5	31.7	34.7	34.7	35.5	46.7
06/01/1985	08:00	24.7	38.3	42.8	43.3	43.3	43.3	43.3	36.9	37.0	37.0	37.2	37.2	37.2	50.5	55.1	55.6	55.8	55.8	55.8
23/10/1985	01:00	28.6	33.5	33.5	33.5	33.5	33.5	33.5	32.6	32.6	32.6	32.6	34.2	37.6	37.5	37.5	37.5	37.5	39.1	42.5
22/01/1987	22:00	18.5	33.3	35.1	35.5	36.1	36.3	36.3	23.0	24.7	38.0	55.9	62.5	63.1	37.8	41.3	55.0	73.5	80.3	80.9
24/10/1987	12:00	14.4	17.8	21.1	21.8	21.8	21.8	21.8	18.0	25.2	35.0	39.8	46.5	50.1	21.4	31.9	42.4	47.2	53.9	57.5
26/09/1989	00:00	29.4	29.4	29.4	29.4	29.4	29.4	29.4	47.0	70.1	88.3	92.6	92.6	96.5	47.0	70.1	88.3	92.6	92.6	96.5
18/09/1990	14:00	37.7	37.7	37.7	37.7	37.7	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.9	37.9
08/12/1990	01:00	31.0	40.2	40.2	40.2	40.2	40.2	40.2	32.0	33.9	33.9	35.0	36.6	36.6	41.2	43.1	43.1	44.2	45.8	45.8
29/10/1991	11:00	25.4	41.8	41.8	41.8	49.0	49.0	49.0	28.1	28.1	28.1	28.1	28.1	28.1	44.5	44.5	44.5	51.7	51.7	51.7
09/05/1993	10:00	18.6	19.8	20.2	35.0	48.0	54.3	55.6	18.7	21.6	21.6	24.6	24.6	24.6	19.9	23.2	38.0	54.0	60.3	61.6
29/10/1993	03:00	29.8	33.4	40.0	47.7	57.1	62.3	64.4	29.8	30.8	31.0	31.1	31.3	31.7	33.4	41.0	48.9	58.4	63.8	66.3
07/10/1994	16:00	10.9	14.5	14.8	14.8	14.8	14.9	14.9	20.0	29.2	36.4	41.4	44.1	44.8	23.6	33.1	40.3	45.3	48.1	48.8
22/03/1996	13:00	32.5	37.8	37.9	38.0	38.4	38.4	38.4	32.5	32.5	32.5	32.5	32.5	32.5	37.8	37.9	38.0	38.4	38.4	38.4
19/03/1997	05:00	15.9	15.9	15.9	15.9	15.9	15.9	15.9	18.2	24.9	25.5	25.5	25.5	26.0	18.2	24.9	25.5	25.5	25.5	26.0
01/02/1998	03:00	28.7	32.1	33.0	35.4	37.6	37.6	37.8	46.7	49.8	50.1	50.1	50.2	51.8	50.1	54.1	56.8	59.0	59.1	60.9
05/11/1998	21:00	11.9	19.2	20.1	20.1	20.1	20.1	20.1	21.3	21.4	21.4	21.4	21.4	21.4	28.6	29.6	29.6	29.6	29.6	29.6
10/10/1999	03:00	26.5	39.8	39.8	39.8	39.8	39.8	39.8	26.5	26.5	26.5	26.7	26.7	26.7	39.8	39.8	39.8	40.0	40.0	40.0
18/12/2000	23:00	20.4	21.6	21.7	21.7	21.7	21.7	21.7	28.5	30.0	34.8	35.8	35.9	36.1	29.7	31.3	36.1	37.1	37.2	37.4
18/11/2001	13:00	20.6	35.8	51.8	56.0	58.6	58.8	58.8	21.6	22.5	22.6	22.7	22.7	22.7	36.8	53.7	58.0	60.7	60.9	60.9
24/11/2002	14:00	29.9	44.1	50.6	51.9	53.0	53.8	53.9	45.4	52.9	54.1	54.1	54.1	54.1	59.6	73.6	76.1	77.2	78.0	78.1
10/10/2003	23:00	18.4	21.8	21.8	21.8	25.1	25.1	25.1	25.0	25.1	25.1	25.1	25.1	25.1	28.4	28.5	28.5	31.8	31.8	31.8
17/10/2004	00:00	21.4	31.2	34.4	35.3	36.2	40.5	45.1	21.5	21.7	21.7	21.7	23.0	29.2	31.3	34.7	35.6	36.5	42.1	52.9
24/01/2006	10:00	15.5	16.7	16.7	16.7	16.7	16.7	16.7	16.9	17.5	17.8	22.8	22.8	22.8	18.1	18.7	19.0	24.0	24.0	24.0
07/04/2007	22:00	22.1	22.5	22.5	22.5	23.1	32.5	38.3	40.8	40.8	40.8	40.9	40.9	40.9	41.2	41.2	41.2	41.9	51.3	57.1
08/04/2008	09:00	41.4	45.6	46.1	46.9	47.0	47.6	55.8	42.9	42.9	42.9	42.9	43.4	66.1	47.1	47.6	48.4	48.5	49.6	80.5
26/12/2008	22:00	17.2	22.5	22.7	24.2	24.9	24.9	24.9	20.7	20.7	21.3	24.0	31.1	34.2	26.0	26.2	28.3	31.7	38.8	41.9
20/02/2010	10:00	51.2	80.2	91.0	96.3	98.8	101.5	102.8	62.3	71.6	73.8	75.1	78.0	89.5	91.3	111.4	118.9	122.7	128.3	141.1
25/11/2010	14:00	37.3	46.7	47.6	47.6	47.6	47.6	47.6	39.0	44.2	46.9	58.1	61.4	81.6	48.4	54.5	57.2	68.4	71.7	91.9
23/10/2011	23:00	10.2	13.8	14.1	14.1	14.1	14.3	14.4	18.5	23.3	23.7	23.7	24.6	24.7	22.1	27.2	27.6	27.6	28.7	28.9
25/11/2012	01:00	21.5	27.9	38.1	45.7	50.9	55.5	57.3	21.6	24.4	30.3	30.4	30.6	30.8	28.0	41.0	54.5	59.8	64.6	66.6
18/10/2013	14:00	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7

Based on the rainfall datasets presented in Table 6 and Annex II, eighteen copulas were tested for each time level (hourly or daily), adding to a total of thirty-six copulas used for analysis in this thesis. Each of the two sets of eighteen copulas can be subdivided with respect to the before, after and before and after analyses: six copulas containing the six series of cumulative rainfall before the annual maximum, six copulas containing the six series of cumulative rainfall after the annual maximum and six copulas containing the six of series cumulative rainfall before and after the annual maximum. This sums up to eighteen copulas for the hourly rainfall analysis and eighteen copulas for the daily rainfall analysis.

The exact establishment of the copulas and their variables are thoroughly explained in the next two subchapters – *5.3 Marginal distribution type and parameter estimation and selection* and *5.4 Copula parameter estimation and selection*. Subsequently. Return periods for each coupled rainfall event can be calculated from the bivariate probability distribution given by the respective copula and the various series previously presented. This provides a measure of the exceptionality for the coupled rainfall event and its possibly associated alluvium event that - according to the criteria and information previously summarised chapter *3 Data* and in Tables 1, 2 and 3.

5.3 Marginal distribution type and parameter estimation and selection

As previously mentioned, to suitably analyse the extreme rainfall events, a bivariate copula approach was applied, where one of the two variables always represents the hourly or daily AMS rainfall and the other variable represents one of the various hourly or daily cumulative rainfall series.

To use the copulas, it is first necessary to ensure that the coupled variables are random. In the application carried out in this thesis, this constraint is naturally assumed, because the series under consideration are annual series referred to as the hydrological year (either the AMS series or the cumulative series in association with the AMS series). The use of copulas also requires that the variables being associated should not be independent and should possess some correlation. The scatterplots of Figure 2 show the apparent strong correlation that exists between two series considered in the figure – AMS rainfall, X_0, and the cumulative rainfall of 1 hour before, $\mathrm{X}_1^{\mathrm{B}}$, with hourly rainfall (on the left side) and daily rainfall (on the right side). The correlations seen in Figure 2 are representative of all the associations between the hourly and daily AMS and the respective hourly and daily cumulative series.

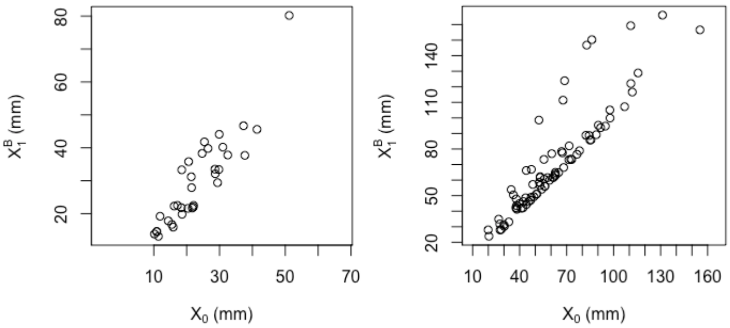


Figure 2: Scatter plot of daily (right) and hourly (left) X_0 with $\mathrm{X}_1^{\mathrm{B}}$

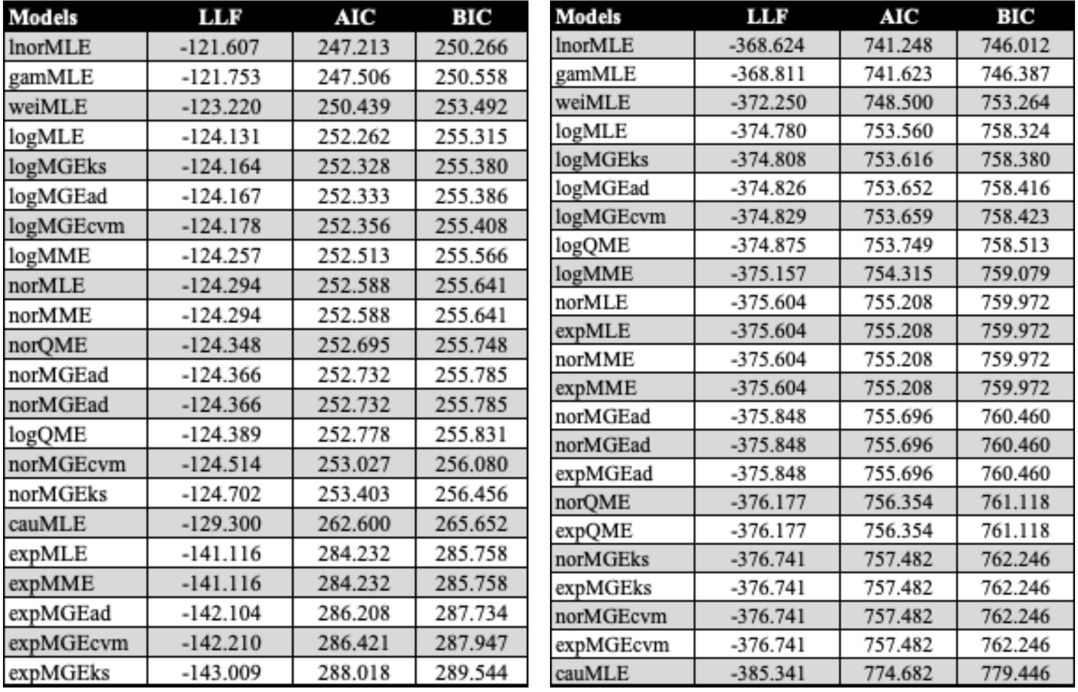
Noticeably, the plotted points are always above a fictitious 45° diagonal line. This is because, for any point, its $\mathrm{X}_1^{\mathrm{B}}$ (y-axis) value is always equal or larger to its corresponding X_0 (x-axis) value, since the cumulative series (y-axis) will always include the annual maximum – See equations (5.2.1) to (5.2.3).

The second step to use copula modelling is to have continuous marginal distributions fit the series previously defined in subchapters *3.1 Rainfall data* and *5.2 Rainfall datasets* and their calculated values presented in Table 6 and Annex II. Marginal distributions are defined as univariate probability density functions and are used to calculate the copula. As defined in subchapter *4.3 Fitting methods*, to fit these series, the Maximum Likelihood Estimation method, the Moment Matching Estimation method, Quantile Matching Method (quantiles set at 0.25 and 0.75) and finally the Maximum Goodness-Of-Fit Estimation method were used. For each of the estimation methods used, the various distributions were tested and, as defined in subchapter *4.4 Selection criteria*, the relative fitting quality was compared using Log-Likelihood Function (LLF), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Then, by ordering these different distributions based on the referred criteria, the best marginal distribution was selected for use in the copulas. As defined in chapter *4.2 Marginal distributions*, the different fitting methods used in the analysis were as follows:

- Maximum Likelihood Estimation (MLE): Normal (nor); Gamma (gam); Weibull (wei); Exponential (exp); Cauchy (cau); Logistic (log); and Lognormal (lnor).
- Moment Matching Estimation (MME: Normal (nor); Exponential (exp) and Logistic (log).
- Quantile Matching Estimation (QME): Normal (nor) and Logistic (log).
- Moment Goodness-of-fit Estimation (MGE) with Cramer-Von Mises (cvm), Kolmogorov-Smirnov (ks) and Anderson-Darling (ad) distances: Normal (nor), Exponential (exp) and Logistic (log).

Table 7 contains the identification of the fitted marginal distributions and their relative fitting quality value for the hourly AMS on the left and the daily AMS on the right. As previously mentioned, for the selection of the marginal distributions functions, the values for the LLF, AIC and BIC tests always represent the relative quality of fitting within their respective test for each marginal distribution estimation. This is, the tests indicate if a distribution is better fitted to the series than another distribution. But, it does not demonstrate that that distribution is sufficiently well fitted in an absolute perspective.

Table 7 – Marginal distribution fitting for hourly and daily X_0 (AMS): LLF, AIC and BIC criteria. On the left side, for hourly rainfalls and on the right side, for daily rainfalls. Rank-ordered by AIC form best to worst fitting.

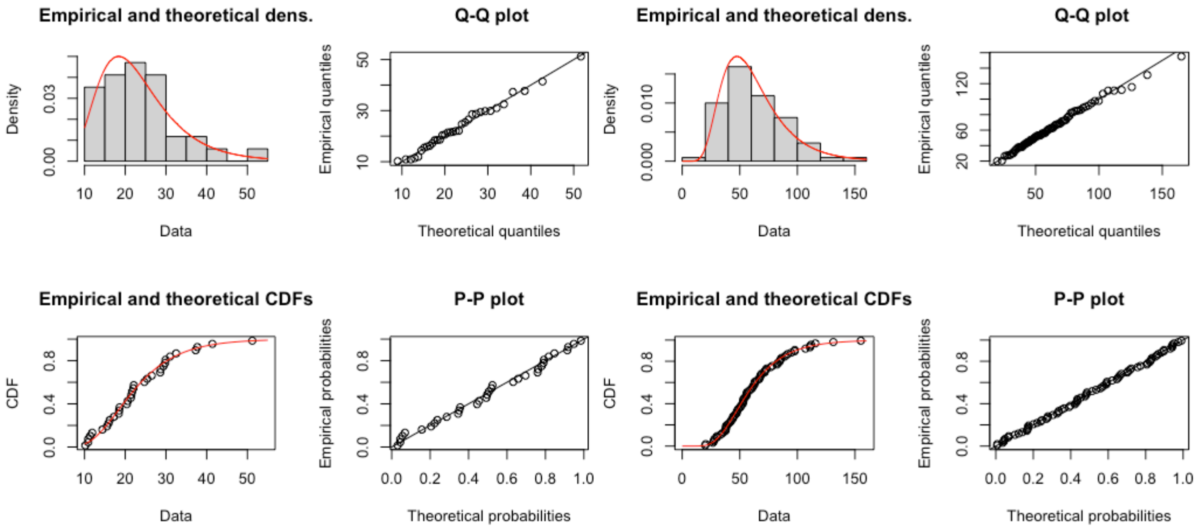


Models	LLF	AIC	BIC
lnorMLE	-121.607	247.213	250.266
gamMLE	-121.753	247.506	250.558
weiMLE	-123.220	250.439	253.492
logMLE	-124.131	252.262	255.315
logMGEks	-124.164	252.328	255.380
logMGEad	-124.167	252.333	255.386
logMGEcvm	-124.178	252.356	255.408
logMME	-124.257	252.513	255.566
norMLE	-124.294	252.588	255.641
norMME	-124.294	252.588	255.641
norQME	-124.348	252.695	255.748
norMGEad	-124.366	252.732	255.785
norMGEad	-124.366	252.732	255.785
logQME	-124.389	252.778	255.831
norMGEcvm	-124.514	253.027	256.080
norMGEks	-124.702	253.403	256.456
cauMLE	-129.300	262.600	265.652
expMLE	-141.116	284.232	285.758
expMME	-141.116	284.232	285.758
expMGEad	-142.104	286.208	287.734
expMGEcvm	-142.210	286.421	287.947
expMGEks	-143.009	288.018	289.544

Models	LLF	AIC	BIC
lnorMLE	-368.624	741.248	746.012
gamMLE	-368.811	741.623	746.387
weiMLE	-372.250	748.500	753.264
logMLE	-374.780	753.560	758.324
logMGEks	-374.808	753.616	758.380
logMGEad	-374.826	753.652	758.416
logMGEcvm	-374.829	753.659	758.423
logQME	-374.875	753.749	758.513
logMME	-375.157	754.315	759.079
norMLE	-375.604	755.208	759.972
expMLE	-375.604	755.208	759.972
norMME	-375.604	755.208	759.972
expMME	-375.604	755.208	759.972
norMGEad	-375.848	755.696	760.460
norMGEad	-375.848	755.696	760.460
expMGEad	-375.848	755.696	760.460
norQME	-376.177	756.354	761.118
expQME	-376.177	756.354	761.118
norMGEks	-376.741	757.482	762.246
expMGEks	-376.741	757.482	762.246
norMGEcvm	-376.741	757.482	762.246
expMGEcvm	-376.741	757.482	762.246
cauMLE	-385.341	774.682	779.446

Note: lnor – log normal or Galton distribution; gam – gamma distribution; wei – Weibull distribution; log – Logistic distribution; cau – Cauchy distribution; exp – Exponential distribution; MLE – maximum likelihood estimator; MGEks – maximum goodness of fit by Kolmogorov-Smirnov; MGEad – maximum goodness of fit by Anderson-Darling; MGEcvm – maximum goodness of fit by Cramer-Von Mises; MME – moment matching estimation; QME – quantile matching method.

The graphs in Figure 3 exemplify the performance of the selected distributions fit the data series in the absolute sense, which is based on the empirical and theoretical densities and cumulative distribution functions and Q-Q and P-P plots for the hourly and daily AMS fitted data. This good fitting is representative of all the distributions used fitted and selected for the copula analysis.



a) Hourly AMS (34 values)

b) Daily AMS (80 values)

Figure 3 – Four graphs on the left and the four on the right are for the hourly and daily X_0 (AMS) best fitted marginal distribution (log normal distribution) respectively.

5.4 Copula parameter estimation and selection

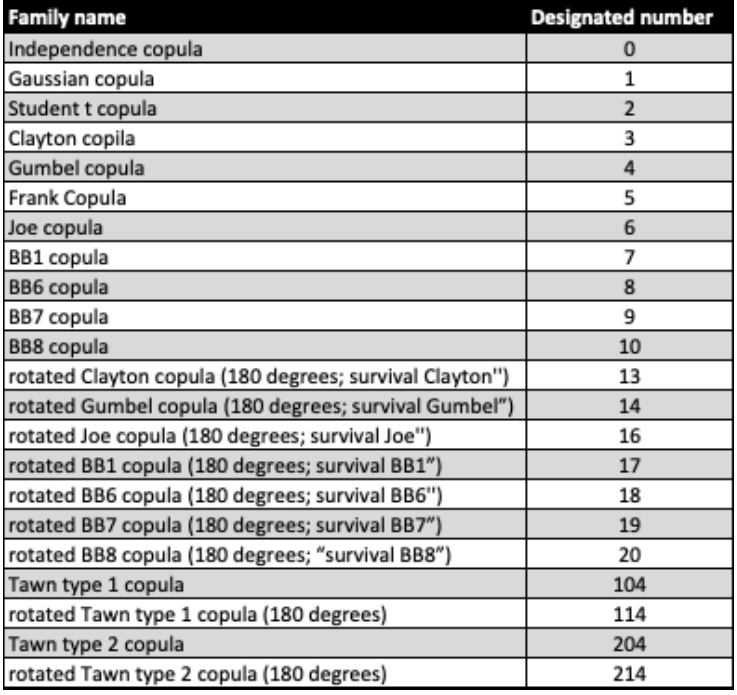
After all the marginal models were fitted to the series, tested and the best selected, each series has its values reduced according to the distribution that best fitted it. These reduced series are what constitute the two variables of the copula. Whilst the original rainfall series (*X*) have units (mm), the reduced rainfall series are dimensionless and are represented with the variable U. For example, the hourly and daily X_0 was reduced to U_0, according to the best-fitted distribution - in this case, presented in Table 7. For the U notation, the accompanying subscripts and superscripts remain the same as the X notation. “Before”, “After” and “Before and After” are respectively represented by B, A and BA. The numbers in subscript also represent the cumulative hours or days from the annual maximum, where 0 in U_0 continues to represent that this series is of the annual maximum rainfall, i.e. the reduced AMS. For explanation purposes, some random examples will now be presented: X_3^B is reduced to U_3^B, X_2^A to U_2^A, X_6^{BA} to U_6^{BA}. As previously stated, each reduction is done according to the respective best-fitted distribution and its location and scale parameters (or any other parameters the distribution might have).

Once all the reduced series were calculated, the copulas were modelled. In the case of this study, two variables are compared, AMS and a cumulative series. Therefore, as previously mentioned, the bivariate copula estimation results in eighteen hourly copulas and eighteen daily copulas. For this, different copula types also had to be compared, tested and selected. The selected copulas were then studied for nonlinear correlations and return periods.

For the bivariate analysis, the nomenclature and numbering of the copulas tested using the “VineCopula” package (https://cran.r-project.org/web/packages/VineCopula/) are presented in Table 8.

The table identifies the family and identification number, as provided by the R package. The copula families are defined in subchapter *4.5 Copulas*.

Table 8 – Copula family name and assigned identification number.



Family name	Designated number
Independence copula	0
Gaussian copula	1
Student t copula	2
Clayton copila	3
Gumbel copula	4
Frank Copula	5
Joe copula	6
BB1 copula	7
BB6 copula	8
BB7 copula	9
BB8 copula	10
rotated Clayton copula (180 degrees; survival Clayton'')	13
rotated Gumbel copula (180 degrees; survival Gumbel")	14
rotated Joe copula (180 degrees; survival Joe'')	16
rotated BB1 copula (180 degrees; survival BB1")	17
rotated BB6 copula (180 degrees; survival BB6'')	18
rotated BB7 copula (180 degrees; survival BB7")	19
rotated BB8 copula (180 degrees; "survival BB8")	20
Tawn type 1 copula	104
rotated Tawn type 1 copula (180 degrees)	114
Tawn type 2 copula	204
rotated Tawn type 2 copula (180 degrees)	214

The bivariate copulas, totalling thirty-six for each of the twenty-two families were composed of two reduced marginal distributions, one of the variables was always U_0 which is combined with the second variable which takes up any of the U_n^m reduced marginal distributions, where n ∈ {1, 2, 3, 4, 5, 6} and m is an indicator of if the series represents cumulative series of rainfalls before (B), after (A) or simultaneously before and after (BA) the annual maximum. This is done both for the hourly and daily analysis.

Once all the copulas were calculated, three estimators (LLF, AIC and BIC) were applied to compare the relative quality of the fitted family in much the same way as for the analyses of the marginal distributions. This was performed for each bivariate combination. Table 9 presents two examples of this ordering. An example for the hourly data and another for the daily. The best-fitting copula family is selected for further study.

Once these tests are done with every twenty-two (number of families tested) for each of the thirty-six variable combinations and the best is selected - in the cases of Table 9 the Gaussian and the rotated Tawn type 1 copula, thirty-six selected copulas. One for each of the thirty-six cases that have been constantly mentioned throughout this chapter. Furthermore, every copula also has its estimated parameters (Parameter 1, Parameter 2 and Kendall's tau – "τ") and are laid out in Table 10. Notably, as defined in item *4.5.7 Kendall's tau and copula selection criteria*, Kendall's tau – "τ" is a value for correlation between the copula's variables.

Table 9 – Copula fitting: likelihood, AIC and BIC criteria. On the left side, for hourly rainfalls and on the right side, for daily rainfalls. Rank-ordered by AIC from best fitting to worst.

family	logLik	AIC	BIC
1	30.42	-58.84	-57.31
2	30.22	-56.45	-53.39
14	29.09	-56.18	-54.65
7	29.86	-55.73	-52.67
17	29.85	-55.7	-52.64
19	29.65	-55.3	-52.24
9	29.59	-55.18	-52.13
18	29.09	-54.17	-51.12
114	28.17	-52.35	-49.30
4	26.83	-51.66	-50.14
214	27.76	-51.52	-48.47
8	26.83	-49.66	-46.61
3	25.58	-49.15	-47.63
5	25.43	-48.86	-47.33
16	25.14	-48.29	-46.76
204	25.96	-47.93	-44.87
20	25.88	-47.75	-44.7
104	25.45	-46.89	-43.84
10	24.17	-44.35	-41.29
13	22.48	-42.96	-41.44
6	21.85	-41.71	-40.18
0	0	0	0

family	LogLikelihood	AIC	BIC
114	96.93	-189.86	-185.10
204	89.66	-175.32	-170.56
14	85.47	-168.95	-166.57
17	85.72	-167.44	-162.68
18	85.47	-166.94	-162.18
214	84.73	-165.46	-160.70
7	84.61	-165.23	-160.46
2	84.51	-165.03	-160.27
1	82.35	-162.71	-160.33
5	82.06	-162.13	-159.75
19	81.71	-159.42	-154.66
20	81.54	-159.08	-154.32
9	78.91	-153.83	-149.06
3	76.50	-151.01	-148.63
16	76.39	-150.77	-148.39
4	74.67	-147.34	-144.96
8	74.66	-145.32	-140.55
104	73.94	-143.88	-139.11
10	67.00	-129.99	-125.23
13	56.69	-111.39	-109.01
6	56.49	-110.97	-108.59
0	0.00	0.00	0.00

Note: On the left, hourly bivariate copula combination of U_0 and U_1^B reduced series. On the right, daily bivariate copula combination of U_0 and U_1^B reduced series.

Table 10 – Parameters and Kendell's tau for each of the 18 selected copulas for hourly data on the left and 18 selected copulas for hourly data on the right. Each selected copula represents a combination of two reduced marginal distributions, the Hours/Days column indicates the extent of the collected rainfall of prior, posterior or both, which is indicated in Figure 1.

	Hours	Family	Parameter 1	Parameter 2	τ
Prior rainfall	1	1	0.91	-	0.73
	2	1	0.87	-	0.67
	3	9	1.86	2.45	0.60
	4	9	1.65	2.38	0.58
	5	9	1.56	2.39	0.58
	6	9	1.65	2.34	0.58
Posterior rainfall	1	1	0.86	-	0.66
	2	5	7.22	-	0.57
	3	1	0.68	-	0.47
	4	114	2.45	0.62	0.42
	5	114	2.38	0.59	0.39
	6	1	0.63	-	0.43
Prior & posterior rainfall	1	1	0.82	-	0.62
	2	1	0.75	-	0.54
	3	1	0.68	-	0.48
	4	1	0.64	-	0.44
	5	1	0.61	-	0.42
	6	4	1.83	-	0.45

	Days	Family	Parameter 1	Parameter 2	τ
Prior rainfall	1	114	9.93	0.81	0.74
	2	114	9.03	0.74	0.67
	3	4	2.81	-	0.64
	4	114	3.00	0.82	0.58
	5	14	2.32	-	0.57
	6	14	2.05	-	0.51
Posterior rainfall	1	114	9.49	0.76	0.70
	2	114	4.23	0.80	0.64
	3	1	0.86	-	0.66
	4	1	0.84	-	0.64
	5	1	0.85	-	0.65
	6	1	0.84	-	0.64
Prior & posterior rainfall	1	114	5.92	0.72	0.63
	2	114	3.72	0.73	0.57
	3	14	2.31	-	0.57
	4	14	2.18	-	0.54
	5	1	0.77	-	0.56
	6	14	1.95	-	0.49

6 Results

6.1 Copulas

As explained in the previous chapter, each copula addresses association between two variables - an hourly or daily annual maximum series and one of the eighteen hourly or eighteen daily cumulative series – in terms of their joint probability density function. Depending on the selected family of copula and its estimated parameters, some descriptive information can be obtained about the association of the two variables in the bivariate analysis. Because of the non-linear nature of copulas, the correlation between the variables that constitute a certain copula can be also analysed with a non-linear perspective.

The following two graphs of Figure 4 show the joint probability density function of the occurrence of the yearly hourly maximum rainfall and the rainfall of the sum of the yearly hourly maximum rainfall and the rainfall of the previous hour of said AMS. For legibility reasons, the axes of the graph on the left, the contour graph, are normalised. And on the right, the 3-dimensional perspective of the probability density function of the same copula, with non-normalised axes.

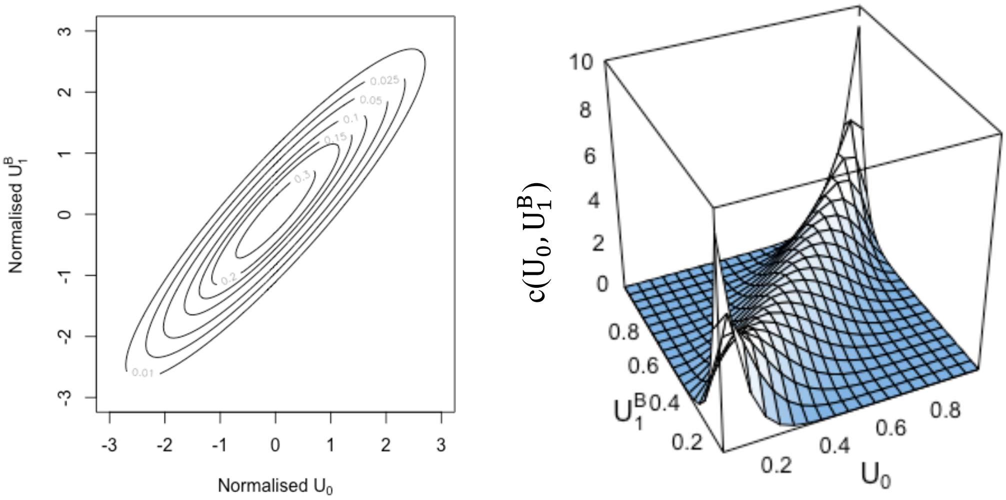
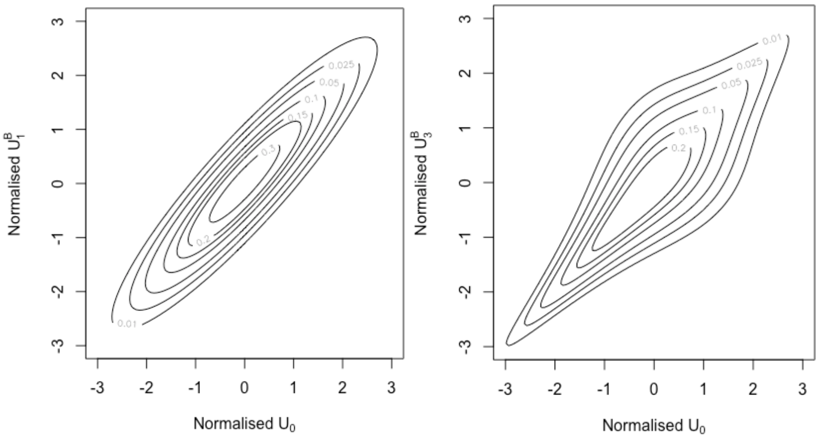
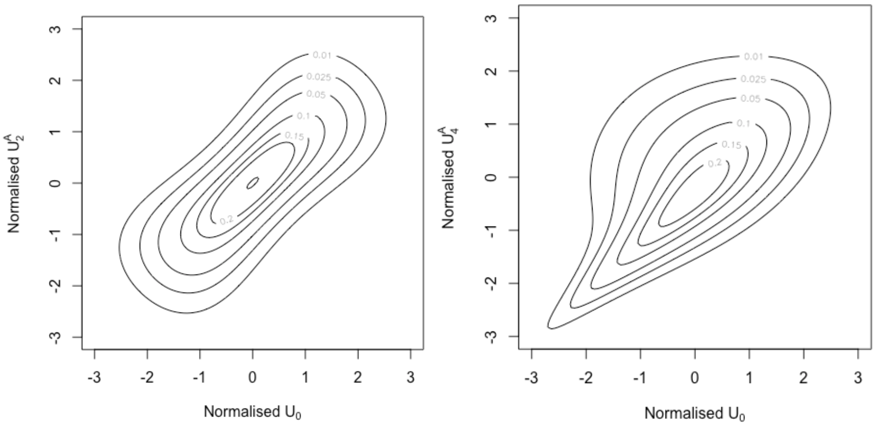


Figure 4 – Contour graph (left side) of the probability density function of hourly AMS and cumulative of one hour before (U_0 - U_1^B) copula, with normalised axes; and same copula (right side) with non-normalised axes.

Both these two types of graphs can be obtained for every copula that was calculated. However, this not being the necessary object of this thesis, only a representative batch is presented in Figure 5. This figure indicates the joint probability density function (copula) of the occurrence of the yearly hourly maximum rainfall and a cumulative rainfall series. For legibility reasons, the axes of the six contour graphs are normalised. These graphs are also representative of all the contour graphs produced by the other copulas fittings. The graphs in Figure 5 are respectively an example of the (a)&(e) Gaussian, (b) Joe - Clayton, (c) Frank, (d) rotated Tawn type 1, (f) Gumbel copulas.

In this figure, U_n^B U_n^A U_n^{BA} are the reduced cumulative rainfall in n hours before the annual maximum. A qualitative analysis of the contour graphs produced by looking at the correlation between the two variables can now be made. In Figure 5 the six copulas have their contours plotted with normalised axes.


a) U_0 - U_1^B copula b) U_0 - U_3^B copula


c) U_0 - U_2^A copula d) U_0 - U_4^A copula

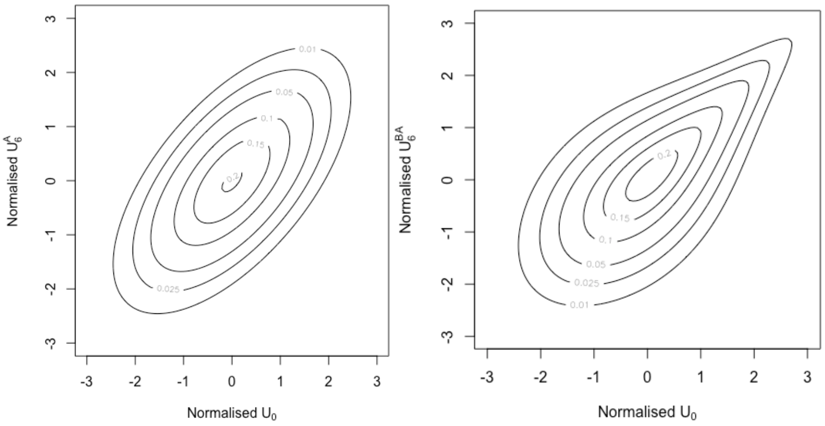

e) U_0 - U_6^A copula f) U_0 - U_6^{BA} copula

Figure 5 – Six contour graphs of the six different copulas with x-axis variable as the hourly reduced AMS; the y-axis variable of graph (a) is the cumulative of one hour before the annual maximum (U_0 - U_1^B copula); graph (b) is the cumulative of three hours before (U_0 - U_3^B copula); graph (c) is the cumulative of two hours after (U_0 - U_2^A copula)); graph (d) is the cumulative of four hours after (U_0 - U_4^A copula)); graph (e) is the cumulative of six hours after (U_0 - U_6^A copula)); graph (b) is the cumulative of three hours before (U_0 - U_6^{BA} copula). All axes are normalised.

In the figure above, the six families of copulas used in this thesis are represented graphically. A qualitative analysis of the contour graphs produced by looking at the correlation between the two variables can now be made. For example, graph (a) shows a close to equal medium-to-strong correlation along all the spectrum of values. This is characterised by its thin oval shape. Whereas graph (e) has little correlation for all values, though it is the Gaussian copula, same as in graph (a), it has a different parameter. Graph (b) shows a stronger correlation between the extreme values of rainfall, especially for low values of rainfall. For "average" values of rainfall, there is less of a correlation. This means that when the AMS presents higher values the cumulative rainfall of hours before are likely to be high too. However, when it presents "average" or more common values, we have less of an idea of what the cumulative values are. This analysis can be made for the other graphs, where the closer the contour lines are, the higher the correlation. These types of dependencies can reveal interesting information about the data.

Essential to this thesis is the calculation of joint and conditional return period values. These can be calculated directly from the copulas. Next, the notable rainfalls that are linked with alluviums can be associated with their respective return periods. This is discussed in the next subchapter.

6.2 Return periods

6.2.1 Introduction

As mentioned, this work addresses bivariate copula and return periods of hydrological variables. Therefore, once return periods of the bivariate rainfall associations are obtained, there is sufficient data to have a substantive association of the rainfall events with the recorded alluvium events.

The bivariate return periods are a continuation of the same systematics used in the copula analysis, this is, joint analyses of two types of statistical series. The first always being the hourly or daily AMS and the second being one of the hourly or daily cumulative series already described in equations (5.2.1), (5.2.2) and (5.2.3) and in Figure 1.

Four types of return periods were calculated. With this large variety of types, a vaster understanding of the events may be achieved. The four types are "or", "and", "X knowing Y" and "Y knowing X". The formulae found from equations (6.2.1) to (6.2.12) are this thesis' applied versions of the formulae found in equations (4.6.2) to (4.6.5).

Equations (6.2.1), (6.2.2) and (6.2.3) are the formulae for the calculation of "or" joint return periods expressing the return period of either the annual maximum (or greater) happening or the associated (prior, posterior, and prior and posterior) cumulative series (or greater) happening.

$$T_{X_0\ or\ X_n^B} = \frac{E(L)}{P(X_0 \geq x_0\ or\ X_n^B \geq x_n^B)} = \frac{E(L)}{1 - F_{X_0\ X_n^B}(x_0, x_n^B)} = \frac{E(L)}{1 - C(F_{X_0}(x_0), F_{X_n^B}(x_n^B))} \tag{6.2.1}$$

$$T_{X_0\ or\ X_n^A} = \frac{E(L)}{P(X_0 \geq x_0\ or\ X_n^A \geq x_n^A)} = \frac{E(L)}{1 - F_{X_0 X_n^A}(x_0, x_n^A)} = \frac{E(L)}{1 - C(F_{X_0}(x_0), F_{X_n^A}(x_n^A))} \tag{6.2.2}$$

$$T_{X_0\ or\ X_n^{BA}} = \frac{E(L)}{P(X_0 \geq x_0\ or\ X_n^{BA} \geq x_n^{BA})} = \frac{E(L)}{1 - F_{X_0 X_n^A}(x_0, x_n^{BA})} = \frac{E(L)}{1 - C(F_{X_0}(x_0), F_{X_n^{BA}}(x_n^{BA}))} \tag{6.2.3}$$

Subsequently, as defined in equations (6.2.4), (6.2.5) and (6.2.6), the second form of joint return period was calculated. This being the “and” joint return period. Which is the return period of a rainfall event where the annual maximum is equal or greater than both the annual maximum and the associated cumulative series happening.

$$T_{X_0 \; and \; X_n^B} = \frac{E(L)}{P(X_0 \geq x_0, X_n^B \geq x_n^B)} = \frac{E(L)}{1 - F_{X_0}(x_0) - F_{X_n^B}(x_n^B) + C(F_{X_0}(x_0), F_{X_n^B}(x_n^B))} \tag{6.2.4}$$

$$T_{X_0 \; and \; X_n^A} = \frac{E(L)}{P(X_0 \geq x_0, X_n^A \geq x_n^A)} = \frac{E(L)}{1 - F_{X_0}(x_0) - F_{X_n^A}(x_n^A) + C(F_{X_0}(x_0), F_{X_n^A}(\square_n^A))} \tag{6.2.5}$$

$$T_{X_0 \; and \; X_n^{BA}} = \frac{E(L)}{P(X_0 \geq x_0, X_n^{BA} \geq x_n^{BA})} = \frac{E(L)}{1 - F_{X_0}(x_0) - F_{X_n^{BA}}(x_n^{BA}) + C(F_{X_0}(x_0), F_{X_n^{BA}}(x_n^{BA}))} \tag{6.2.6}$$

Finally, conditional return periods were calculated. These formulations are presented from Equation (6.2.7) to (6.2.12). They can either calculate the return period of an occurrence where the rainfall is equal to or greater than the annual maximum given its coupled cumulative series (equations (6.2.7), (6.2.8) and (6.2.9)). Or they calculate the return period of an occurrence where the rainfall is equal to or greater than the cumulative series given its annual maximum (equations (6.2.7), (6.2.8) and (6.2.9)). This conditional type of return period might help add temporal and causal significance to the data.

$$T_{X_0|X_n^B} = \frac{T_{X_n^B}}{P(X_0 \geq x_0, X_n^B \geq x_n^B)} \tag{6.2.7}$$

$$T_{X_0|X_n^A} = \frac{T_{X_n^A}}{P(X_0 \geq x_0, X_n^A \geq x_n^A)} \tag{6.2.8}$$

$$T_{X_0|X_n^{BA}} = \frac{T_{X_n^{BA}}}{P(X_0 \geq x_0, X_n^{BA} \geq x_n^{BA})} \tag{6.2.9}$$

$$T_{X_n^B|X_0} = \frac{T_{X_0}}{P(X_0 \geq x_0, X_n^B \geq x_n^B)} \tag{6.2.10}$$

$$T_{X_n^A|X_0} = \frac{T_{X_0}}{P(X_0 \geq x_0, X_n^A \geq x_n^A)} \tag{6.2.11}$$

$$T_{X_n^{BA}|X_0} = \frac{T_{X_0}}{P(X_0 \geq x_0, X_n^{BA} \geq x_n^{BA})} \tag{6.2.12}$$

From equations (6.2.1) to (6.2.12), n takes values from 1 to 6. All the results from the return period analysis can be found in Annex III for the hourly analysis, and in Annex IV for the daily analysis.

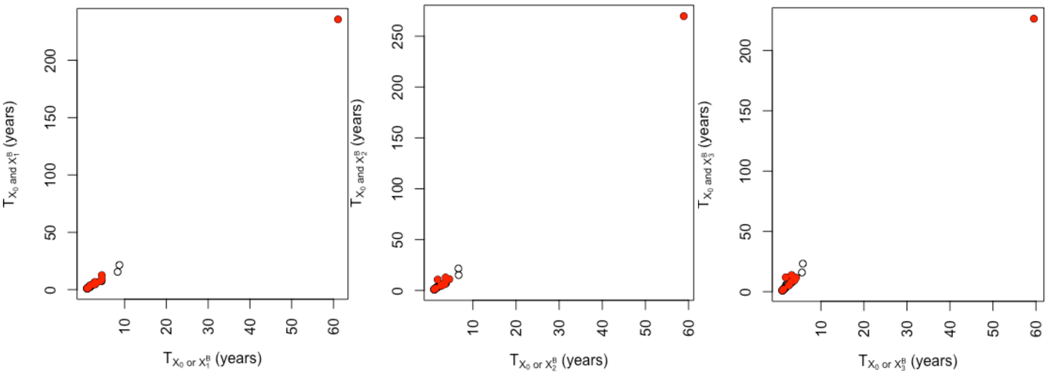
6.2.2 Bivariate return periods or-and comparison for hourly rainfall

For the hourly rainfalls, Figures 6 to 8 depict the scatter plots of joint bivariate return periods given by equations (6.2.1) to (6.2.6) for the annual maximum rainfalls coupled with, rainfalls before, after and before and after the annual maximum respectively. The values associated with alluviums are represented by red dots. To ensure legibility, the vertical and horizontal axes may have different scales. The alluvium that took place in late February 2010, always has the highest bivariate return period value on the x and y-axis, this is, it is always near the top right corner.

Some main conclusions can be drawn from the figures:

- the return periods given by equations (6.2.4) to (6.2.6) are always higher than those resulting from equations (6.2.1) to (6.2.3), which is expectable and statistically mandatory, and often from around 3 to 5 times higher.
- Except for the late February 2010 event, the rest of the return periods for the extreme rainfall events are very similar and cluttered, regardless of the number of hours of the cumulative rainfalls and if the series of those rainfalls are prior or posterior to the annual maximum X_0. They also denote relatively non-exceptional events: with only a few exceptions between 50 years, for “and” joint return periods, and 10 years, for “or” joint return periods.
- The association of the late February 2010 alluvium event with the rainfall conditions that preceded and followed it is truly exceptional, in absolute terms, but especially when compared with other alluvium triggering rainfall events.

a) 1h before b) 2h before c) 3h before



d) 4h before e) 5h before f) 6h before

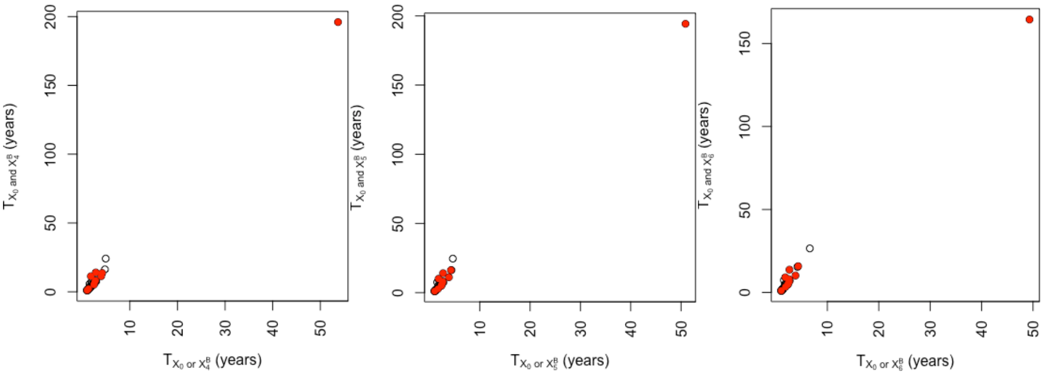
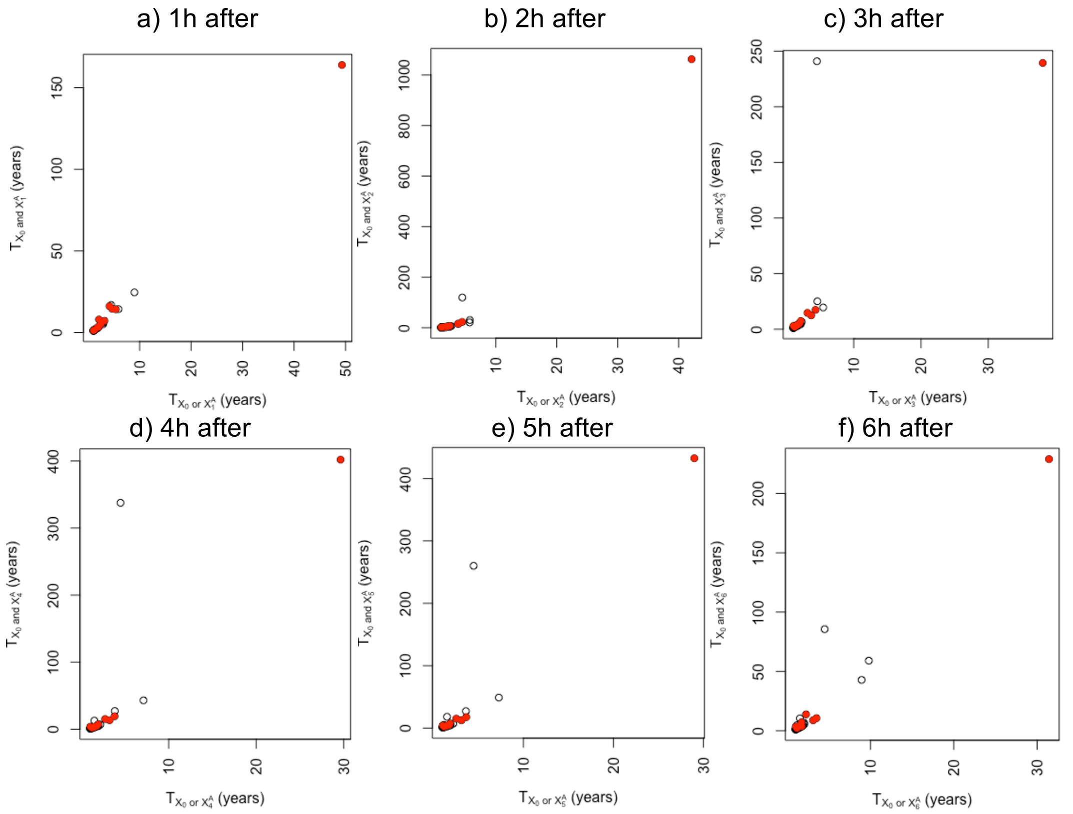


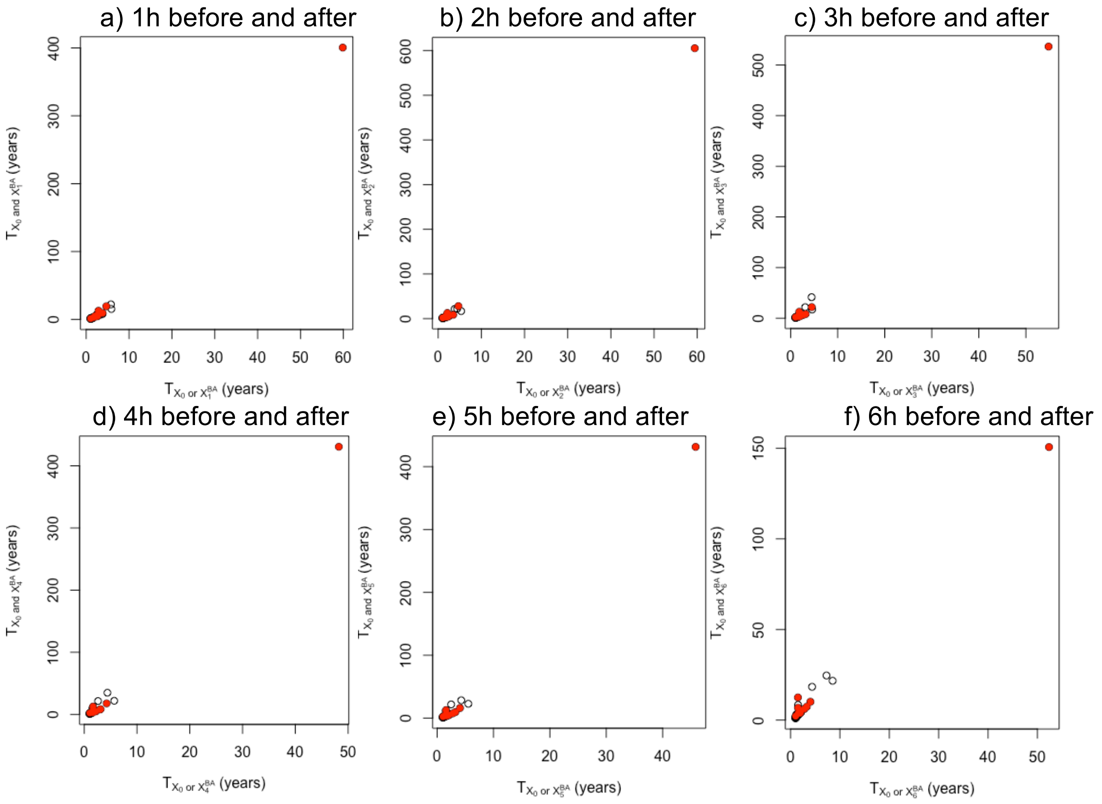
Figure 6 – Hourly rainfall: annual maximum rainfall and cumulative prior rainfall for n from 1 to 6 h. Scatter plots for joint bivariate return periods $T_{X_0\ or\ X_n^B}$ (x-axis) and $T_{X_0\ and\ X_n^B}$ (y-axis) from the “or” and “and” analyses respectively.



a) 1h after b) 2h after c) 3h after

d) 4h after e) 5h after f) 6h after

Figure 7 – Hourly rainfall: annual maximum rainfall and cumulative posterior rainfall for n from 1 to 6 h. Scatter plots for bivariate return periods $T_{X_0\ or\ X_n^A}$ (x-axis) and $T_{X_0\ and\ X_n^A}$ (y-axis) from the “or” and “and” analyses respectively.



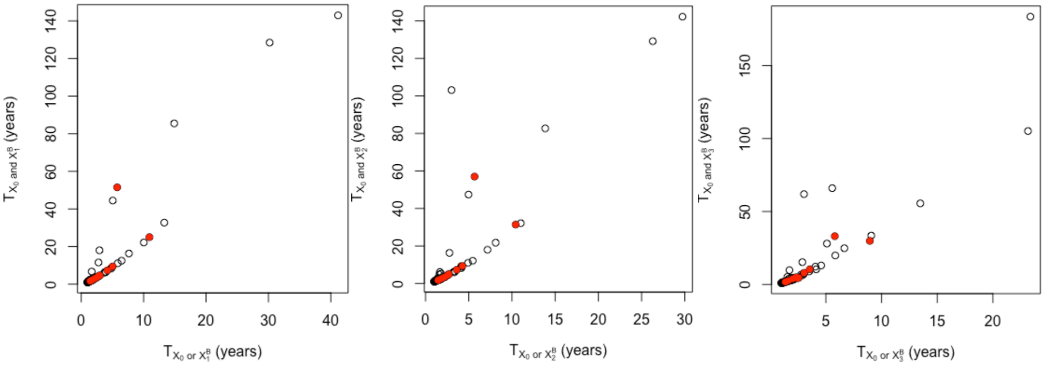
a) 1h before and after b) 2h before and after c) 3h before and after

d) 4h before and after e) 5h before and after f) 6h before and after

Figure 8 – Hourly rainfall: annual maximum rainfall and cumulative prior and posterior rainfall for n from 1 to 6 h. Scatter plots for bivariate return periods $T_{X_0\ or\ X_n^{BA}}$ (x-axis) and $T_{X_0\ and\ X_n^{BA}}$ (y-axis) from the “or” and “and” analyses respectively.

6.2.3 Bivariate return periods “or” and “and” comparison for daily rainfall

The return periods of the daily rainfall show something quite different from its hourly counterpart. The relation between the daily joint “or” and “and” return periods presented in Figures 9 to 11 shows the same positive correlation structure, however in some cases suggesting two that different mathematical relationships may apply to the same coupled series, as is the case of Figure 9 a) and b). The data points are also much less clustered. Though both joint “or” and “and” return period analyses are in a general range of 1 to 10 years and 1 to 50 years respectively, the daily analysis has more exceptional data points or outliers. The late February 2010 alluvium was not part of the samples at the daily level. In fact, the event with the highest bivariate return periods, although also refer to 2010, took place later, namely on the 26th of September 2010. Contrary to the hourly analysis, the association between extreme rainfall events and alluvium flood events for the daily data differs between the “before”, “after” and “before and after” analyses. This is due to the application of the temporal criterion explained in subchapter *3.3 Alluvium data*. Since for the daily analysis a rainfall event can last up to 6 days before and/or 6 days after the date of the annual maximum, this has to be taken into account when using the temporal criterion. For example, if an alluvium event occurs three days before the date of annual maximum daily rainfall, the “after” analysis is not useful. However, the “before” analysis is still useful since the 3, 4, 5 and 6 days prior calculations serve to make inferences on the alluvium event. In contrast, as laid out in subchapter *3.3 Alluvium data* the hourly analysis only couples rainfall events with alluvium events that occurred on the same day as the maximum or up to 6 days after it. The dates of the rainfall-alluvium events that were coupled can be found in Annex IV, where they are highlighted in orange in each table.


a) 1 day before
b) 2 days before
c) 3 days before

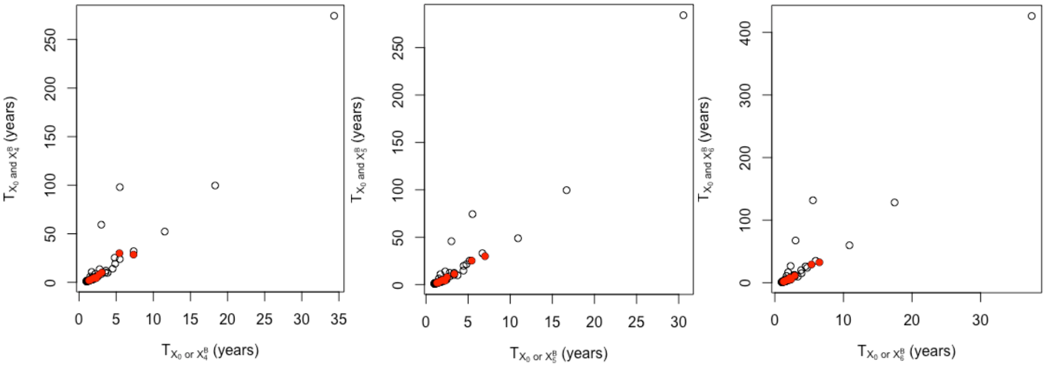

d) 4 days before
e) 5 days before
f) 6 days before

Figure 9 – Daily rainfall: annual maximum rainfall and cumulative prior rainfall for n from 1 to 6 days. Scatter plots for bivariate return periods $T_{X_0\ or\ X_n^B}$ (x-axis) and $T_{X_0\ and\ X_n^B}$ (y-axis) from the “or” and “and” analyses respectively.

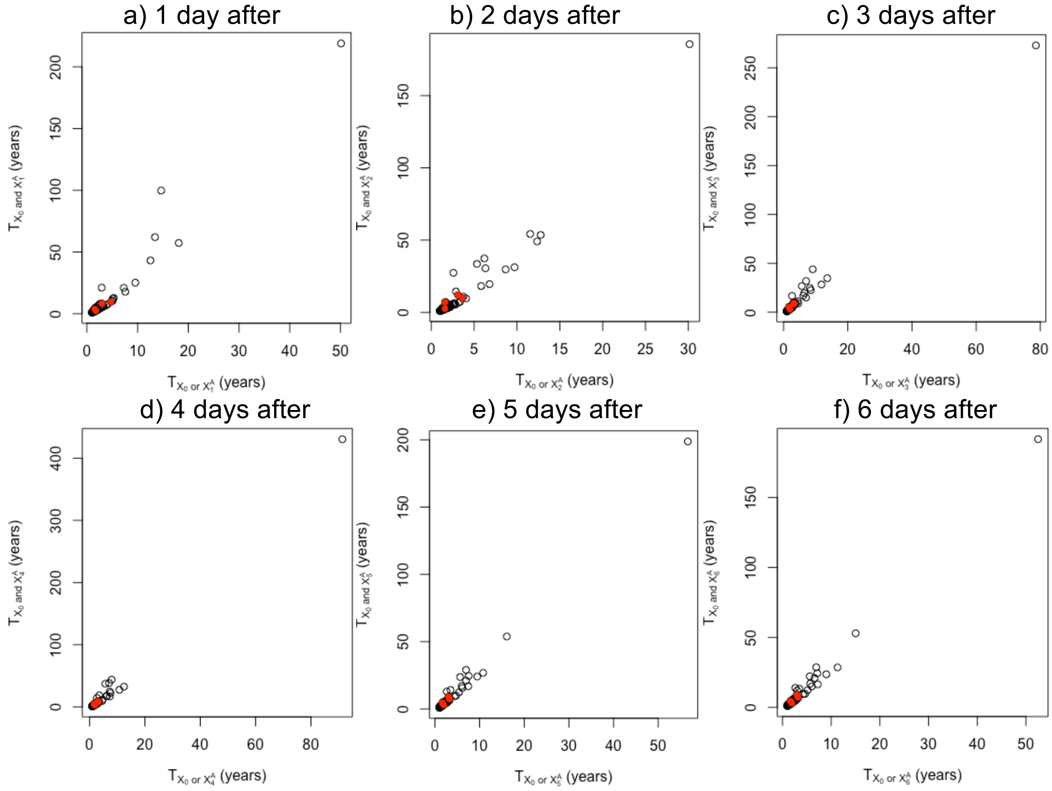


Figure 10 – Daily rainfall: annual maximum rainfall and cumulative posterior rainfall for n from 1 to 6 days. Scatter plots for bivariate return periods $T_{X_0\ or\ \square_n^A}$ (x-axis) and $T_{X_0\ and\ X_n^A}$ (y-axis) from the “or” and “and” analyses respectively.

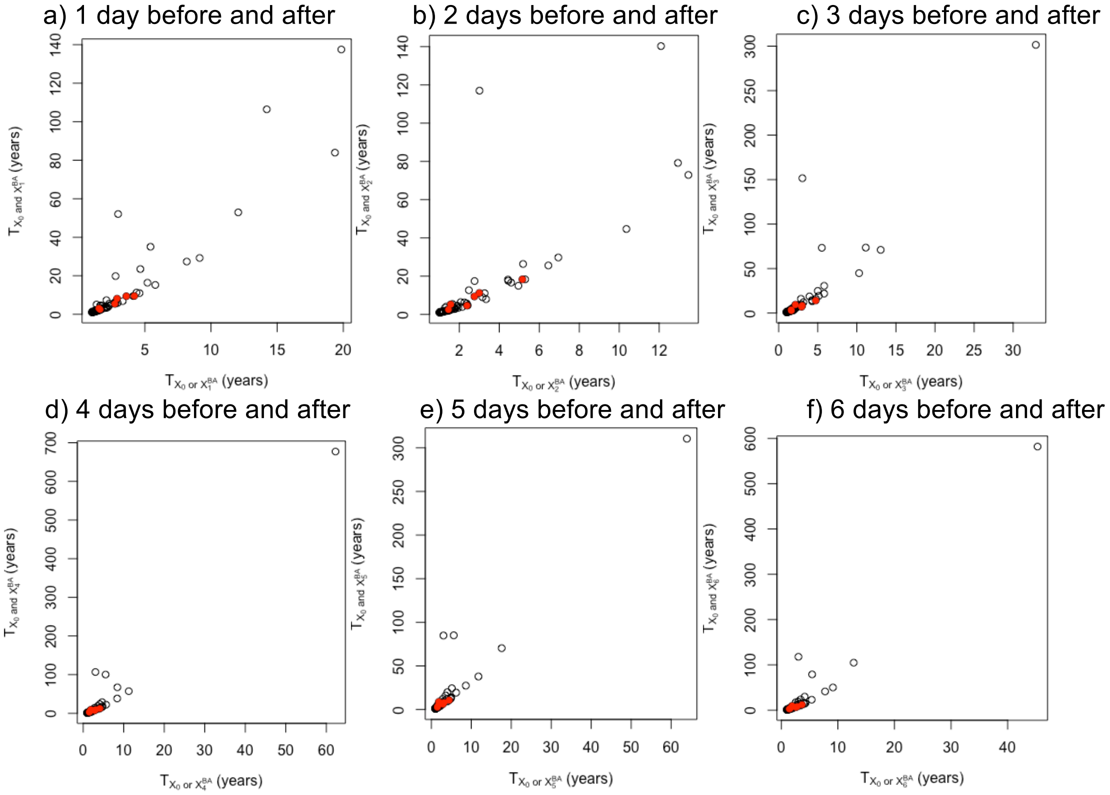


Figure 11 – Daily rainfall: annual maximum rainfall and cumulative prior and posterior rainfall for n from 1 to 6 days. Scatter plots for bivariate return periods $T_{X_0\ or\ X_n^{\square A}}$ (x-axis) and $T_{X_0\ and\ X_n^{BA}}$ (y-axis) from the “or” and “and” analyses respectively.

6.2.4 Hourly bivariate return periods and their two respective rainfall variables

In this section, the analysis of the coupled rainfall-alluvium events is addressed based on Figures 12 to 14, included in the pages (each figure is presented in two pages).

The visualisation of each event's rainfall data and their respective return period shown in Figures 12 to 14 make it easy for the reader to understand and analyse some of the results reached in this thesis.

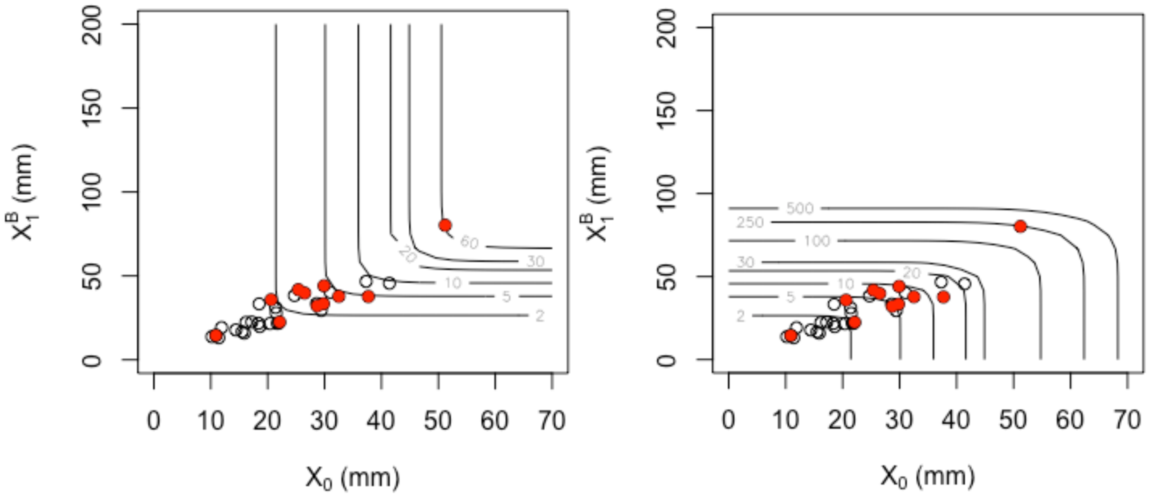
From the previous three figures, it is possible to understand the exceptionality of the 2010 late February rainfall event. The red and white circles contain the same connotation as in Figures 6 to 11, this is, the white circles represent rainfall events that are not associated with an alluvium event and the red circles represent rainfall events that are associated with an alluvium event. The contour lines depict the return periods that are calculated from the graph's respective bivariate copula where the two variables are the ones represented by the x and y axes. The x-axis is always the hourly AMS series (X_0) and the y-axis is always a cumulative hourly series.

Some main conclusions can be drawn from the figures:

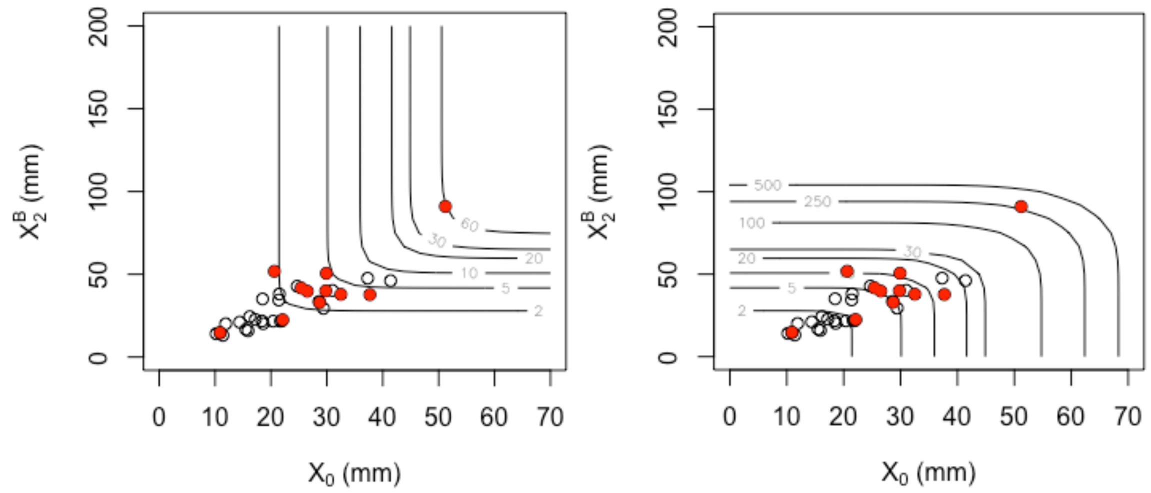
- There is always one rainfall event that has the highest return period, namely, the 2010 late February rainfall that is associated with the deadly alluviums. This event is always set apart from the other thirty-three hourly rainfall events analysed in this thesis. This consistent separation shows true exceptionality.
- There is a noticeable tendency for rainfall events that were associated with alluviums (red dots) to have higher values of return periods. This is quite clear for the "before" and "before and after" rainfall analyses found in Figure 12 and Figure 14 respectively.
- In the "before and after" analysis of Figure 14, the rainfall events seem to be slightly more dispersed. Which may indicate a possible increase of variation in hourly rainfall with the increase of observations.

This analysis and its resulting graphs were only performed for hourly rainfall data because, as previously mentioned in section *6.2.2 Bivariate return periods or-and comparison for daily rainfall,* the extreme rainfall series extracted and formed from the daily rainfall data by way AMS and cumulative series did not contain the 2010 late February event.

a) 1h before, “or” (left side) and “and” (right side) bivariate return periods



b) 2h before, “or” (left side) and “and” (right side) bivariate return periods



c) 3h before, “or” (left side) and “and” (right side) bivariate return periods

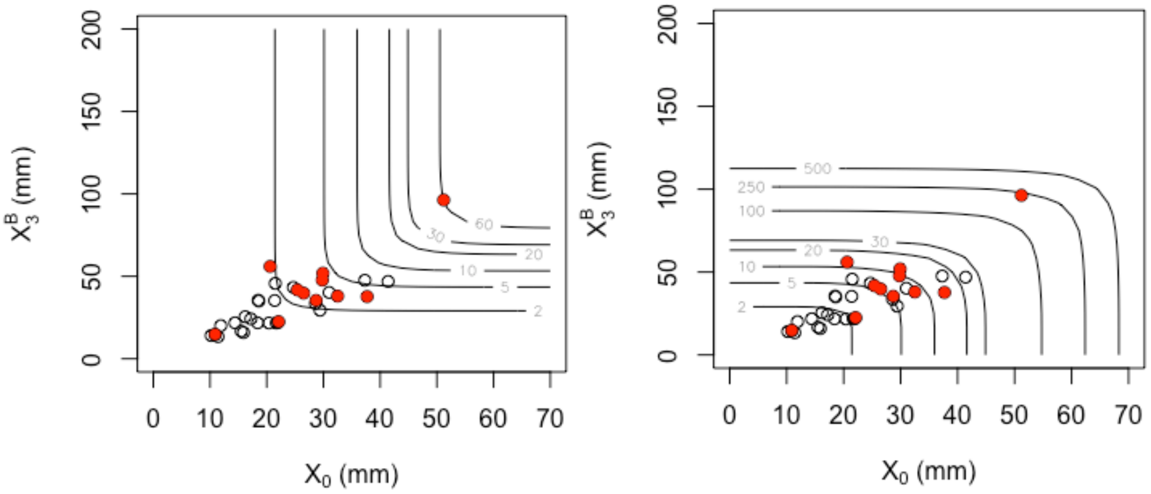
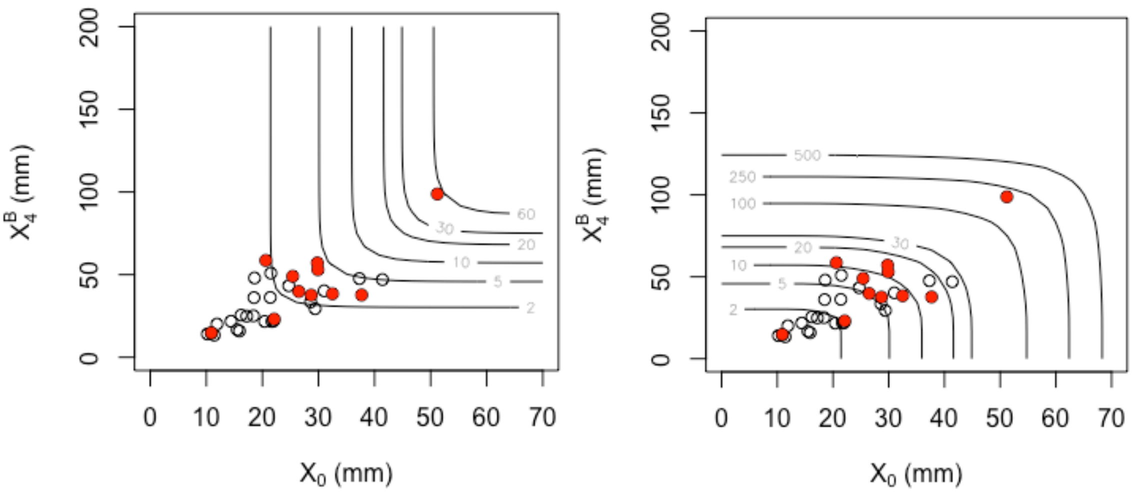
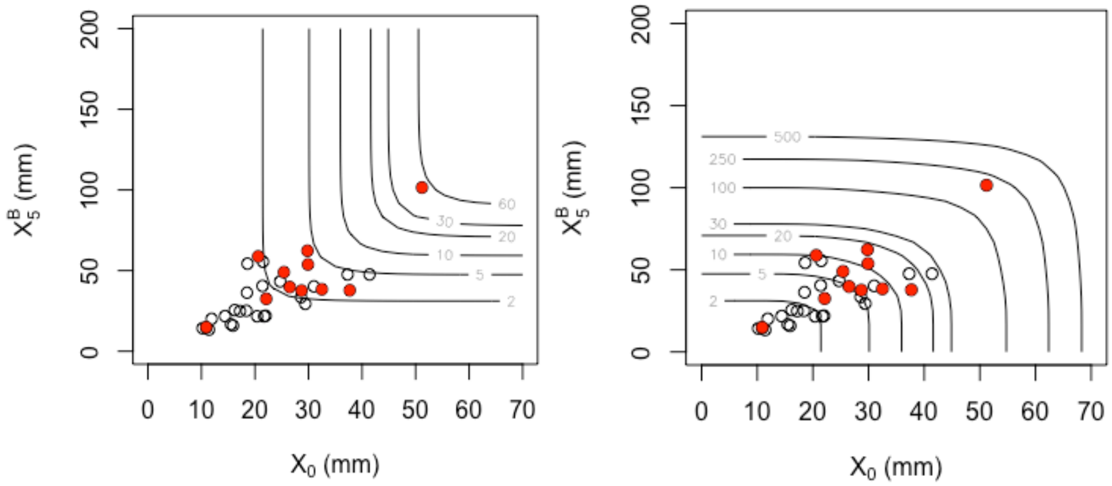


Figure 12 (1/2) - Contour lines of return periods for coupled hourly annual maximum rainfalls (X_0) and cumulative hourly rainfalls in 1 to 6 h prior, X_1^B to X_6^B. On the left side, the results from the joint “or” bivariate copula, and on the right side, those from the joint “and” copula analysis.

d) 4h before, “or” (left side) and “and” (right side) bivariate return periods



e) 5h before, “or” (left side) and “and” (right side) bivariate return periods



f) 6h before, “or” (left side) and “and” (right side) bivariate return periods

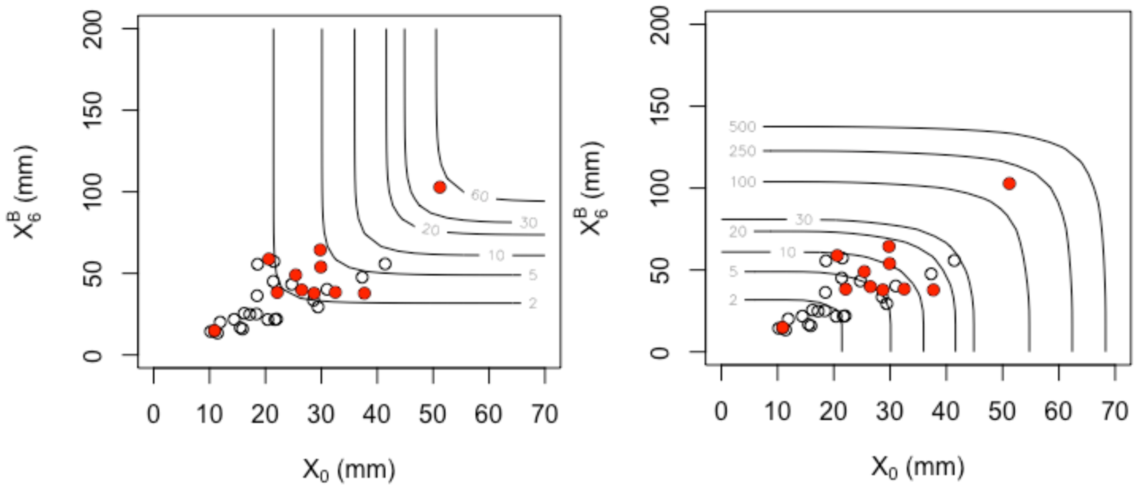
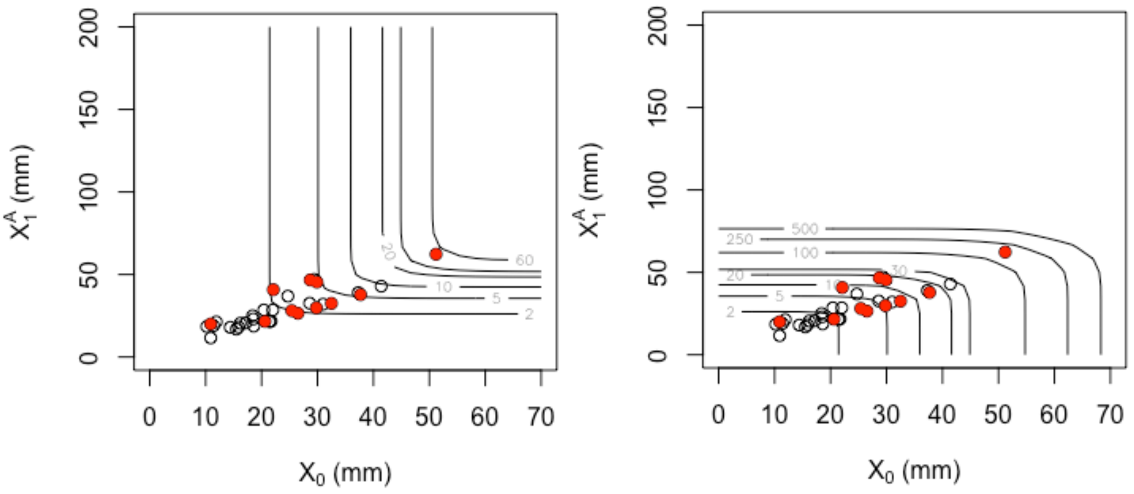
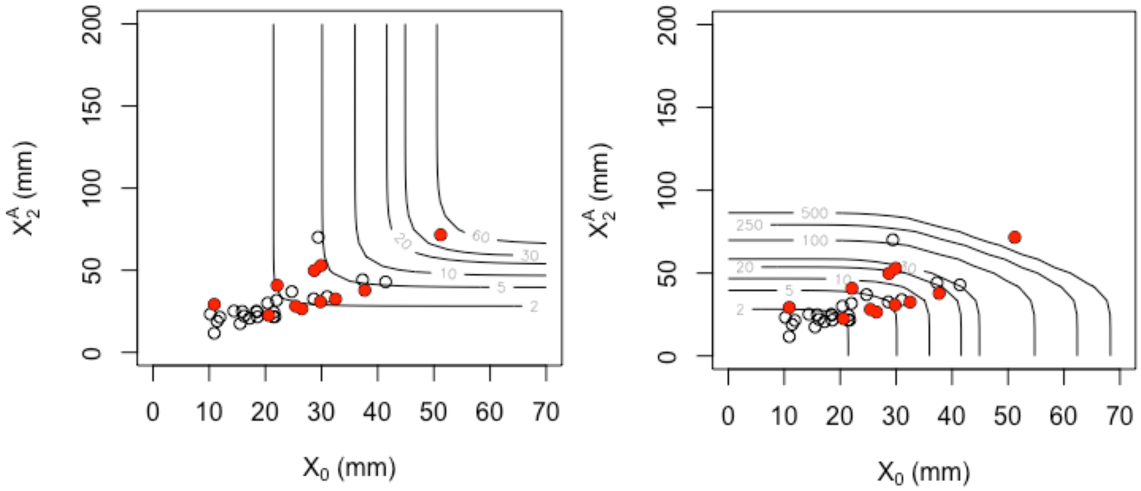


Figure 12 (2/2) - Contour lines of return periods for coupled hourly annual maximum rainfalls (X_0) and cumulative hourly rainfalls in 1 to 6 h prior, X_1^B to X_6^B. On the left side, the results from the joint “or” bivariate copula, and on the right side, those from the joint “and” copula analysis.

a) 1h after, “or” (left side) and “and” (right side) bivariate return periods



b) 2h after, “or” (left side) and “and” (right side) bivariate return periods



c) 3h after, “or” (left side) and “and” (right side) bivariate return periods

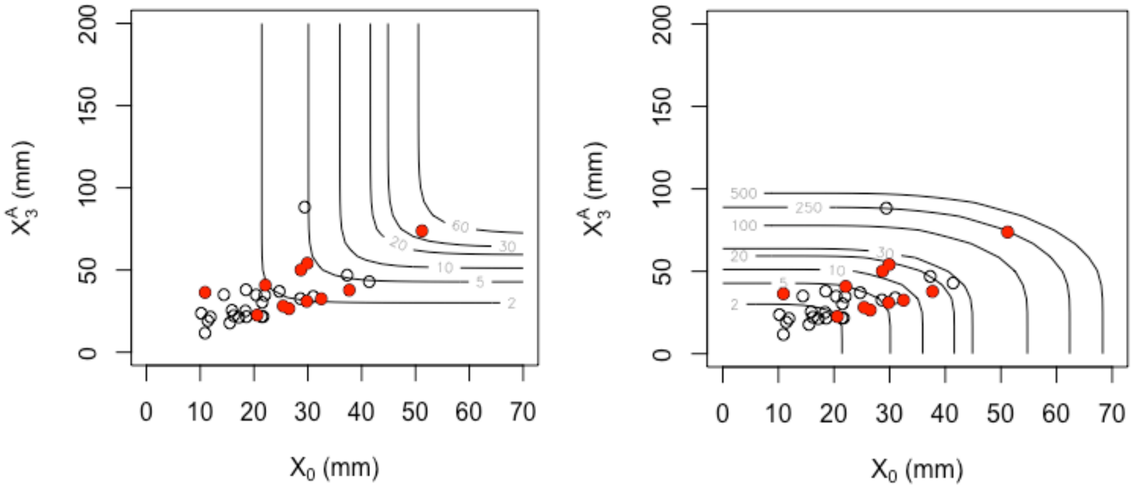
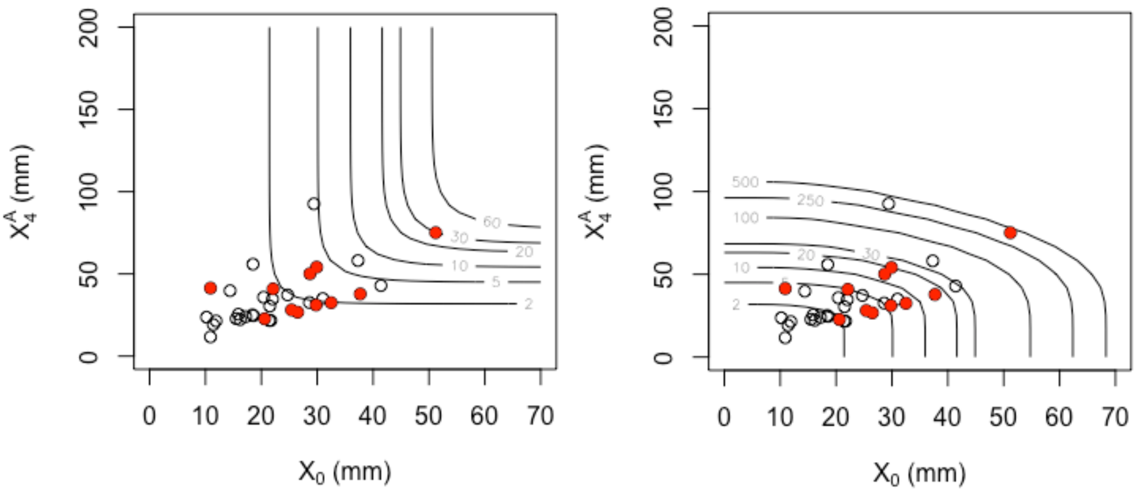
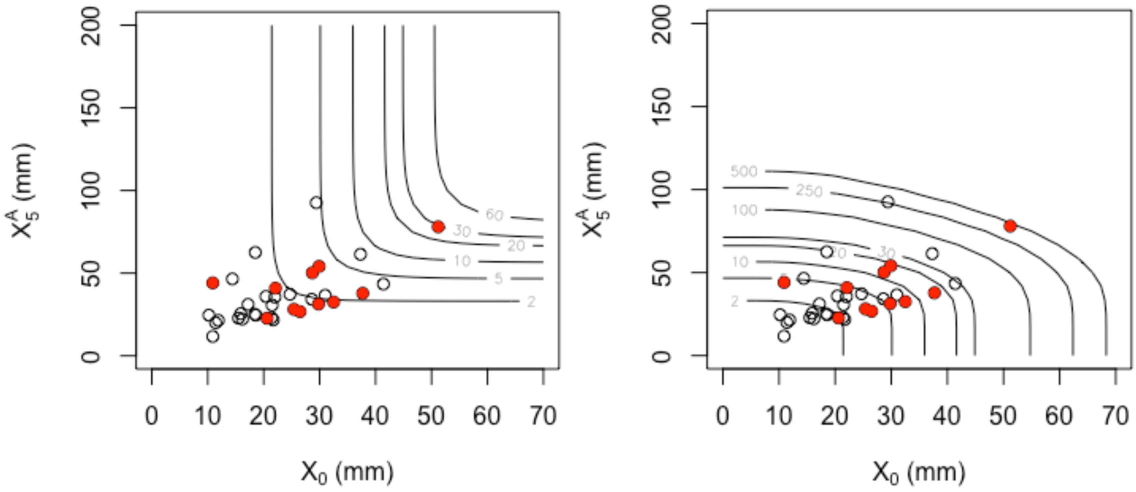


Figure 13 (1/2) - Contour lines of return periods for coupled hourly annual maximum rainfalls (X_0) and the cumulative hourly rainfalls in 1 to 6 h posterior, X_1^A to X_6^A. On the left are the results from the joint “or” bivariate copula, and on the right side, those from the joint “and” copula analysis.

d) 4h after, “or” (left side) and “and” (right side) bivariate return periods



e) 5h after, “or” (left side) and “and” (right side) bivariate return periods



f) 6h after, “or” (left side) and “and” (right side) bivariate return periods

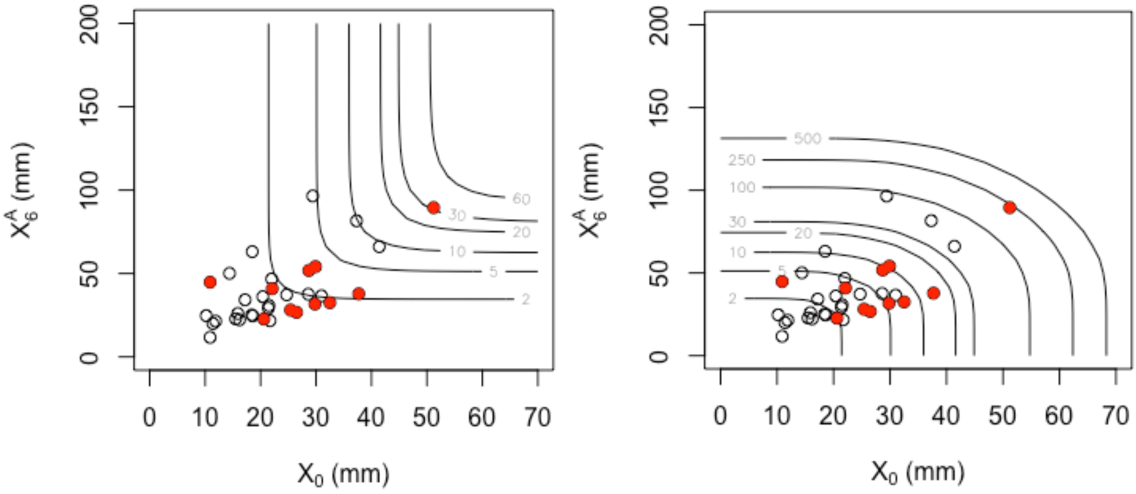
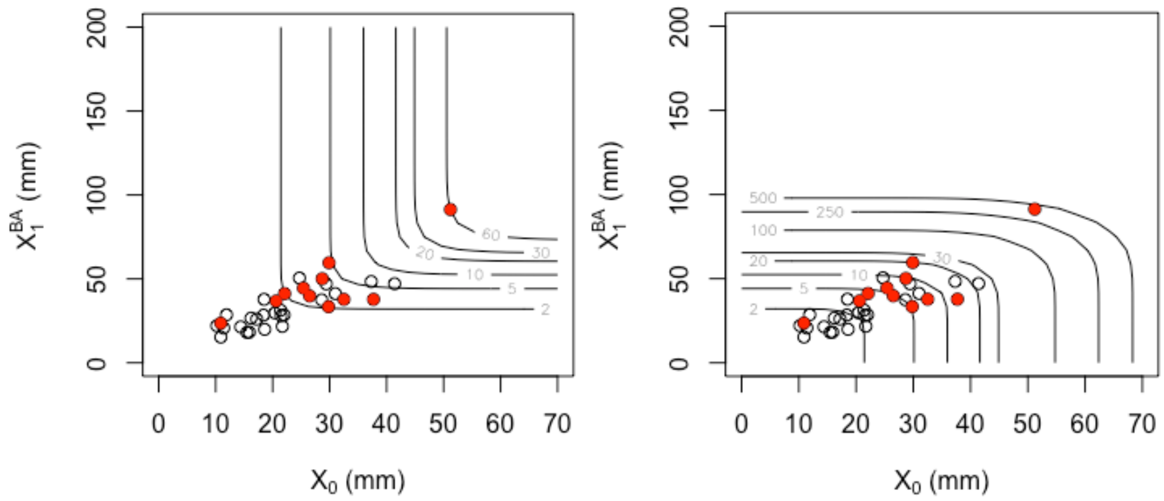
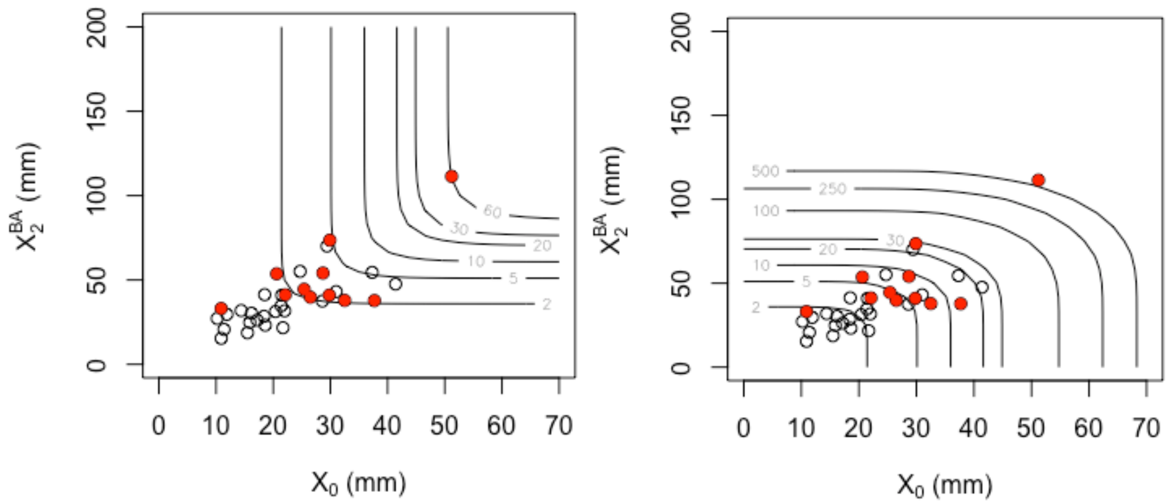


Figure 13 (2/2) Contour lines of return periods for coupled hourly annual maximum rainfalls (X_0) and the cumulative hourly rainfalls in 1 to 6 h posterior, X_1^A to X_6^A. On the left are the results from the joint “or” bivariate copula, and on the right side, those from the joint “and” copula analysis.

a) 1h before and after, “or” (left side) and “and” (right side) bivariate return periods



b) 2h before and after, “or” (left side) and “and” (right side) bivariate return periods



c) 3h before and after, “or” (left side) and “and” (right side) bivariate return periods

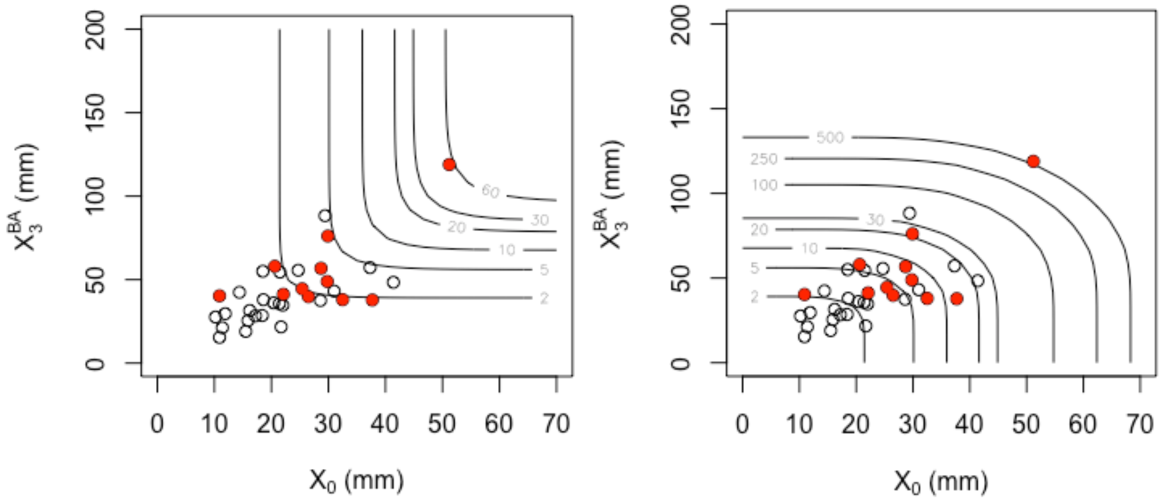
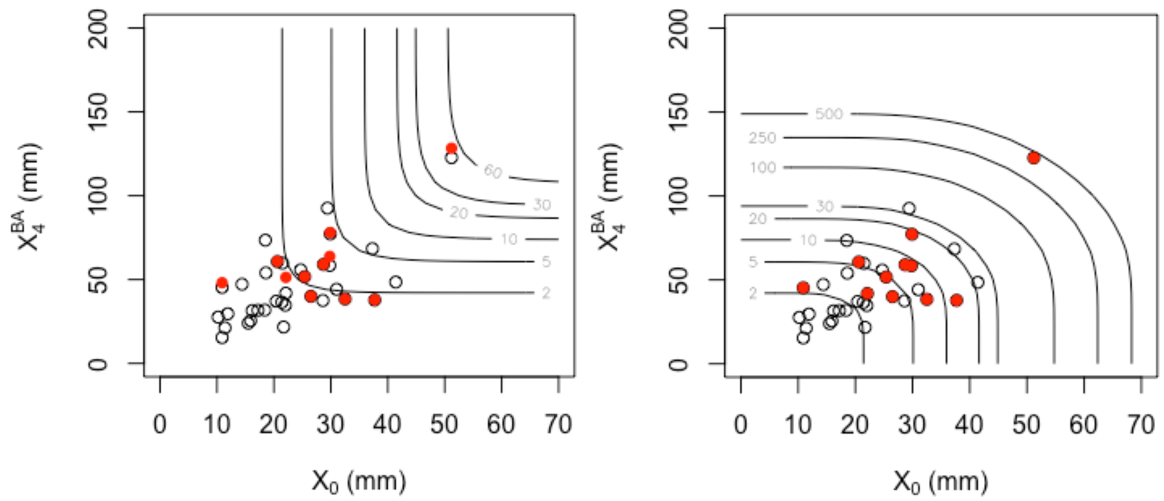
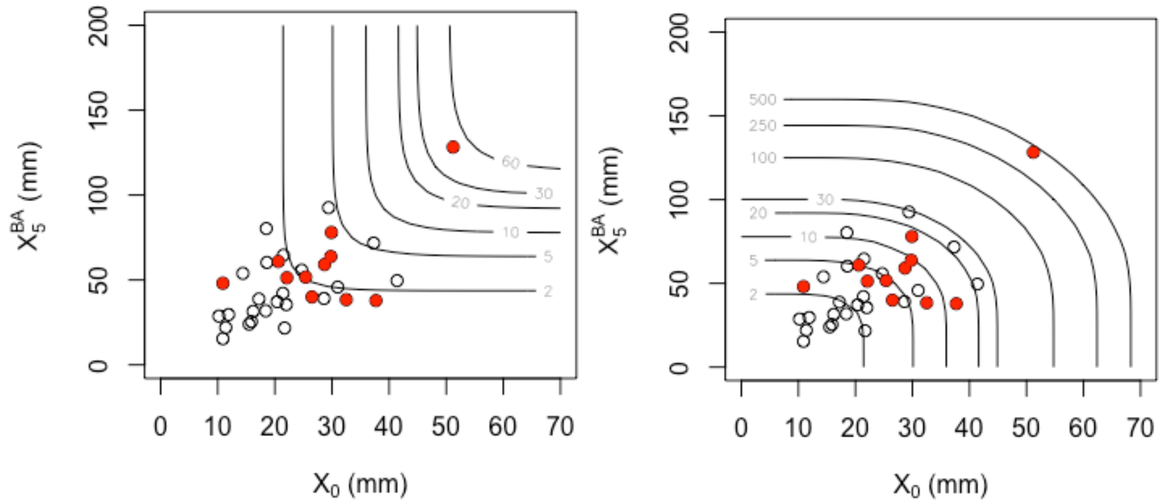


Figure 14 (1/2) - Contour lines of return periods for coupled hourly annual maximum rainfalls (X_0) and the cumulative hourly rainfalls in 1 to 6 h prior and posterior, X_1^{BA} to X_6^{BA}. On the left side are the results from the joint “or” bivariate copula, and on the right side, those from the joint “and” copula analysis.

d) 4h before and after, “or” (left side) and “and” (right side) bivariate return periods



e) 5h before and after, “or” (left side) and “and” (right side) bivariate return periods



f) 6h before and after, “or” (left side) and “and” (right side) bivariate return periods

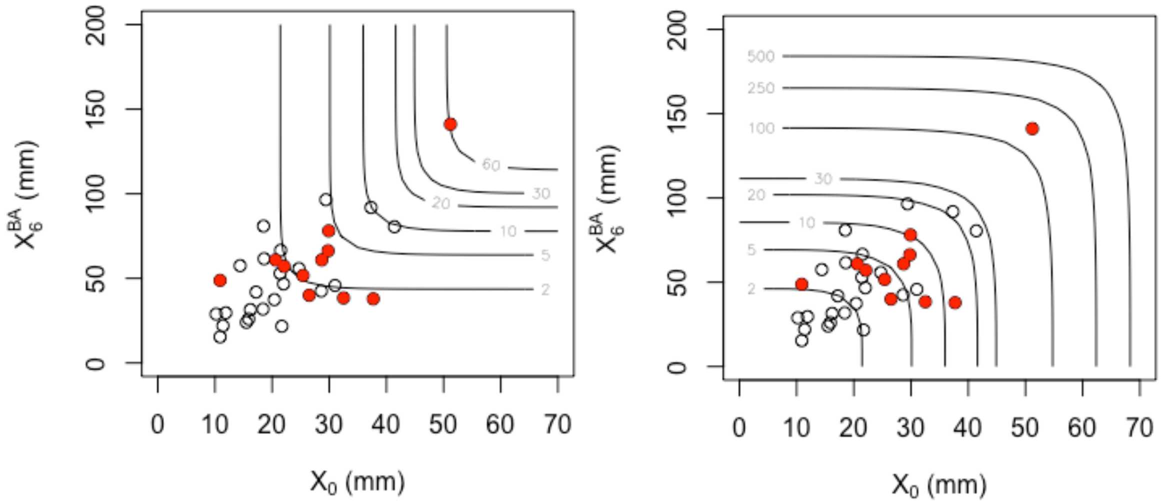


Figure 14 (2/2) - Contour lines of return periods for coupled hourly annual maximum rainfalls (X_0) and the cumulative hourly rainfalls in 1 to 6 h prior and posterior, X_1^{BA} to X_6^{BA}. On the left side are the results from the joint “or” bivariate copula, and on the right side, those from the joint “and” copula analysis.

6.2.5 Conditional return period analysis

The conditional return periods for the data and series utilised in the copula analysis also prove the 2010 late February rainfall event to be exceptional. However, because of the nature of conditional probabilities and conditional return periods, this analysis may not provide correct values for return periods, maybe not even in the correct power of 10 (1 to 9, 10 to 99, 100 to 999, 1000 to 9999, etc.). This thesis is already studying extreme events; therefore, it is expected that the most exceptional of these extreme events are going to have very low probabilities. This is especially notable for the 2010 late February event where the hourly analysis provides return periods of over ten thousand or even over one hundred thousand. For example, for the hourly analysis, if Equation (6.2.9) is applied to the annual maximum of the 2009/2010 hydrological year (20/02/2010) given the cumulative series of 2h before and after the annual maximum it results in the following value:

$$T_{X_0|X_2^{BA}} = \frac{T_{X_2^{BA}}}{P(X_0 \geq x_0, X_2^{BA} \geq x_2^{BA})} = 208395.70 \text{ years}$$

There is a similar situation for the conditional return periods that result from the daily analysis. For example, for the hydrological year after the year of the previous example, by applying Equation 6.2.8 to the copula that results from the daily analysis of the condition, the probability of the annual maximum (26/11/2010) given the cumulative series of 4 days after, the return period gives us the following value:

$$T_{X_0|X_4^{A}} = \frac{T_{X_4^{A}}}{P(X_0 \geq x_0, X_4^{A} \geq x_4^{A})} = 109478.20 \text{ years}$$

Even apart from these examples of the highest values of the conditional return periods for the hourly and daily analysis, the other conditional return periods are in general much larger than the joint ("or" or "and") analyses. As stated before, all the return periods that were calculated from the hourly rainfall analysis can be found in Annex III and the ones calculated from the daily rainfall analysis, can be found in Annex IV.

7 Discussion and conclusions

In this research, a bivariate approach was implemented to analyse the relationship between intense rainfall and alluvium flood events in Funchal, Madeira. Firstly, by using the annual maximum series, AMS, technique, a definition of extreme events was created. Then, by creating several cumulative series based on the AMS, a bivariate understanding of the rainfall events was admitted. After calculating bivariate copulas from the fitted rainfall data, an analysis of those copulas was performed. Such analysis included the calculation of return periods from the daily and hourly analysis, for each the univariate return period type, two joint ("or" and "and") return period types and the two conditional return period types. Finally, an analysis of the association of the rainfall events and the alluvium events could be performed.

This study concludes that the methodology of copula analysis is adequate for the purpose of understanding how the temporal distribution of the rainfall during a rainfall event defines its exceptionality, either with the use of joint or conditional return periods. There must be a warning made for when time-series data, such as the one used in this thesis, are small. Because in this thesis annual maximum series were used to select the coupled rainfall events, the lengths of the periods with available data were 34 years (1980/1981 to 2013/2014), for the hourly series, and 80 years (1937/1938 to 2016/2017), for the daily series (Table 1), which are compatible with the establishment of the copulas models. For series that are smaller, for example, less than twenty places, it might be difficult to have meaningful marginal distribution fitting which is necessary for the copula calculations.

The analysis confirmed the exceptionality of the late February 2010 rainfall event based on the joint and conditional return periods. However, these joint and conditional probabilities do not result in similar return periods, even to the power of ten. Conditional return periods were larger than the joint return periods. Sometimes they were unreasonable high, suggesting that they may not be adequate to characterize the rainfall events. The "and" return periods values were larger than its "or" counterpart, which is conceptually understandable. However, the "or" combination might not provide the most exact probability values when trying to relate extreme rainfalls to another event, in this case, alluvium flooding. This is because the "or" combination expresses the return period of either the annual maximum (or greater) happening or the cumulative, which also includes the maximum (or greater) happening. This lowers the value of the return period values considerably and this thesis is not too interested in the possibility of merely the annual maximum (or greater) happening. This thesis reaches the conclusion that the "and" joint return period values might be the best to estimate the actual and real values of the return periods of rainfall events and their associated alluvium events. Further study could be performed on this point which would allow for a clearer and more definite understanding of this issue. The following figures were created to further compare the hourly "or" and "and" bivariate analysis, and to compare these two types of bivariate models to the univariate approach. And the figures also are aimed at providing additional insights on the characteristics and exceptionality of the rainfall that triggered the late February 2010 alluvium flood event.

Figure 15, based on the data from Table 6, presents a line graph of the cumulative (including the annual maximum) rainfall data from the measurements taken on the 20th of February 2010. The return periods that were assigned to the rainfall events of Figure 15 are represented in Figure 16 and were obtained based on the data presented in Annex III. This figure presents three different line graphs which compare the univariate and both bivariate joint models for the hourly rainfall before, after and before and after the annual maximum analyses. In Figure 17 the graphs show the same values for the return periods but with a different perspective. This is, three graphs were created in which the before, after and before and after return period values are compared for the three types of models, namely, univariate and "or" and "and" models. The results from the conditional return period were not included in the analysis because of the reason previously stated.

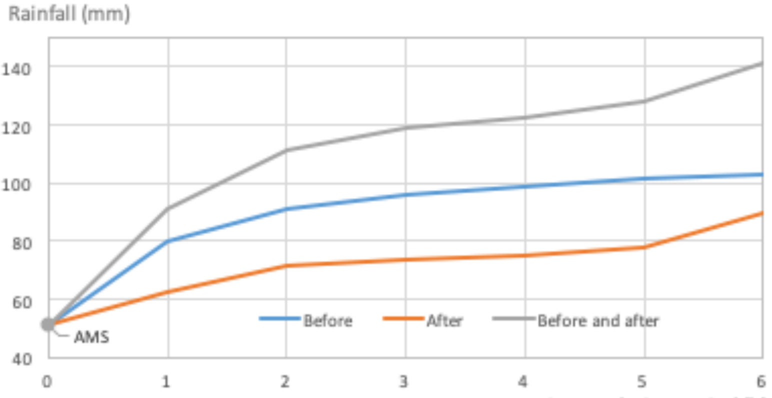


Figure 15 - Rainfall event of the 20th of February 2010. Annual maximum rainfall and cumulative rainfall before, after and before and after, from 1 to 6 h.

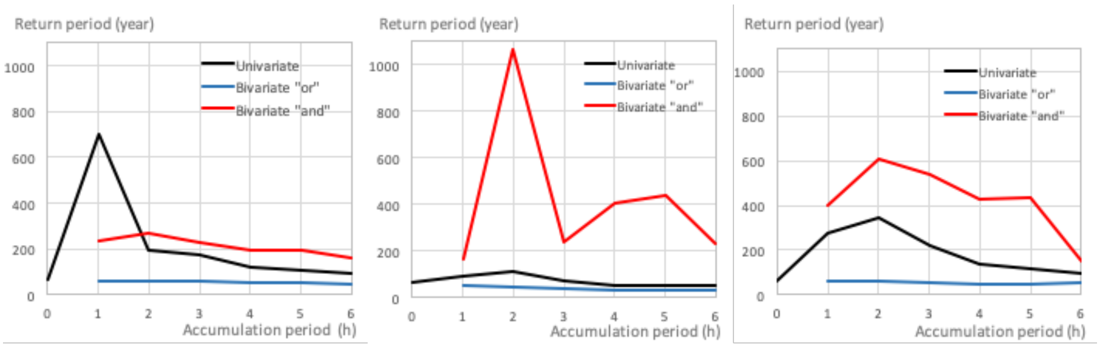

a) Cumulative rainfall before b) Cumulative rainfall after c) Cumulative rainfall before and after

Figure 16 - Rainfall event of the 20th of February 2010. Univariate and bivariate return periods for the annual maximum rainfall and for the cumulative rainfall, from 1 to 6 h: a) before; b) after; and c) before and after.

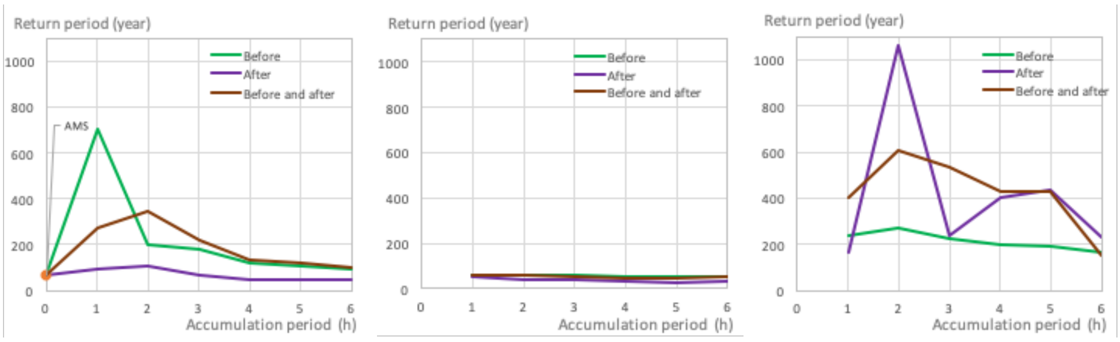

a) Univariate b) Bivariate "or" c) Bivariate "and"

Figure 17 - Rainfall event of the 20th of February 2010. Return periods for the annual maximum rainfall and for the cumulative rainfall, from 1 to 6 h: a) univariate; b) bivariate "or"; and c) bivariate "and".

From the previous figures, it can be concluded that the univariate approach also results in high values for return periods. It shows a particularly high return period for the cumulative rainfall of one hour before the annual maximum. Whilst the bivariate "and" approach presents higher values for the cumulative rainfalls of two hours before and after the annual maximum. What is seemingly apparent is how the joint bivariate approach results differ from the results of the univariate approach, and how within the joint approach the "or" and "and" analyses substantially differ in their return period values. Though from section *6.2.3 Hourly bivariate return periods and their two respective rainfall variables* it is possible to come to the conclusion that the late February 2010 events are exceptional based on the "or" analysis when compared to the analysis for the extreme rainfall events of other years, the return period values for the rainfall of the cumulative hours analysed on that day do not show exceptionality within themselves.

Another conclusion is that the use of the annual maximum series technique was useful due to its simplicity in the composition of the series and the calculation of the return periods, but it could have not captured the fullness of the original data and its intense rainfalls. This is apparent in the application of the AMS to the daily rainfall data. This technique indicated that a 2009/2010 hydrological year's extreme rainfall event was on 02/02/2010. This meant that this thesis was not able to use the daily analysis to study the late February 2010 event. A possible improvement could be to use another method for selecting extreme rainfall events. For example, one possible technique is the threshold technique (or partial duration series) used by Liu *et al.* (2013) or Mase (1996). The threshold technique allows the researcher to set a limit, whereby any value that is above it is considered an extreme value. This allows each series to possibly have more than one value per year, which results in longer series, which in turn generally results in more accurate fittings for marginal distributions and higher quality copula analyses. It also allows for the consideration of other intense rainfall events, that with lay eyes may too seem extreme, like the late February 2010 event, yet may not be selected by the AMS technique, as was the case with the daily analysis in this thesis. This could give more exact values for the return periods and a more accurate comprehension of the subject matter.

Another discussion researchers could have on this topic is the use of a multivariate analysis of more than two variables. There could be an attempt to quantify the "degree of destruction" or "intensity" of the alluvium flood events that were coupled with extreme rainfall events. Thereby creating time-series data with a quantified measurement/analysis of the alluvium events. Then, by using copulas where one of the variables would represent this series of intensity values for alluvium flood events and the other variable represents the rainfall measurements for the extreme rainfall events, it would be possible to analyse the correlations between the intense rainfalls and their coupled alluviums. Because, in this scenario, it would be possible to compare if more destructive alluviums are correlated with more extreme rainfalls. This could potentially be a strong development on the work done in chapter *3 Data* of this thesis. This is because the approach used in coupling rainfall and alluvium events was not quantitative or definite. Neither was it this thesis' approach to identify what exactly constituted an alluvium flood event. Though the three criteria used in chapter *3 Data* were necessary, there was insufficient data to quantitatively model the potency of alluvium flood events.

An interesting aspect to add to this work is a study of other areas of the island of Madeira and not just the capital, Funchal. There were many alluvium events that Sepúlveda (2011) collected and are presented in Annex I that could not be associated with any of the rainfall events simply because of the spatial criterion found in chapter *3 Data*. Using rainfall data from different locations in Madeira will allow for a more complete understanding of the rainfall and alluvium interactions.

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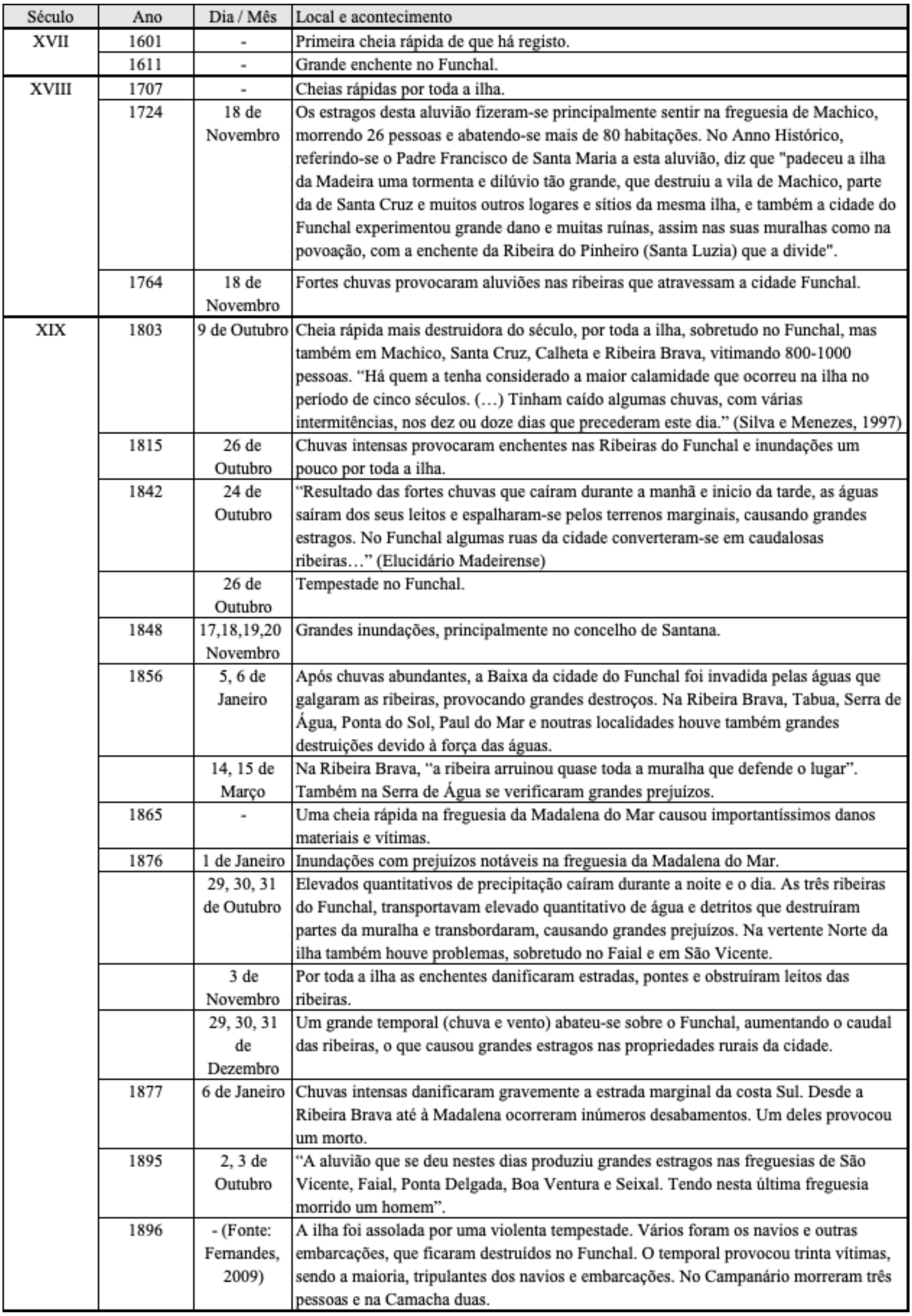
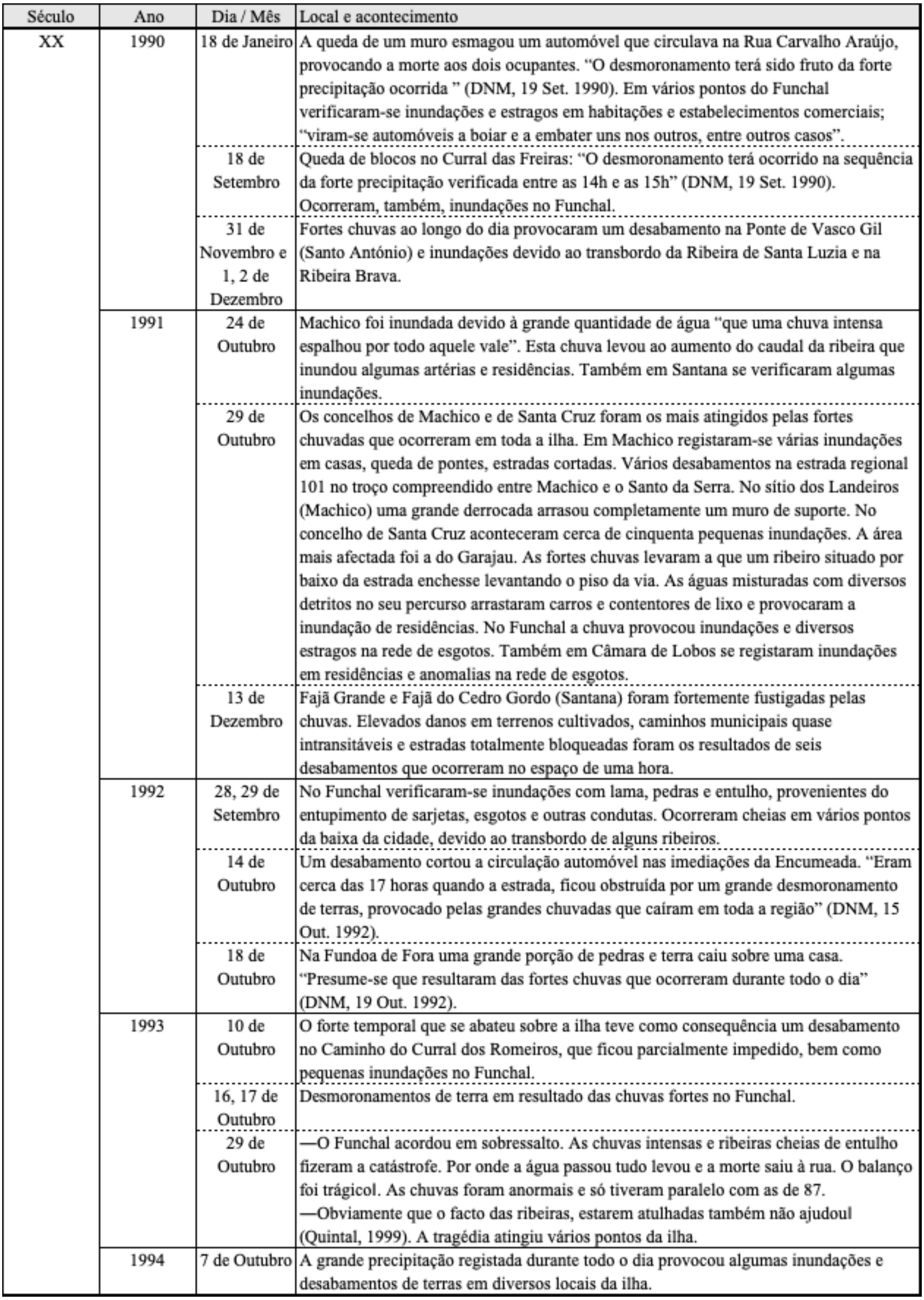
Annex I – Alluviums in Madeira

Table with description of extreme weather events in the island of Madeira and their dates. Reproduced from Sepúlveda, S.M.F., 2011, Avaliação da Precipitação Extrema na Ilha da Madeira. MSc Thesis. Environmental Engineering. IST/UL.



Século	Ano	Dia / Mês	Local e acontecimento
XVII	1601	-	Primeira cheia rápida de que há registo.
	1611	-	Grande enchente no Funchal.
XVIII	1707	-	Cheias rápidas por toda a ilha.
	1724	18 de Novembro	Os estragos desta aluvião fizeram-se principalmente sentir na freguesia de Machico, morrendo 26 pessoas e abatendo-se mais de 80 habitações. No Anno Histórico, referindo-se o Padre Francisco de Santa Maria a esta aluvião, diz que "padeceu a ilha da Madeira uma tormenta e dilúvio tão grande, que destruiu a vila de Machico, parte da de Santa Cruz e muitos outros logares e sítios da mesma ilha, e também a cidade do Funchal experimentou grande dano e muitas ruínas, assim nas suas muralhas como na povoação, com a enchente da Ribeira do Pinheiro (Santa Luzia) que a divide".
	1764	18 de Novembro	Fortes chuvas provocaram aluviões nas ribeiras que atravessam a cidade Funchal.
XIX	1803	9 de Outubro	Cheia rápida mais destruidora do século, por toda a ilha, sobretudo no Funchal, mas também em Machico, Santa Cruz, Calheta e Ribeira Brava, vitimando 800-1000 pessoas. "Há quem a tenha considerado a maior calamidade que ocorreu na ilha no período de cinco séculos. (…) Tinham caído algumas chuvas, com várias intermitências, nos dez ou doze dias que precederam este dia." (Silva e Menezes, 1997)
	1815	26 de Outubro	Chuvas intensas provocaram enchentes nas Ribeiras do Funchal e inundações um pouco por toda a ilha.
	1842	24 de Outubro	"Resultado das fortes chuvas que caíram durante a manhã e inicio da tarde, as águas saíram dos seus leitos e espalharam-se pelos terrenos marginais, causando grandes estragos. No Funchal algumas ruas da cidade converteram-se em caudalosas ribeiras…" (Elucidário Madeirense)
		26 de Outubro	Tempestade no Funchal.
	1848	17,18,19,20 Novembro	Grandes inundações, principalmente no concelho de Santana.
	1856	5, 6 de Janeiro	Após chuvas abundantes, a Baixa da cidade do Funchal foi invadida pelas águas que galgaram as ribeiras, provocando grandes destroços. Na Ribeira Brava, Tabua, Serra de Água, Ponta do Sol, Paul do Mar e noutras localidades houve também grandes destruições devido à força das águas.
		14, 15 de Março	Na Ribeira Brava, "a ribeira arruinou quase toda a muralha que defende o lugar". Também na Serra de Água se verificaram grandes prejuízos.
	1865	-	Uma cheia rápida na freguesia da Madalena do Mar causou importantíssimos danos materiais e vítimas.
	1876	1 de Janeiro	Inundações com prejuízos notáveis na freguesia da Madalena do Mar.
		29, 30, 31 de Outubro	Elevados quantitativos de precipitação caíram durante a noite e o dia. As três ribeiras do Funchal, transportavam elevado quantitativo de água e detritos que destruíram partes da muralha e transbordaram, causando grandes prejuízos. Na vertente Norte da ilha também houve problemas, sobretudo no Faial e em São Vicente.
		3 de Novembro	Por toda a ilha as enchentes danificaram estradas, pontes e obstruíram leitos das ribeiras.
		29, 30, 31 de Dezembro	Um grande temporal (chuva e vento) abateu-se sobre o Funchal, aumentando o caudal das ribeiras, o que causou grandes estragos nas propriedades rurais da cidade.
	1877	6 de Janeiro	Chuvas intensas danificaram gravemente a estrada marginal da costa Sul. Desde a Ribeira Brava até à Madalena ocorreram inúmeros desabamentos. Um deles provocou um morto.
	1895	2, 3 de Outubro	"A aluvião que se deu nestes dias produziu grandes estragos nas freguesias de São Vicente, Faial, Ponta Delgada, Boa Ventura e Seixal. Tendo nesta última freguesia morrido um homem".
	1896	- (Fonte: Fernandes, 2009)	A ilha foi assolada por uma violenta tempestade. Vários foram os navios e outras embarcações, que ficaram destruídos no Funchal. O temporal provocou trinta vítimas, sendo a maioria, tripulantes dos navios e embarcações. No Campanário morreram três pessoas e na Camacha duas.

Século	Ano	Dia / Mês	Local e acontecimento
XX	1901	8, 9 de Novembro	Chuvas abundantes no Funchal. As águas inundaram as ruas, causando muitos danos e alguns desmoronamentos.
	1920	24, 25 de Fevereiro	Violento temporal (vento e chuva) causou inúmeros prejuízos em toda a ilha. Em toda a ilha, ficaram mais de quinhentas pessoas sem abrigo. Ribeira Brava "correu grande risco de ser destruída pelas águas" (Silva e Menezes (1997) e Quintal (1999)). Na freguesia da Camacha morreu uma mulher e uma criança. Desapareceram com os tripulantes alguns barcos de pesca de Câmara de Lobos.
	1921	5, 6 de Março	Chuvas abundantes acompanhadas de trovoadas em toda a ilha, provocaram inundações e estragos em Machico, Ribeira Brava e em muitos outros pontos da ilha. Em Machico as águas subiram ao primeiro andar das casas. Na Ribeira Brava morreram quatro crianças, "três em virtude do desmoronamento de um prédio e uma arrastada pelas águas" (Silva e Menezes (1997) e Quintal (1999)).
	1929	6 de Março	Na sequência das "chuvas torrenciais" que se registaram , verificou-se a cheia da ribeira na freguesia de São Vicente, seguida de um desabamento, que causou cerca de 32 mortes e incalculáveis estragos – ficaram destruídas 11 casas e 100 palheiros, perdendo-se, mais de 100 cabeças de gado. Para Silva e Menezes (1997) e Quintal (1999), tratou-se da mais pavorosa e confrangedora catástrofe de que até à data havia memória na ilha da Madeira, só tendo paralelo com a aluvião de 1803.
	1931	2 de Outubro	Registaram-se várias inundações no Funchal, resultado de chuvas intensas.
		4 de Outubro	Chuvas torrenciais acompanhadas de uma violenta trovoada, no Funchal. Algumas ruas transformaram-se em leito de torrente caudalosa que tudo arrastava.
	1933	31 de Janeiro	A água das chuvas avolumou o caudal das ribeiras, ameaçando vidas, destruindo propriedades e danificando casas. Registou-se uma vítima mortal.
	1936	4 de Dezembro	No Funchal e arredores ocorreram chuvas abundantes. "Durante largo tempo choveu sem interrupção, vendo-se algumas ruas transformadas em ribeiras" (Quintal, 1999). A água invadiu as ruas, estabelecimentos e residências. Registaram-se dois desabamentos. Verificaram-se inundações, desabamentos e muitos prejuízos por toda a ilha.
	1939	30 de Dezembro	A freguesia da Madalena do Mar foi assolada por uma cheia rápida, resultado do forte temporal com "chuva contínua e vento forte". As chuvas quase ininterruptas engrossaram o caudal da ribeira de Santa Maria Madalena, que transbordou e arrastou uma parte considerável da sua área, foi levada para o mar sob "o fulminante impulso da aluvião," que arrastou cerca de 40 casas e vários terrenos de cultura, 4 mortos foi o resultado da tragédia" (Quintal, 1999).
	1956	3 de Novembro	"Admite-se a hipótese de uma grande tromba de água ter caído na zona da Portela, acentuadamente para os lados do Porto da Cruz, Ribeira de Machico, estendendo-se até à zona de Santa Cruz. Só assim se pode explicar o engrossamento imediato dos caudais das ribeiras e das inundações repentinas desta região" (Quintal, 1999). Os prejuízos causados na lavoura, nas propriedades urbanas, nas pontes, nos caminhos e nas estradas, foram incalculáveis. Em Machico danificou estradas, pontes, rede de água potável, casas e culturas. Para além dos muitos feridos que ocasionou, morreram cinco pessoas. No concelho vizinho, Santa Cruz, foram três pontes e duas casas destruídas, houve muitos danos, ruas cheias de lama e rochas e uma criança desapareceu.
	1958	21 de Dezembro	Uma violenta tempestade levou a que as ribeiras aumentassem consideravelmente o seu caudal, provocando desabamentos e grandes estragos por toda a ilha.
	1970	9 de Janeiro	Na Ribeira Brava "a força das águas destruiu a estrada em sete pontos, entre a vila e a Serra de Água, tendo sido levado o miradouro, que desapareceu, juntamente com duas pessoas" (Quintal, 1999).
	1972	21 de Setembro	Durante a madrugada, o caudal da Ribeira de Santo António aumentou repentinamente, tendo atingido um bairro de barracas localizado perto do Campo da Imaculada Conceição. Duas crianças e uma mulher não resistiram à força das águas.
	1979	23 e 24 de Janeiro	Aluviões atingiram Machico, Porto da Cruz, Camacha, Canhas, Calheta, e Fajã do Penedo, vitimando 14 pessoas.
	1985	2, 3 de Outubro	Uma cheia rápida provocou várias inundações e graves prejuízos. Alguns mortos, muitas casas soterradas, estradas e pontes destruídas foi o balanço do temporal que se abateu sobre a ilha.



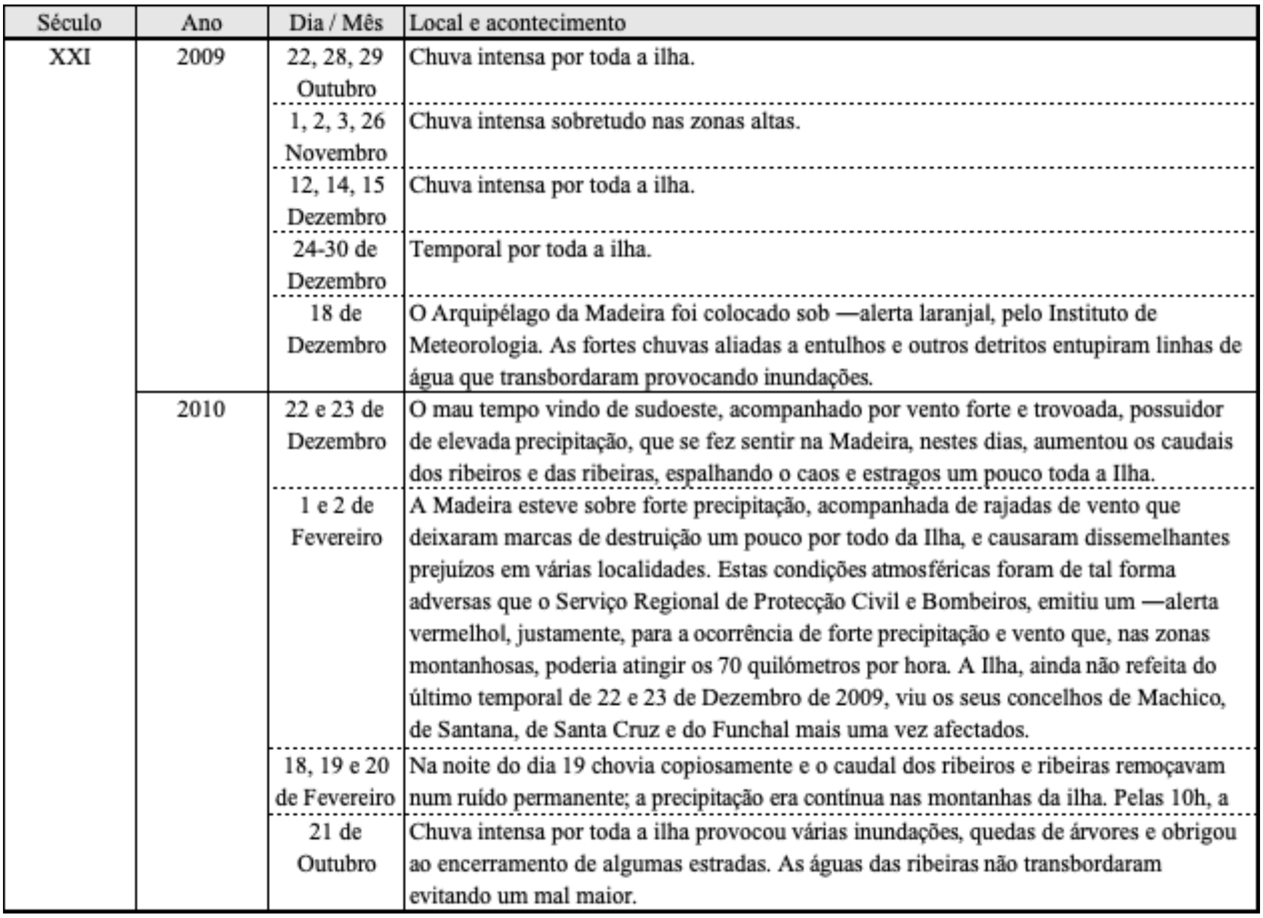
Século	Ano	Dia / Mês	Local e acontecimento
XX	1990	18 de Janeiro	A queda de um muro esmagou um automóvel que circulava na Rua Carvalho Araújo, provocando a morte aos dois ocupantes. "O desmoronamento terá sido fruto da forte precipitação ocorrida " (DNM, 19 Set. 1990). Em vários pontos do Funchal verificaram-se inundações e estragos em habitações e estabelecimentos comerciais; "viram-se automóveis a boiar e a embater uns nos outros, entre outros casos".
		18 de Setembro	Queda de blocos no Curral das Freiras: "O desmoronamento terá ocorrido na sequência da forte precipitação verificada entre as 14h e as 15h" (DNM, 19 Set. 1990). Ocorreram, também, inundações no Funchal.
		31 de Novembro e 1, 2 de Dezembro	Fortes chuvas ao longo do dia provocaram um desabamento na Ponte de Vasco Gil (Santo António) e inundações devido ao transbordo da Ribeira de Santa Luzia e na Ribeira Brava.
	1991	24 de Outubro	Machico foi inundada devido à grande quantidade de água "que uma chuva intensa espalhou por todo aquele vale". Esta chuva levou ao aumento do caudal da ribeira que inundou algumas artérias e residências. Também em Santana se verificaram algumas inundações.
		29 de Outubro	Os concelhos de Machico e de Santa Cruz foram os mais atingidos pelas fortes chuvadas que ocorreram em toda a ilha. Em Machico registaram-se várias inundações em casas, queda de pontes, estradas cortadas. Vários desabamentos na estrada regional 101 no troço compreendido entre Machico e o Santo da Serra. No sítio dos Landeiros (Machico) uma grande derrocada arrasou completamente um muro de suporte. No concelho de Santa Cruz aconteceram cerca de cinquenta pequenas inundações. A área mais afectada foi a do Garajau. As fortes chuvas levaram a que um ribeiro situado por baixo da estrada enchesse levantando o piso da via. As águas misturadas com diversos detritos no seu percurso arrastaram carros e contentores de lixo e provocaram a inundação de residências. No Funchal a chuva provocou inundações e diversos estragos na rede de esgotos. Também em Câmara de Lobos se registaram inundações em residências e anomalias na rede de esgotos.
		13 de Dezembro	Fajã Grande e Fajã do Cedro Gordo (Santana) foram fortemente fustigadas pelas chuvas. Elevados danos em terrenos cultivados, caminhos municipais quase intransitáveis e estradas totalmente bloqueadas foram os resultados de seis desabamentos que ocorreram no espaço de uma hora.
	1992	28, 29 de Setembro	No Funchal verificaram-se inundações com lama, pedras e entulho, provenientes do entupimento de sarjetas, esgotos e outras condutas. Ocorreram cheias em vários pontos da baixa da cidade, devido ao transbordo de alguns ribeiros.
		14 de Outubro	Um desabamento cortou a circulação automóvel nas imediações da Encumeada. "Eram cerca das 17 horas quando a estrada, ficou obstruída por um grande desmoronamento de terras, provocado pelas grandes chuvadas que caíram em toda a região" (DNM, 15 Out. 1992).
		18 de Outubro	Na Fundoa de Fora uma grande porção de pedras e terra caiu sobre uma casa. "Presume-se que resultaram das fortes chuvas que ocorreram durante todo o dia" (DNM, 19 Out. 1992).
	1993	10 de Outubro	O forte temporal que se abateu sobre a ilha teve como consequência um desabamento no Caminho do Curral dos Romeiros, que ficou parcialmente impedido, bem como pequenas inundações no Funchal.
		16, 17 de Outubro	Desmoronamentos de terra em resultado das chuvas fortes no Funchal.
		29 de Outubro	—O Funchal acordou em sobressalto. As chuvas intensas e ribeiras cheias de entulho fizeram a catástrofe. Por onde a água passou tudo levou e a morte saiu à rua. O balanço foi trágicol. As chuvas foram anormais e só tiveram paralelo com as de 87. —Obviamente que o facto das ribeiras, estarem atulhadas também não ajudoul (Quintal, 1999). A tragédia atingiu vários pontos da ilha.
	1994	7 de Outubro	A grande precipitação registada durante todo o dia provocou algumas inundações e desabamentos de terras em diversos locais da ilha.

Século	Ano	Dia / Mês	Local e acontecimento
XX	1995	25 de Outubro	Como resultado das primeiras chuvas outonais, registaram-se cerca de uma dezena de inundações na baixa da cidade do Funchal.
		17 de Novembro	Chuva e vento atingiram toda a ilha. Sucederam-se inundações, desabamentos e queda de árvores. No Funchal e na Ribeira Brava verificaram-se inundações e desabamentos com relativa dimensão.
		17 de Dezembro	Vento forte e chuva torrencial durante todo o dia, em particular nas áreas da Camacha, Santa Cruz, Machico, Ribeira Brava e São Vicente. A forte ondulação marítima fustigou durante o dia toda a faixa da Costa Oeste da Região.
		26, 27, 28 de Dezembro	Por toda a ilha, a elevada precipitação provocou inundações, quedas de pedras, desabamentos de terras, esgotos entupidos e quedas de árvores. Muitos troços de estrada ficaram obstruídos e o grande caudal de água, com pedras e terras provocou pânico na população e o abandono das residências ameaçadas. O concelho do Funchal foi o mais atingido, mas os desmoronamentos, que ocorreram por toda a ilha, tiveram maior incidência no Monte e em toda a Estrada Regional.
	1996	7, 8 de Janeiro	Muita chuva e vento assolaram a Madeira. —Muitos desabamentos e árvores a obstruir estradas estiveram na —ordem do diaǁ (DNM, 9 Jan.1996). A Estrada Regional entre São Vicente e Seixal esteve bloqueada durante algumas horas, devido ao mar alteroso e a alguns desabamentos que fustigaram norte da ilha. Verificaram-se pequenas inundações por toda a ilha.
		28, 29, 31 de Janeiro	Enormes pedras e terra desprenderam-se no sítio da Alegria (São Roque). Em Santa Cruz, as chuvas torrenciais e o vento forte provocaram diversas inundações. A escola de Santa Cruz encerrou devidas às inundações que provocaram avultados estragos, também nas Estações de Tratamento de Resíduos Sólidos do Funchal e de Câmara de Lobos. Na área rural, um dos casos mais graves registou-se na Calheta, onde o mar provocou elevados estragos junto ao cais. Na estrada para o Curral das Freiras, verificaram-se dois desabamentos.
		22, 23, 24 de Março	Forte temporal com grande descarga de água em toda a ilha. Verificaram-se desabamentos, quedas de árvores e obstrução de estradas.
		12 de Dezembro	A água da chuva provocou inundações um pouco por toda a ilha. Os casos mais relevantes registaram-se na capital madeirense, onde o túnel da —Cota 40l ficou inundado e várias casas sofreram inundações.
		15, 16 de Dezembro	Chuva copiosa na Travessa dos Três Paus. Um desabamento terá entupimento da Levada do Pico do Cardo, —As terras lamacentas deslizaram de rompante pela encosta, destruindo duas casasl (DNM, 17 Dez. 1996). Na enxurrada foram arrastadas duas viaturas.
	1997	30 de Setembro	A chuva que se registou durante a tarde no Funchal alagou ruas onde as sarjetas estavam entupidas e inundou algumas casas e estabelecimentos. Ocorreram derrocadas no início da cota 200.
		17, 18, 19, 20 de Outubro	Como consequência das fortes chuvas que ocorreram durante o fim-de-semana, no dia 17 a Estrada Regional 222 ficou totalmente obstruída devido a um deslizamento de terras. Nos dias 18 e 19 ocorreram graves inundações e derrocadas por toda a ilha. A —anormal precipitação que se registou no sitio do Ribeiro Serrãol (DNM, 21 Out. 1997), provocou um deslizamento de terras e o rebentamento de um cano de água, água que foi desaguar à estrada do Ribeiro Serrão, a mais de 600 m acima da estrada e —provocou uma impressionante descida de lama por uma vereda, servindo a estrada como receptor final desta —ondal de lamal (DNM, 21 Out. 1997).
		23 de Outubro	Um pouco por todo o lado houve caudais de água lamacenta a provocar diversas inundações, pequenos desabamentos e estradas intransitáveis.
		25 de Outubro	As fortes chuvadas que se abateram sobre toda a ilha, com especial incidência na zona norte, provocaram alguns estragos, aluimentos de terras e desabamentos. O mais grave incidente ocorreu no Lombo do Mouro, na estrada que liga a Encumeada ao Paul da

Século	Ano	Dia / Mês	Local e acontecimento
XX	1997	02-Nov	Em consequência do mau tempo, no Pico do Lombo (Monte) houve terras arrastadas que ameaçaram casas. Ocorreram inundações, desabamentos e árvores caídas no Funchal. —As chuvas que caíram durante a madrugada varreram terras e pedras pelas encostas, cujo resultado viria a ser notório nas estradas de toda a ilhal (DNM, 3 Nov. 1997).
		5, 6, 7, 8 de Dezembro	Fortes chuvas provocaram diversos desabamentos um pouco por toda a ilha. A forte ondulação também deixou rasto de destruição no Garajau e na Praia Formosa, as ondas galgaram o perímetro da praia, tal como na Ribeira Brava e na Ponta do Sol.
		17 de Dezembro	O mau tempo deixou rasto de destruição um pouco por toda a ilha, tendo ocorrido diversas inundações, quedas de árvores e desabamentos. O caudal das ribeiras aumentou significativamente, a orla costeira foi assolada por forte ondulação.
		21 de Dezembro	Ocorreram enxurradas que arrastaram pedregulhos de mais de 4 toneladas. —A precipitação dos últimos dias e uma suposta fenda na rocha fez desabar a encosta no leito do ribeiro íngreme. A derrocada chegou à estrada e ameaçou bens patrimoniais e vidas humanas, na Meia Légua (Ribeira Brava) (DNM, 22 Dez.1997).
	1998	11, 12 de Janeiro	Devido a forte precipitação, registaram-se inundações e desabamentos um pouco por toda a ilha. As zonas mais afectadas foram Funchal e Machico.
		31 de Janeiro	—A enxurrada de terras e pedras, arame de latadas, estacas e árvores atingiu o malogrado levando-o à morte (…). Um morto no Garachico (Estreito de Câmara de Lobos), dois transbordos de ribeiros, três dezenas de inundações e duas dezenas de desabamentos foi o balanço do temporall (DNM, Fev.1998). Entre as 9h de Sábado e as 9h de Domingo, a maior precipitação aconteceu em Santa Cruz (82,7 litros por m2), Lugar de Baixo e Ponta do Sol (71 litros), Funchal (64,2 litros), Quinta Magnólia (64,2 litros), Santana (48 litros) e Porto Santo 32,2 litros). O vento atingiu os 80km/h.
		7 de Fevereiro	—Um pouco por todo o lado, os terrenos estão a ceder devido ao peso da água da chuval (DNM, 8 Fev. 1998).
		9 de Maio	Como resultado das chuvas que caíram de madrugada, vários foram os estragos ocorridos, sobretudo no início da vereda do Livramento (Funchal).
		17, 18 de Outubro	Fortes chuvas durante a madrugada do dia 17, provocaram diversas inundações e lamaçais no Funchal, Santo António, Encumeada e Ribeira Brava.
	1999	12, 13 de Janeiro	Temporal um pouco por toda a ilha, sobretudo a norte e no Funchal.
		10 de Outubro	Fortes chuvas no Funchal, seguidas de desmoronamentos.
		27 de Outubro	—Fortes chuvas por toda a ilha provocaram desabamentos, inundações, desmoronamentos de muros, terrenos e de parte de residênciasl (DNM, 28 Out. 1999).
		29, 30 de Outubro	—Em resultado das últimas chuvas, algumas casas tremeram e ruíram parcialmente. Outras ameaçam ruir caso a chuva teime em cair com tamanha intensidadel (DNM, 30 Out.1999). As inundações foram incontáveis, sobretudo no Funchal e no na Vertente Norte.
		4 de Dezembro	A chuva que caiu de madrugada e durante o dia, arrastou lama e alagou algumas áreas e residências.
		7 de Dezembro	Uma pessoa morreu na sequência de uma enxurrada ocorrida no sítio do Ribeiro Serrão (Camacha).
	2000	18 de Janeiro	Forte precipitação nas zonas mais altas provocou um deslizamento no Santo da Serra.
		31 de Março	Forte precipitação por toda a ilha.
		6 de Abril	Chuva intensa um pouco por toda a ilha: na Terra Chã, Curral das Freiras (fez transbordar a ribeira, causando inundações e derrocadas); no Carvalhal (Canhas) e no Pomar D. João, concelho da Ponta do Sol; na Estrada Regional 101 entre a Bica da Cana e a Encumeada (provocando a queda de várias pedras na estrada).
		12 de Abril	Queda de pedras de consideráveis dimensões na estrada marginal entre Ribeira Brava e Tabua, como consequência de precipitações intensas.
		15 de Abril	Desabamento no Curral das Freiras, consequente de precipitações intensas.
		15 de Maio	Desabamentos e quedas de blocos devido a precipitações intensas na Boaventura.
		13 de Agosto	Chuva intensa na vertente Norte, com inundações em S. Vicente.
		8 de Setembro	Inundações e derrocadas provocadas por precipitações intensas em toda a ilha.
		21 de Setembro	Inundações, derrocadas e queda de árvores provocadas por precipitações intensas em toda a ilha.
		24 de Dezembro	Temporal por toda a ilha.

Século	Ano	Dia / Mês	Local e acontecimento
XXI	2001	2 de Março	Temporal por toda a ilha.
		5, 6 e 7 de Março	Forte precipitação por toda a ilha. No dia 6, ocorreu um forte temporal sobre S. Vicente e o Curral das Freiras.
		21 de Setembro	Precipitação intensa causou diversas inundações no Funchal.
		18 e 19 de Novembro	Temporal sobretudo na Vertente Sul da ilha provocou inundações, desabamentos e queda de árvores.
		9 de Dezembro	Temporal por toda a ilha, sobretudo na Vertente Sul.
	2002	1 e 2 de Janeiro	Temporal por toda a ilha.
		14, 18, 24 e 27 de Setembro	Precipitações intensas sobretudo nas zonas altas.
		26 de Setembro	Precipitação intensa provocou inundações no Funchal.
		19 e 20 de Outubro	Precipitação intensa, sobretudo em altitude, provocaram um desabamento na Encumeada, inundações no Funchal e queda de blocos na Calheta.
		12 de Novembro	Precipitações intensas sobretudo nas zonas altas.
		24 de Novembro	Temporal por toda a ilha, sobretudo a Sul e Oeste, provocou aluimentos de terras, inundações e obstruções de estradas.
		12 de Dezembro	Precipitações intensas sobretudo nas zonas altas.
		15,16,17,18 Dezembro	Temporal na Vertente Sul da ilha.
		22 de Dezembro	Precipitações intensas por toda a ilha, sobretudo nas zonas altas.
	2003	18, 20, 23 Fevereiro	Precipitações intensas por toda a ilha.
		12, 13, 26, 27 Março	Precipitações intensas por toda a ilha.
		6 e 7 de Abril	Precipitações intensas por toda a ilha.
		12 e 21 de Abril	Precipitações intensas sobretudo nas zonas altas.
		2, 3, 10 de Outubro	Precipitações intensas por toda a ilha.
		6 e 7 de Novembro	Precipitações intensas por toda a ilha.
	2004	20 e 22 de Fevereiro	Precipitações intensas por toda a ilha.
		25 de Março	Precipitações intensas sobretudo nas zonas altas.
		17,18e19 de Outubro	Precipitações intensas por toda a ilha.
		12,13e14 Dezembro	Forte temporal por toda a ilha.
	2005	16 de Janeiro	Precipitações intensas por toda a ilha.
		27 e 31 de Janeiro	Precipitações intensas sobretudo na zona do Areeiro.
		Fevereiro	Chuva intensa ao longo do mês, um pouco por toda a ilha (destacam- se os dias 5, 6, 7, 8, 14, 23, 26, 27 e 28)
		2, 3 e 4 de Março	Chuva intensa um pouco por toda a ilha.
		7, 8, 26, 27, 29 Outubro	Chuva intensa um pouco por toda a ilha.
		18 de Novembro	Desabamento na estrada entre Bica de Cana e Encumeada, devido às chuvas intensas registadas nos dias anteriores.
		27 a 29 de Novembro	Chuva intensa e vento, com inundações sobretudo em Câmara de Lobos devido ao difícil escoamento das águas pluviais. A tempestade desfigurou o litoral do Funchal à

Século	Ano	Dia / Mês	Local e acontecimento
XXI	2005	17 de Dezembro	Chuva intensa um pouco por toda a ilha.
		20, 21 e 22 Dezembro	O aumento do leito da Ribeira Grande, em Machico, fez transboardar a ribeira com violência e inundou habitações do Moinho da Serra e estradas.
		24,25,27,28 Dezembro	Chuva intensa por todo o arquipélago.
	2006	9, 16, 17, 24, 25, 27 Janeiro	Chuva intensa um pouco por toda a ilha.
		7, 8, 9, 14, 27, 28 Fevereiro	Chuva intensa um pouco por toda a ilha.
		1,16,17de Março	Chuva intensa um pouco por toda a ilha.
		8 e 9 de Abril	Chuva intensa um pouco por toda a ilha.
		13 Junho	Chuva intensa um pouco por toda a ilha.
		23 de Setembro	Chuva intensa um pouco por toda a ilha.
		15 de Outubro	Chuva intensa um pouco por toda a ilha.
		22, 23, 24, 25, 28, 29 Outubro de	Temporal por toda a ilha.
		1, 2 e 3 de Novembro	―Bastou meia hora de chuva e logo os estragos foram visíveis, quer na baixa funchalense, quer nas zonas altas da capitall (DNM, 2 Nov. 2006). Temporal por toda a ilha.
		15, 24 e 28 Novembro	Chuva intensa por toda a ilha.
		8 a 12, 28 Dezembro	Chuva copiosa um pouco por toda a ilha.
	2007	1 de Janeiro	Chuva copiosa um pouco por toda a ilha.
		25 de Janeiro	Chuva intensa por toda a ilha.
		5, 15 de Fevereiro	Chuva intensa por toda a ilha.
		13, 17, 20, 21 Março	Chuva intensa por toda a ilha.
		7 e 8 de Abril	Chuva intensa provocou inundações no Funchal.
		10 e 11 de Abril	Chuva intensa provocou queda de pedras na estrada de acesso ao Curral das Freiras, para além de inundações.
		20, 21, 22, 25, 26 Maio	Chuva intensa por toda a ilha.
		23 de Outubro	Chuva Intensa na zona oeste da ilha.
		7 de Novembro	Chuva intensa por todo o arquipélago.
		17-23 Novembro	Chuva intensa por toda a ilha, com maior incidência na costa norte, provocou inundações e inúmeros desabamentos.
	2008	16 e 17 de Fevereiro	Como resultado de chuva intensa, lama e pedras invadiram a estrada no sítio da Caldeira, na Tabua.
		7, 8 e 9 de Abril	O temporal vindo de sudoeste abateu-se sobretudo sobre a costa sul da ilha. A precipitação caiu em abundância nos concelhos da Ribeira Brava, São Vicente, Câmara de Lobos, Funchal e Santa Cruz.
		5, 6, 7 8 e 9 de Maio	Temporal por toda a ilha.
		Setembro	Chuva intensa por toda a ilha vários dias ao longo do mês (destacam- se os dias 11, 19, 20, 24, 26).



Século	Ano	Dia / Mês	Local e acontecimento
XXI	2009	22, 28, 29 Outubro	Chuva intensa por toda a ilha.
		1, 2, 3, 26 Novembro	Chuva intensa sobretudo nas zonas altas.
		12, 14, 15 Dezembro	Chuva intensa por toda a ilha.
		24-30 de Dezembro	Temporal por toda a ilha.
		18 de Dezembro	O Arquipélago da Madeira foi colocado sob —alerta laranjal, pelo Instituto de Meteorologia. As fortes chuvas aliadas a entulhos e outros detritos entupiram linhas de água que transbordaram provocando inundações.
	2010	22 e 23 de Dezembro	O mau tempo vindo de sudoeste, acompanhado por vento forte e trovoada, possuidor de elevada precipitação, que se fez sentir na Madeira, nestes dias, aumentou os caudais dos ribeiros e das ribeiras, espalhando o caos e estragos um pouco toda a Ilha.
		1 e 2 de Fevereiro	A Madeira esteve sobre forte precipitação, acompanhada de rajadas de vento que deixaram marcas de destruição um pouco por todo da Ilha, e causaram dissemelhantes prejuízos em várias localidades. Estas condições atmosféricas foram de tal forma adversas que o Serviço Regional de Protecção Civil e Bombeiros, emitiu um —alerta vermelhol, justamente, para a ocorrência de forte precipitação e vento que, nas zonas montanhosas, poderia atingir os 70 quilómetros por hora. A Ilha, ainda não refeita do último temporal de 22 e 23 de Dezembro de 2009, viu os seus concelhos de Machico, de Santana, de Santa Cruz e do Funchal mais uma vez afectados.
		18, 19 e 20 de Fevereiro	Na noite do dia 19 chovia copiosamente e o caudal dos ribeiros e ribeiras remoçavam num ruído permanente; a precipitação era contínua nas montanhas da ilha. Pelas 10h, a
		21 de Outubro	Chuva intensa por toda a ilha provocou várias inundações, quedas de árvores e obrigou ao encerramento de algumas estradas. As águas das ribeiras não transbordaram evitando um mal maior.

Annex II – Daily rainfall AMS and cumulative series

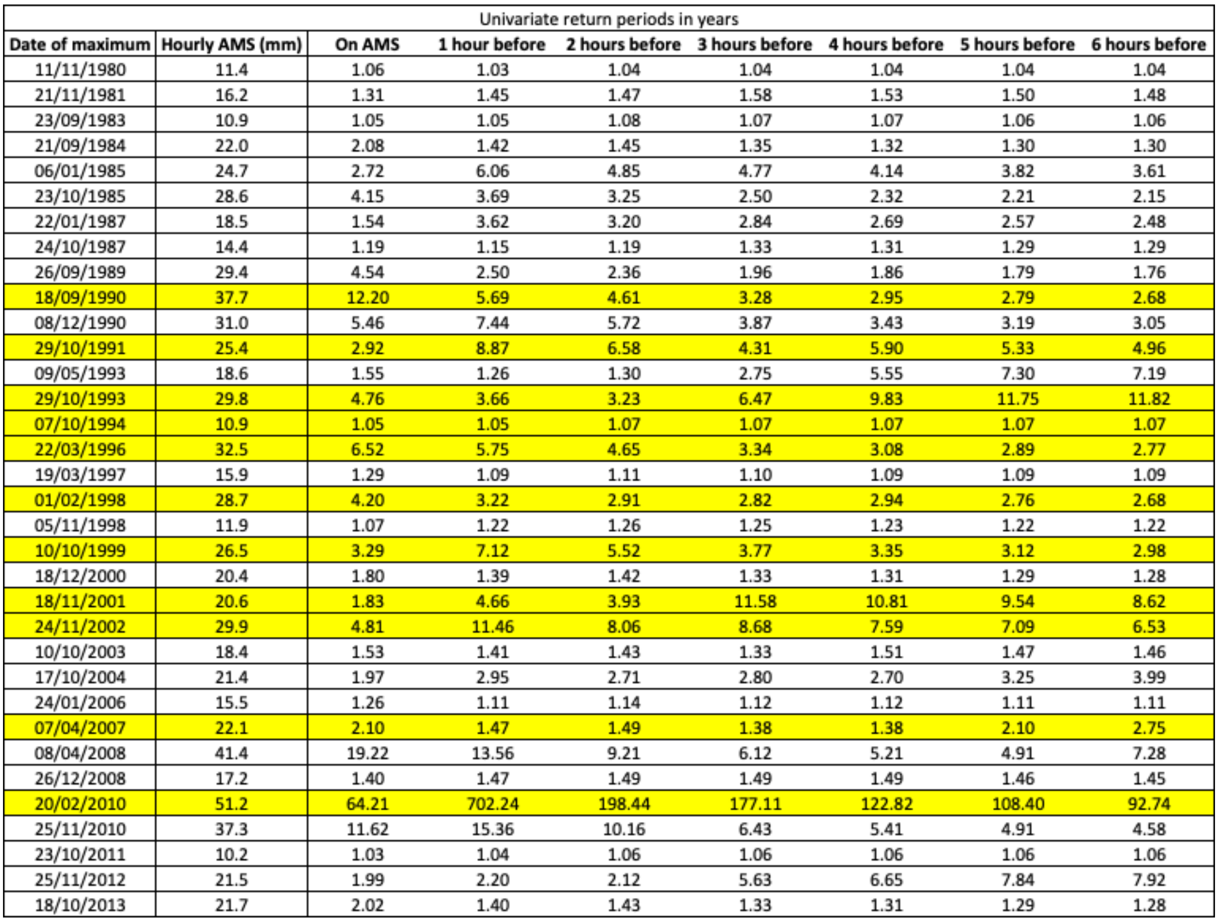
X_0, X_n^B, X_n^A and X_n^{BA} for the daily rainfall data for the 80 years with the date of annual maximum rainfall.

Date of X_0	X_0	X^B_1	X^B_2	X^B_3	X^B_4	X^B_5	X^B_6	X^A_1	X^A_2	X^A_3	X^A_4	X^A_5	X^A_6	X^{BA}_1	X^{BA}_2	X^{BA}_3	X^{BA}_4	X^{BA}_5	X^{BA}_6
19/10/1937	61.2	61.7	71.2	81.3	125.0	149.2	168.8	61.2	61.2	61.2	61.7	61.7	61.7	61.7	71.2	81.3	125.5	125.5	169.3
23/09/1939	28.2	28.2	29.3	47.9	47.9	47.9	58.5	28.6	30.2	55.4	81.1	81.1	81.1	28.6	31.3	75.1	100.8	100.8	111.4
23/12/1939	60.5	77.0	80.2	80.2	80.2	80.2	80.2	96.8	102.8	115.1	115.1	115.1	118.1	113.3	122.5	134.8	134.8	134.8	137.8
12/02/1941	107.0	107.2	113.2	113.2	113.2	113.2	113.2	110.5	113.0	121.5	125.5	126.9	126.9	110.7	119.2	127.7	131.7	133.1	133.1
06/11/1941	67.7	111.4	126.8	138.7	138.7	142.3	142.3	103.0	103.0	103.0	110.0	111.3	111.3	146.7	162.1	174.0	181.0	182.3	185.9
06/10/1942	56.0	56.0	56.0	57.0	109.8	109.8	155.8	64.0	68.0	68.0	68.1	68.2	68.2	64.0	68.0	69.0	121.9	122.0	168.0
09/02/1944	43.8	48.6	48.6	48.6	48.6	48.6	48.6	43.8	43.8	43.8	43.8	43.8	43.8	48.6	48.6	48.6	48.6	48.6	48.6
11/11/1944	38.2	41.2	42.3	55.8	57.8	58.9	58.9	38.2	38.2	38.2	38.2	38.2	38.9	41.2	42.3	55.8	57.8	57.8	59.6
13/12/1945	59.1	59.9	62.6	75.6	81.6	81.6	81.6	59.1	59.1	59.1	65.9	68.6	81.3	59.9	62.6	75.6	88.4	91.1	103.8
24/01/1947	51.0	51.1	93.1	93.7	93.7	93.7	93.7	51.1	51.1	54.1	55.1	55.1	59.1	51.2	93.2	96.8	97.8	97.8	101.8
23/02/1948	41.0	41.9	42.4	42.4	53.0	53.0	58.8	45.2	53.6	55.8	55.8	55.8	62.2	46.1	55.0	57.2	67.8	67.8	80.0
23/11/1948	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	31.8	31.8	31.8	30.2	30.2	30.2	31.8	31.8	31.8
03/11/1949	66.8	78.4	78.4	79.1	79.6	85.7	86.4	66.8	66.8	66.8	66.8	66.8	66.8	78.4	78.4	79.1	79.6	79.6	86.4
02/06/1951	27.5	27.9	27.9	27.9	28.2	28.2	28.2	33.8	33.8	33.8	33.8	37.5	37.5	34.2	34.2	34.2	34.5	38.2	38.2
31/03/1952	48.4	57.2	73.9	104.7	114.1	122.8	122.8	48.9	48.9	48.9	48.9	48.9	48.9	57.7	74.4	105.2	114.6	114.6	123.3
19/11/1952	111.9	116.6	116.6	117.4	117.5	118.8	118.8	133.0	133.0	133.0	133.0	133.0	133.0	137.7	137.7	138.5	138.6	138.6	139.9
09/10/1953	115.6	128.9	129.9	129.9	129.9	129.9	129.9	115.8	126.1	130.7	130.8	136.1	136.1	129.1	140.4	145.0	145.1	150.4	150.4
02/01/1955	27.3	31.8	36.5	36.5	36.5	40.2	48.9	27.3	39.4	48.1	48.1	48.1	48.1	31.8	48.6	57.3	57.3	57.3	69.7
12/01/1956	97.6	105.1	105.1	105.3	112.9	116.2	116.2	97.6	97.6	110.4	116.9	125.0	125.0	105.1	105.1	118.1	132.2	140.3	143.6
04/11/1956	131.2	166.1	169.7	169.7	169.7	169.7	169.7	132.5	132.5	132.5	132.5	169.3	169.3	167.4	171.0	171.0	171.0	207.8	207.8
09/12/1957	38.0	43.6	44.2	47.5	49.0	67.9	100.7	38.3	38.3	49.0	61.0	63.5	63.5	43.9	44.5	58.5	72.0	74.5	126.2
24/01/1959	52.6	58.6	58.6	58.6	61.9	94.1	94.1	92.5	112.9	116.5	116.6	116.6	116.6	98.5	118.9	122.5	125.9	125.9	158.1
21/03/1960	47.4	49.0	49.0	49.0	49.5	49.5	49.5	49.7	65.4	65.4	65.4	65.4	65.4	51.3	67.0	67.0	67.5	67.5	67.5
22/10/1960	20.4	23.9	23.9	25.5	25.5	25.5	25.6	20.4	20.4	20.4	24.0	31.4	31.4	23.9	23.9	25.5	29.1	36.5	36.6
22/09/1962	49.1	49.3	50.1	50.1	50.1	50.1	50.1	59.4	62.3	66.5	66.7	66.7	66.7	59.6	63.3	67.5	67.7	67.7	67.7
31/01/1963	62.7	63.9	63.9	65.7	86.8	103.7	107.4	64.5	76.3	97.6	107.0	107.0	125.4	65.7	77.5	100.6	131.1	131.1	170.1
21/06/1964	57.8	61.6	61.6	61.6	61.6	61.6	61.6	58.0	58.0	58.0	58.5	58.6	58.6	61.8	61.8	61.8	62.3	62.4	62.4
01/06/1965	44.3	44.3	44.3	44.3	44.3	44.3	44.3	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6
26/10/1965	54.1	54.1	61.9	71.4	88.9	91.7	91.8	57.1	62.3	63.3	63.3	63.3	63.5	57.1	70.1	80.6	98.1	98.1	101.2
31/10/1966	68.7	123.9	184.8	186.7	193.3	193.3	193.3	126.5	130.1	132.1	132.1	132.1	154.3	181.7	246.2	250.1	256.7	256.7	278.9
21/11/1967	64.9	64.9	66.4	66.9	77.5	80.2	108.0	101.4	148.2	149.9	149.9	155.1	161.2	101.4	149.7	151.9	162.5	167.7	204.3
04/01/1969	84.4	88.7	103.3	185.8	206.7	206.7	206.8	92.3	93.7	120.7	126.7	132.9	132.9	96.6	112.6	222.1	249.0	255.2	255.3
26/03/1970	45.8	46.2	46.2	46.2	47.3	47.3	47.3	51.7	51.7	52.8	65.6	65.6	78.3	52.1	52.1	53.2	67.1	67.1	79.8
29/12/1970	52.3	98.6	100.8	125.9	134.8	142.4	143.6	52.3	52.3	58.4	58.5	73.1	73.1	98.6	100.8	132.0	141.0	155.6	164.4
21/09/1972	72.6	73.5	73.5	73.5	73.5	73.5	73.5	96.1	96.1	134.4	157.5	157.6	157.6	97.0	97.0	135.3	158.4	158.5	158.5
23/10/1972	38.0	41.8	53.5	53.5	54.9	64.8	66.8	46.0	53.6	73.5	73.5	73.5	73.5	49.8	69.1	89.0	90.4	90.4	102.3
27/05/1974	71.4	73.1	73.6	73.6	73.6	73.6	74.1	71.4	71.4	71.4	71.4	71.4	71.4	73.1	73.6	73.6	73.6	73.6	74.1
27/02/1975	47.0	47.0	47.0	47.0	47.0	47.0	47.0	51.9	53.0	53.0	53.0	53.0	53.0	51.9	53.0	53.0	53.0	53.0	53.0
15/12/1975	37.6	42.3	46.9	54.3	57.5	59.3	60.2	37.6	37.6	37.6	37.6	37.6	37.6	42.3	46.9	54.3	57.5	57.5	60.2
27/12/1976	84.9	85.7	85.7	85.7	85.7	85.7	85.7	84.9	148.9	161.9	177.2	177.6	177.6	85.7	149.7	162.7	178.0	178.4	178.4
20/12/1977	55.7	60.6	62.2	77.7	78.0	81.3	102.9	91.7	92.6	92.8	92.8	92.8	92.8	96.6	99.1	114.8	115.1	115.1	140.0
06/11/1978	76.6	76.6	76.6	76.6	76.6	76.6	76.6	78.9	78.9	78.9	78.9	78.9	80.7	78.9	78.9	78.9	78.9	78.9	80.7
14/04/1980	34.6	53.9	54.1	63.7	63.7	63.7	63.7	34.6	34.6	34.6	34.8	34.8	35.5	53.9	54.1	63.7	63.9	63.9	64.6
04/10/1980	26.6	34.9	35.0	40.7	69.1	75.3	75.8	50.3	50.3	50.3	50.3	50.3	50.3	58.6	58.7	64.4	92.8	92.8	99.5
16/09/1982	42.1	42.1	42.1	42.1	42.1	42.1	42.1	49.7	59.9	59.9	59.9	59.9	59.9	49.7	59.9	59.9	59.9	59.9	59.9
06/03/1983	19.9	28.0	28.0	28.0	28.0	28.0	28.0	21.0	21.0	21.0	21.0	21.0	21.0	29.1	29.1	29.1	29.1	29.1	29.1
22/09/1984	73.2	73.2	73.2	73.2	73.2	73.4	73.4	97.7	97.7	97.7	97.7	100.0	100.1	97.7	97.7	97.7	97.7	100.0	100.3
06/01/1985	55.5	73.3	95.3	99.8	99.8	99.8	99.8	60.6	60.6	63.2	63.2	63.2	63.2	78.4	100.4	107.5	107.5	107.5	107.5
23/10/1985	47.5	66.9	74.3	74.3	74.3	74.3	74.3	50.8	50.8	50.8	50.8	50.8	50.8	70.2	77.6	77.6	77.6	77.6	77.6
23/01/1987	90.2	95.3	95.3	95.3	95.3	95.3	95.3	108.8	144.7	166.2	177.1	185.0	187.8	113.9	149.8	171.3	182.2	190.1	192.9
25/10/1987	91.7	93.7	93.7	102.8	102.8	102.9	103.9	102.7	102.7	104.8	104.8	116.1	116.9	104.7	104.7	115.9	115.9	127.2	129.1
27/09/1989	97.7	99.9	99.9	99.9	101.7	101.7	101.7	119.5	127.5	132.6	141.5	149.2	149.4	121.7	129.7	134.8	145.5	153.2	153.4
26/10/1989	82.8	146.8	155.3	155.3	155.3	155.3	155.3	82.8	82.8	82.8	82.8	82.8	82.8	146.8	155.3	155.3	155.3	155.3	155.3
01/12/1990	71.6	82.0	88.6	88.6	88.6	88.6	88.6	102.5	124.0	127.9	128.3	128.3	128.3	112.9	141.0	144.9	145.3	145.3	145.3
23/10/1991	56.1	56.1	56.1	56.1	56.1	56.5	56.5	56.1	57.3	57.3	57.3	57.3	66.8	56.1	57.3	57.3	57.3	57.3	67.2
09/05/1993	42.4	46.2	57.4	57.4	58.0	58.1	58.9	70.4	88.0	88.0	88.0	88.0	88.4	74.2	103.0	103.0	103.6	103.6	104.9
29/10/1993	88.9	89.2	89.2	89.2	89.2	89.2	89.2	108.2	150.6	150.6	150.6	154.5	154.6	108.5	150.9	150.9	150.9	154.8	154.9
08/10/1994	53.0	56.5	56.5	56.5	56.5	56.5	56.5	53.1	69.2	82.4	82.4	84.8	84.8	56.6	72.7	85.9	85.9	88.3	88.3
16/11/1995	94.7	94.7	94.7	94.7	94.7	102.7	102.7	96.8	96.8	96.8	96.8	96.8	96.8	96.8	96.8	96.8	96.8	96.8	104.8
01/02/1997	39.8	44.9	48.0	50.3	50.4	50.7	51.0	39.8	39.8	39.8	39.8	39.8	39.8	44.9	48.0	50.3	50.4	50.4	51.0
21/12/1997	68.1	68.1	69.3	89.1	93.0	94.7	109.2	70.5	70.5	70.5	70.5	70.5	70.5	70.5	71.7	91.5	95.4	95.4	111.6
12/01/1999	53.1	62.2	62.2	62.2	62.2	65.8	89.4	61.3	70.1	70.3	70.3	70.3	70.3	70.4	79.2	79.4	79.4	79.4	106.6
26/10/1999	50.6	50.9	55.6	55.6	71.9	71.9	71.9	84.0	113.0	113.0	113.0	113.0	113.0	84.3	118.0	118.0	134.3	134.3	134.3
05/03/2001	53.1	61.7	64.7	80.5	90.4	90.4	91.0	78.4	79.5	79.5	79.5	79.5	79.5	87.0	91.1	106.9	116.8	116.8	117.4
20/11/2001	86.1	150.3	160.0	160.0	160.0	160.0	160.0	95.8	95.8	95.8	95.8	95.8	95.8	160.0	169.7	169.7	169.7	169.7	169.7
25/11/2002	78.2	78.9	78.9	78.9	78.9	78.9	83.1	78.2	78.2	81.8	81.8	81.8	81.8	78.9	78.9	82.5	82.5	82.5	86.7
04/10/2003	36.0	50.5	53.5	53.5	63.0	63.0	63.2	36.0	45.0	49.5	49.5	49.5	49.5	50.5	62.5	67.0	76.5	76.5	76.7
18/10/2004	61.7	61.7	61.7	61.7	62.7	64.2	64.2	65.3	81.7	81.7	81.7	81.7	81.7	65.3	81.7	81.7	82.7	82.7	84.2
09/02/2006	44.2	66.2	66.2	66.2	66.2	66.2	66.2	83.2	86.7	86.7	86.7	86.7	90.4	105.2	108.7	108.7	108.7	108.7	112.4
08/04/2007	62.9	63.0	64.1	64.1	64.1	64.1	64.1	62.9	62.9	83.1	83.1	83.1	83.1	63.0	64.1	84.3	84.3	84.3	84.3
08/04/2008	110.9	159.3	163.1	163.4	163.4	163.4	163.4	141.6	149.4	149.5	150.3	150.3	150.3	190.0	201.6	202.0	202.8	202.8	202.8
27/02/2009	82.3	88.8	88.8	88.8	88.8	88.8	88.8	84.0	84.3	95.4	103.4	103.7	103.7	90.5	90.8	101.9	109.9	110.2	110.2
02/02/2010	111.0	122.1	131.8	131.8	131.8	134.0	135.2	152.0	152.0	159.1	159.1	159.1	166.2	163.1	172.8	179.9	179.9	179.9	190.4
26/11/2010	155.1	156.6	156.6	158.3	189.0	189.0	189.3	157.6	159.0	207.7	230.5	230.5	230.5	159.1	160.5	210.9	264.4	264.4	264.7
24/10/2011	30.0	31.3	31.5	31.5	31.5	31.5	31.5	30.0	32.0	33.2	33.2	33.2	33.2	31.3	33.5	34.7	34.7	34.7	34.7
25/11/2012	67.3	77.5	77.5	77.5	105.2	105.2	105.2	72.3	84.1	84.4	84.4	84.6	84.6	82.5	94.3	94.6	122.3	122.5	122.5
16/09/2014	33.1	33.1	37.3	40.1	42.8	47.6	47.9	33.1	33.1	33.1	33.1	33.6	33.6	33.1	37.3	40.1	42.8	43.3	48.4
29/11/2014	37.8	47.9	47.9	47.9	47.9	49.5	80.2	37.9	37.9	37.9	37.9	37.9	37.9	48.0	48.0	48.0	48.0	48.0	80.3
22/04/2016	85.5	85.9	87.4	89.6	112.3	114.5	114.7	85.5	85.5	85.5	85.5	85.5	85.5	85.9	87.4	89.6	112.3	112.3	114.7
26/04/2017	62.8	65.0	65.0	65.0	65.0	65.0	65.0	87.3	89.1	97.1	97.1	97.1	97.1	89.5	91.3	99.3	99.3	99.3	99.3

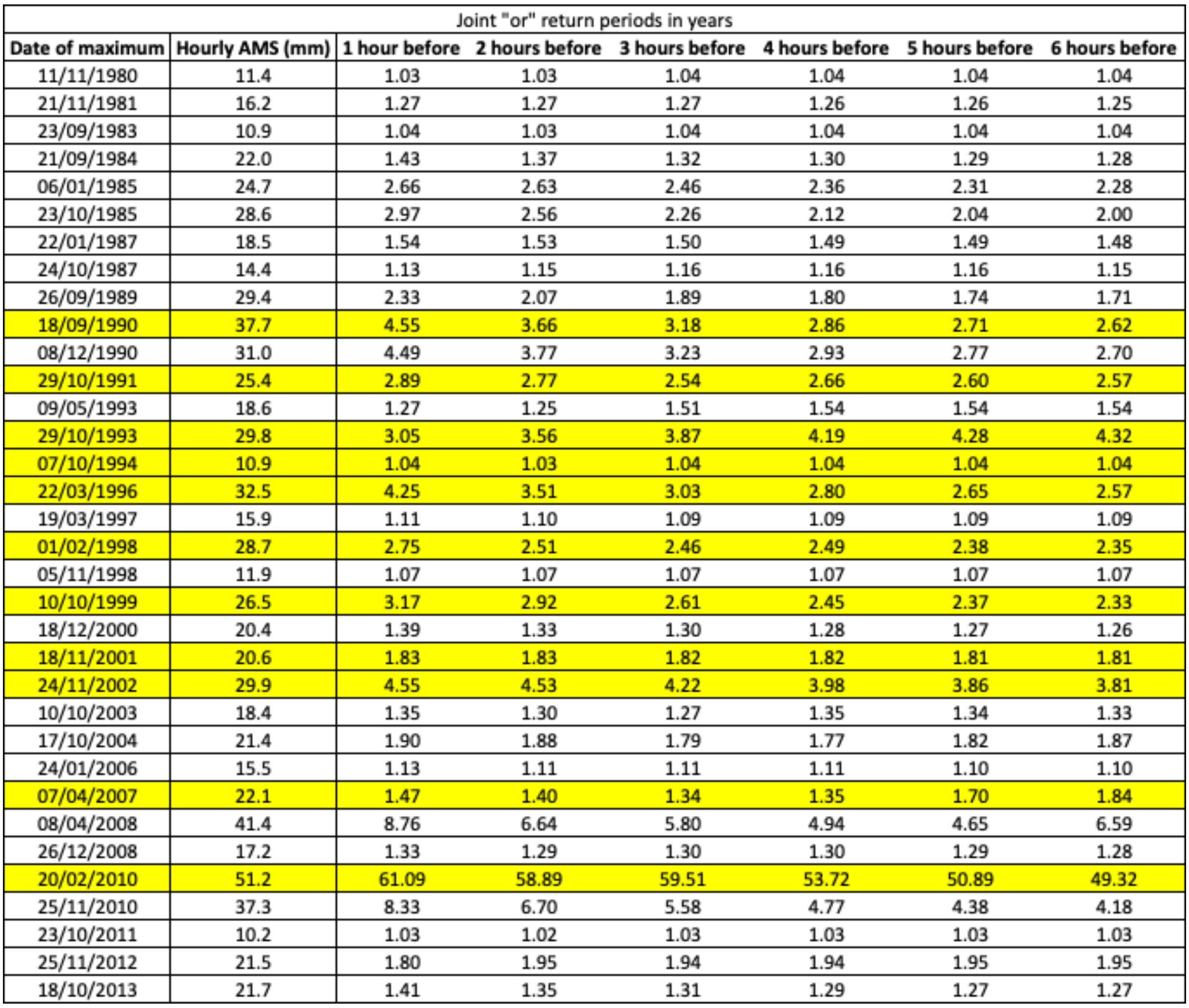
Annex III – Return periods for hourly rainfall

Note: The cells highlighted in yellow identify the hourly extreme rainfall events that are associated with alluvium events.

Return periods of annual maximum hourly rainfalls and cumulative hourly rainfalls in hours before the annual maximum.

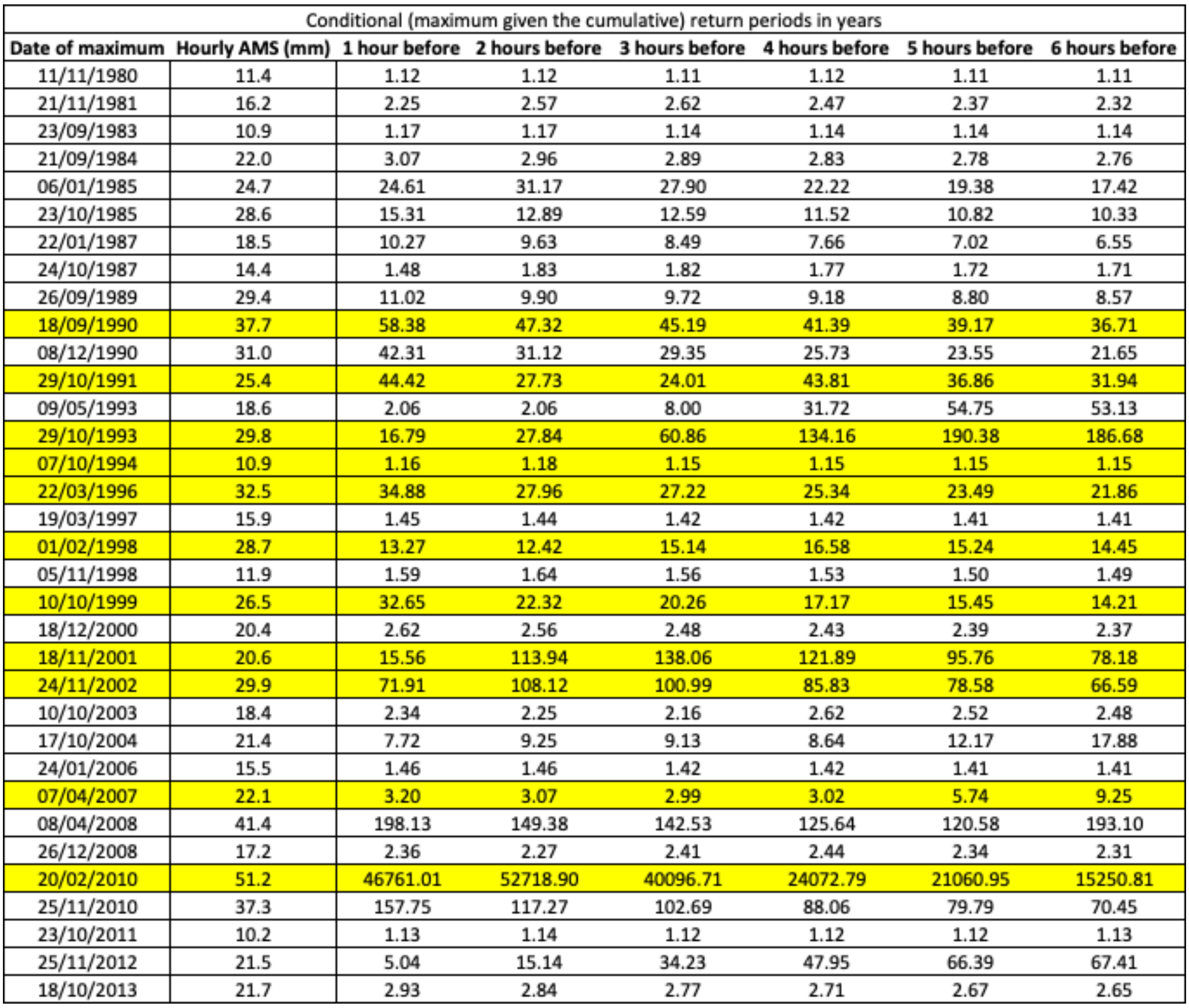


		Univariate return periods in years						
Date of maximum	Hourly AMS (mm)	On AMS	1 hour before	2 hours before	3 hours before	4 hours before	5 hours before	6 hours before
11/11/1980	11.4	1.06	1.03	1.04	1.04	1.04	1.04	1.04
21/11/1981	16.2	1.31	1.45	1.47	1.58	1.53	1.50	1.48
23/09/1983	10.9	1.05	1.05	1.08	1.07	1.07	1.06	1.06
21/09/1984	22.0	2.08	1.42	1.45	1.35	1.32	1.30	1.30
06/01/1985	24.7	2.72	6.06	4.85	4.77	4.14	3.82	3.61
23/10/1985	28.6	4.15	3.69	3.25	2.50	2.32	2.21	2.15
22/01/1987	18.5	1.54	3.62	3.20	2.84	2.69	2.57	2.48
24/10/1987	14.4	1.19	1.15	1.19	1.33	1.31	1.29	1.29
26/09/1989	29.4	4.54	2.50	2.36	1.96	1.86	1.79	1.76
18/09/1990	37.7	12.20	5.69	4.61	3.28	2.95	2.79	2.68
08/12/1990	31.0	5.46	7.44	5.72	3.87	3.43	3.19	3.05
29/10/1991	25.4	2.92	8.87	6.58	4.31	5.90	5.33	4.96
09/05/1993	18.6	1.55	1.26	1.30	2.75	5.55	7.30	7.19
29/10/1993	29.8	4.76	3.66	3.23	6.47	9.83	11.75	11.82
07/10/1994	10.9	1.05	1.05	1.07	1.07	1.07	1.07	1.07
22/03/1996	32.5	6.52	5.75	4.65	3.34	3.08	2.89	2.77
19/03/1997	15.9	1.29	1.09	1.11	1.10	1.09	1.09	1.09
01/02/1998	28.7	4.20	3.22	2.91	2.82	2.94	2.76	2.68
05/11/1998	11.9	1.07	1.22	1.26	1.25	1.23	1.22	1.22
10/10/1999	26.5	3.29	7.12	5.52	3.77	3.35	3.12	2.98
18/12/2000	20.4	1.80	1.39	1.42	1.33	1.31	1.29	1.28
18/11/2001	20.6	1.83	4.66	3.93	11.58	10.81	9.54	8.62
24/11/2002	29.9	4.81	11.46	8.06	8.68	7.59	7.09	6.53
10/10/2003	18.4	1.53	1.41	1.43	1.33	1.51	1.47	1.46
17/10/2004	21.4	1.97	2.95	2.71	2.80	2.70	3.25	3.99
24/01/2006	15.5	1.26	1.11	1.14	1.12	1.12	1.11	1.11
07/04/2007	22.1	2.10	1.47	1.49	1.38	1.38	2.10	2.75
08/04/2008	41.4	19.22	13.56	9.21	6.12	5.21	4.91	7.28
26/12/2008	17.2	1.40	1.47	1.49	1.49	1.49	1.46	1.45
20/02/2010	51.2	64.21	702.24	198.44	177.11	122.82	108.40	92.74
25/11/2010	37.3	11.62	15.36	10.16	6.43	5.41	4.91	4.58
23/10/2011	10.2	1.03	1.04	1.06	1.06	1.06	1.06	1.06
25/11/2012	21.5	1.99	2.20	2.12	5.63	6.65	7.84	7.92
18/10/2013	21.7	2.02	1.40	1.43	1.33	1.31	1.29	1.28

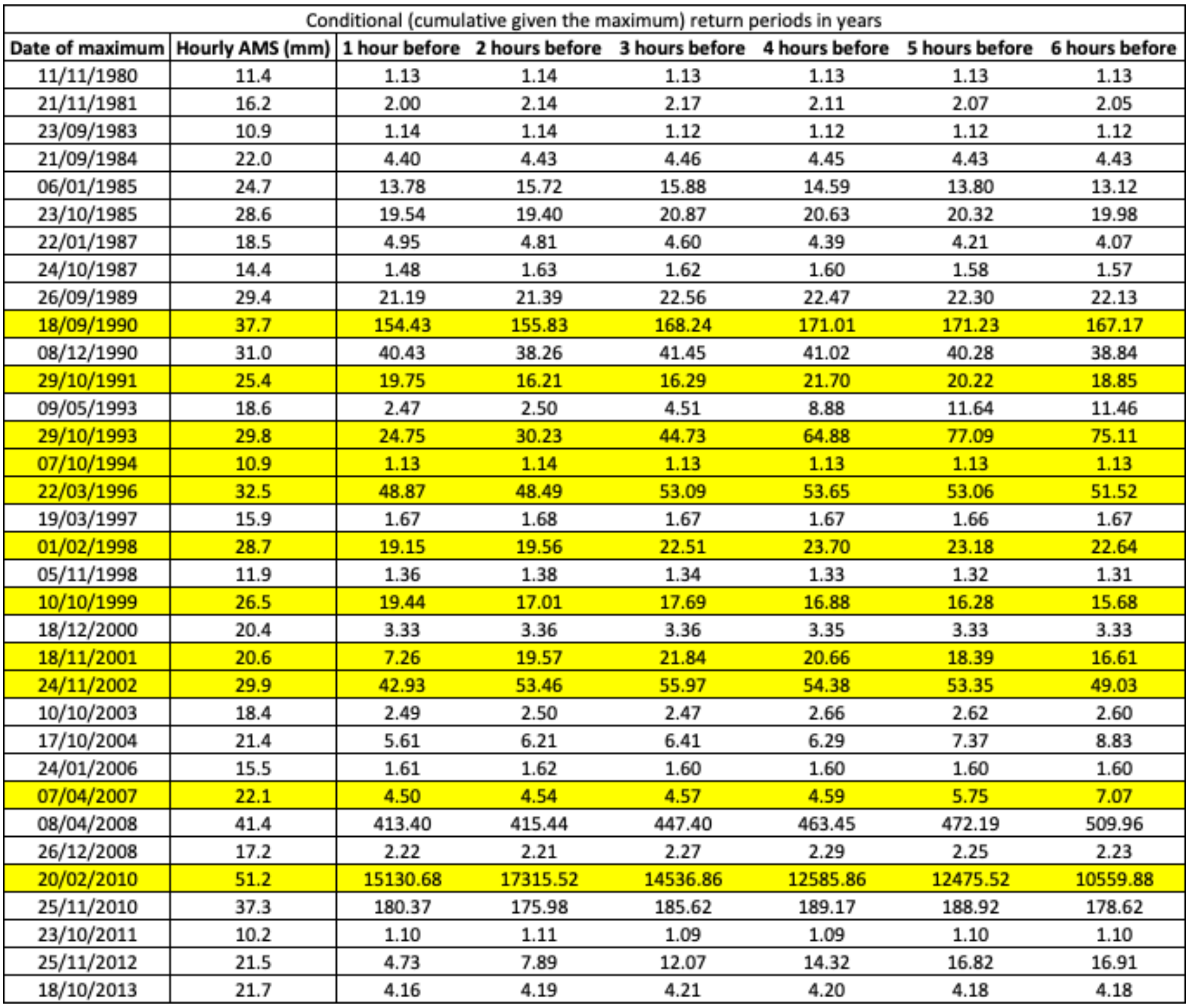


Joint "or" return periods in years							
Date of maximum	**Hourly AMS (mm)**	**1 hour before**	**2 hours before**	**3 hours before**	**4 hours before**	**5 hours before**	**6 hours before**
11/11/1980	11.4	1.03	1.03	1.04	1.04	1.04	1.04
21/11/1981	16.2	1.27	1.27	1.27	1.26	1.26	1.25
23/09/1983	10.9	1.04	1.03	1.04	1.04	1.04	1.04
21/09/1984	22.0	1.43	1.37	1.32	1.30	1.29	1.28
06/01/1985	24.7	2.66	2.63	2.46	2.36	2.31	2.28
23/10/1985	28.6	2.97	2.56	2.26	2.12	2.04	2.00
22/01/1987	18.5	1.54	1.53	1.50	1.49	1.49	1.48
24/10/1987	14.4	1.13	1.15	1.16	1.16	1.16	1.15
26/09/1989	29.4	2.33	2.07	1.89	1.80	1.74	1.71
18/09/1990	37.7	4.55	3.66	3.18	2.86	2.71	2.62
08/12/1990	31.0	4.49	3.77	3.23	2.93	2.77	2.70
29/10/1991	25.4	2.89	2.77	2.54	2.66	2.60	2.57
09/05/1993	18.6	1.27	1.25	1.51	1.54	1.54	1.54
29/10/1993	29.8	3.05	3.56	3.87	4.19	4.28	4.32
07/10/1994	10.9	1.04	1.03	1.04	1.04	1.04	1.04
22/03/1996	32.5	4.25	3.51	3.03	2.80	2.65	2.57
19/03/1997	15.9	1.11	1.10	1.09	1.09	1.09	1.09
01/02/1998	28.7	2.75	2.51	2.46	2.49	2.38	2.35
05/11/1998	11.9	1.07	1.07	1.07	1.07	1.07	1.07
10/10/1999	26.5	3.17	2.92	2.61	2.45	2.37	2.33
18/12/2000	20.4	1.39	1.33	1.30	1.28	1.27	1.26
18/11/2001	20.6	1.83	1.83	1.82	1.82	1.81	1.81
24/11/2002	29.9	4.55	4.53	4.22	3.98	3.86	3.81
10/10/2003	18.4	1.35	1.30	1.27	1.35	1.34	1.33
17/10/2004	21.4	1.90	1.88	1.79	1.77	1.82	1.87
24/01/2006	15.5	1.13	1.11	1.11	1.11	1.10	1.10
07/04/2007	22.1	1.47	1.40	1.34	1.35	1.70	1.84
08/04/2008	41.4	8.76	6.64	5.80	4.94	4.65	6.59
26/12/2008	17.2	1.33	1.29	1.30	1.30	1.29	1.28
20/02/2010	51.2	61.09	58.89	59.51	53.72	50.89	49.32
25/11/2010	37.3	8.33	6.70	5.58	4.77	4.38	4.18
23/10/2011	10.2	1.03	1.02	1.03	1.03	1.03	1.03
25/11/2012	21.5	1.80	1.95	1.94	1.94	1.95	1.95
18/10/2013	21.7	1.41	1.35	1.31	1.29	1.27	1.27

Joint "and" return periods in years							
Date of maximum	**Hourly AMS (mm)**	**1 hour before**	**2 hours before**	**3 hours before**	**4 hours before**	**5 hours before**	**6 hours before**
11/11/1980	11.4	1.07	1.08	1.07	1.07	1.07	1.07
21/11/1981	16.2	1.53	1.64	1.65	1.61	1.58	1.57
23/09/1983	10.9	1.09	1.09	1.07	1.07	1.07	1.07
21/09/1984	22.0	2.11	2.13	2.14	2.14	2.13	2.13
06/01/1985	24.7	5.07	5.78	5.84	5.37	5.08	4.83
23/10/1985	28.6	4.71	4.68	5.03	4.97	4.90	4.81
22/01/1987	18.5	3.21	3.13	2.99	2.85	2.73	2.65
24/10/1987	14.4	1.25	1.38	1.37	1.35	1.33	1.33
26/09/1989	29.4	4.66	4.71	4.97	4.95	4.91	4.87
18/09/1990	37.7	12.66	12.77	13.79	14.02	14.04	13.70
08/12/1990	31.0	7.40	7.00	7.59	7.51	7.37	7.11
29/10/1991	25.4	6.75	5.54	5.57	7.42	6.92	6.44
09/05/1993	18.6	1.59	1.61	2.91	5.72	7.50	7.38
29/10/1993	29.8	5.20	6.36	9.40	13.64	16.21	15.79
07/10/1994	10.9	1.08	1.09	1.08	1.08	1.08	1.08
22/03/1996	32.5	7.50	7.44	8.14	8.23	8.14	7.90
19/03/1997	15.9	1.30	1.30	1.29	1.29	1.29	1.29
01/02/1998	28.7	4.56	4.66	5.36	5.65	5.52	5.39
05/11/1998	11.9	1.26	1.28	1.25	1.24	1.23	1.22
10/10/1999	26.5	5.91	5.17	5.38	5.13	4.95	4.77
18/12/2000	20.4	1.85	1.87	1.87	1.86	1.85	1.85
18/11/2001	20.6	3.96	10.68	11.92	11.28	10.04	9.07
24/11/2002	29.9	8.92	11.11	11.63	11.30	11.09	10.19
10/10/2003	18.4	1.63	1.64	1.62	1.74	1.71	1.70
17/10/2004	21.4	2.85	3.15	3.26	3.19	3.75	4.49
24/01/2006	15.5	1.28	1.29	1.27	1.27	1.27	1.27
07/04/2007	22.1	2.14	2.16	2.18	2.18	2.74	3.36
08/04/2008	41.4	21.51	21.62	23.28	24.12	24.57	26.54
26/12/2008	17.2	1.59	1.58	1.62	1.63	1.60	1.59
20/02/2010	51.2	235.64	269.66	226.39	196.01	194.29	164.45
25/11/2010	37.3	15.52	15.15	15.98	16.28	16.26	15.37
23/10/2011	10.2	1.06	1.07	1.06	1.06	1.06	1.06
25/11/2012	21.5	2.38	3.97	6.08	7.21	8.47	8.51
18/10/2013	21.7	2.05	2.07	2.08	2.08	2.07	2.07

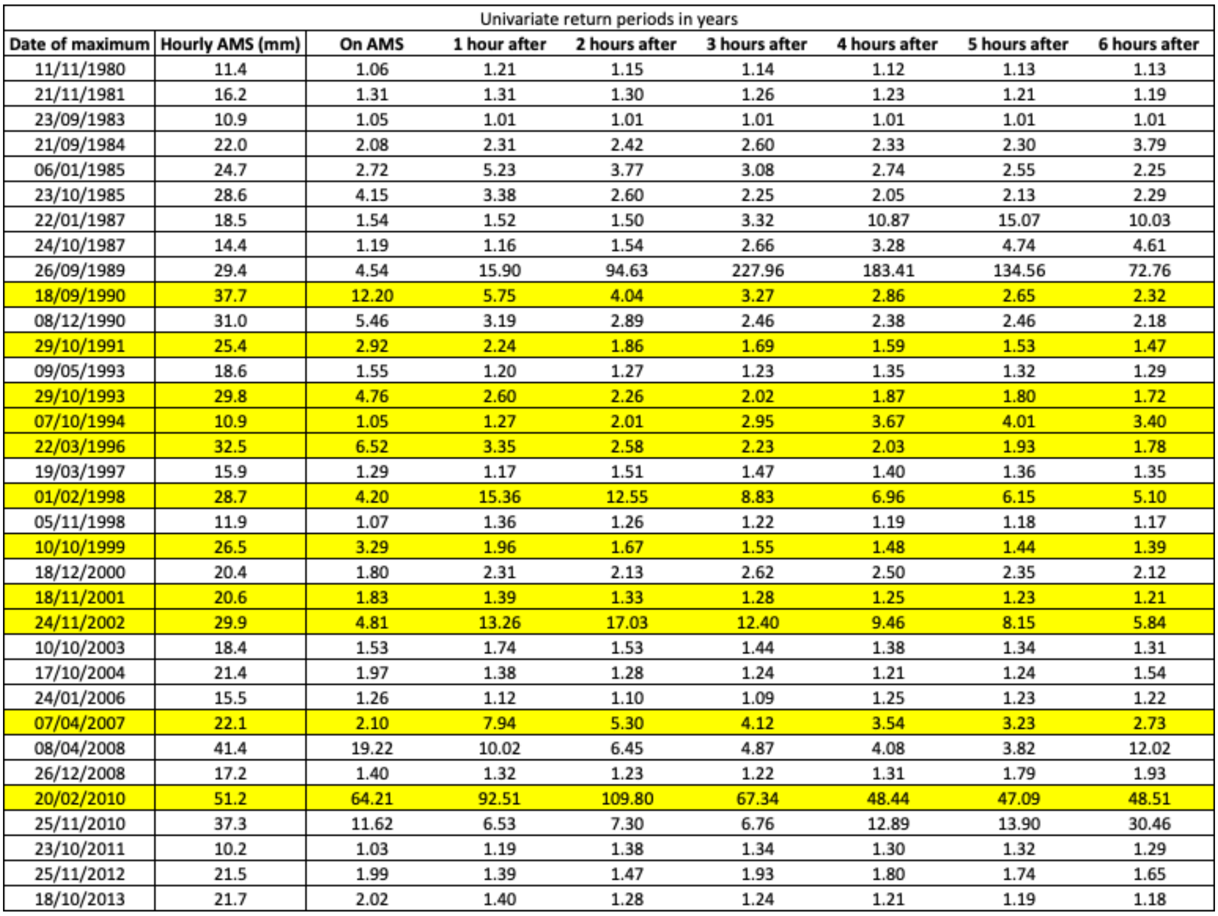


Conditional (maximum given the cumulative) return periods in years							
Date of maximum	**Hourly AMS (mm)**	**1 hour before**	**2 hours before**	**3 hours before**	**4 hours before**	**5 hours before**	**6 hours before**
11/11/1980	11.4	1.12	1.12	1.11	1.12	1.11	1.11
21/11/1981	16.2	2.25	2.57	2.62	2.47	2.37	2.32
23/09/1983	10.9	1.17	1.17	1.14	1.14	1.14	1.14
21/09/1984	22.0	3.07	2.96	2.89	2.83	2.78	2.76
06/01/1985	24.7	24.61	31.17	27.90	22.22	19.38	17.42
23/10/1985	28.6	15.31	12.89	12.59	11.52	10.82	10.33
22/01/1987	18.5	10.27	9.63	8.49	7.66	7.02	6.55
24/10/1987	14.4	1.48	1.83	1.82	1.77	1.72	1.71
26/09/1989	29.4	11.02	9.90	9.72	9.18	8.80	8.57
18/09/1990	37.7	58.38	47.32	45.19	41.39	39.17	36.71
08/12/1990	31.0	42.31	31.12	29.35	25.73	23.55	21.65
29/10/1991	25.4	44.42	27.73	24.01	43.81	36.86	31.94
09/05/1993	18.6	2.06	2.06	8.00	31.72	54.75	53.13
29/10/1993	29.8	16.79	27.84	60.86	134.16	190.38	186.68
07/10/1994	10.9	1.16	1.18	1.15	1.15	1.15	1.15
22/03/1996	32.5	34.88	27.96	27.22	25.34	23.49	21.86
19/03/1997	15.9	1.45	1.44	1.42	1.42	1.41	1.41
01/02/1998	28.7	13.27	12.42	15.14	16.58	15.24	14.45
05/11/1998	11.9	1.59	1.64	1.56	1.53	1.50	1.49
10/10/1999	26.5	32.65	22.32	20.26	17.17	15.45	14.21
18/12/2000	20.4	2.62	2.56	2.48	2.43	2.39	2.37
18/11/2001	20.6	15.56	113.94	138.06	121.89	95.76	78.18
24/11/2002	29.9	71.91	108.12	100.99	85.83	78.58	66.59
10/10/2003	18.4	2.34	2.25	2.16	2.62	2.52	2.48
17/10/2004	21.4	7.72	9.25	9.13	8.64	12.17	17.88
24/01/2006	15.5	1.46	1.46	1.42	1.42	1.41	1.41
07/04/2007	22.1	3.20	3.07	2.99	3.02	5.74	9.25
08/04/2008	41.4	198.13	149.38	142.53	125.64	120.58	193.10
26/12/2008	17.2	2.36	2.27	2.41	2.44	2.34	2.31
20/02/2010	51.2	46761.01	52718.90	40096.71	24072.79	21060.95	15250.81
25/11/2010	37.3	157.75	117.27	102.69	88.06	79.79	70.45
23/10/2011	10.2	1.13	1.14	1.12	1.12	1.12	1.13
25/11/2012	21.5	5.04	15.14	34.23	47.95	66.39	67.41
18/10/2013	21.7	2.93	2.84	2.77	2.71	2.67	2.65



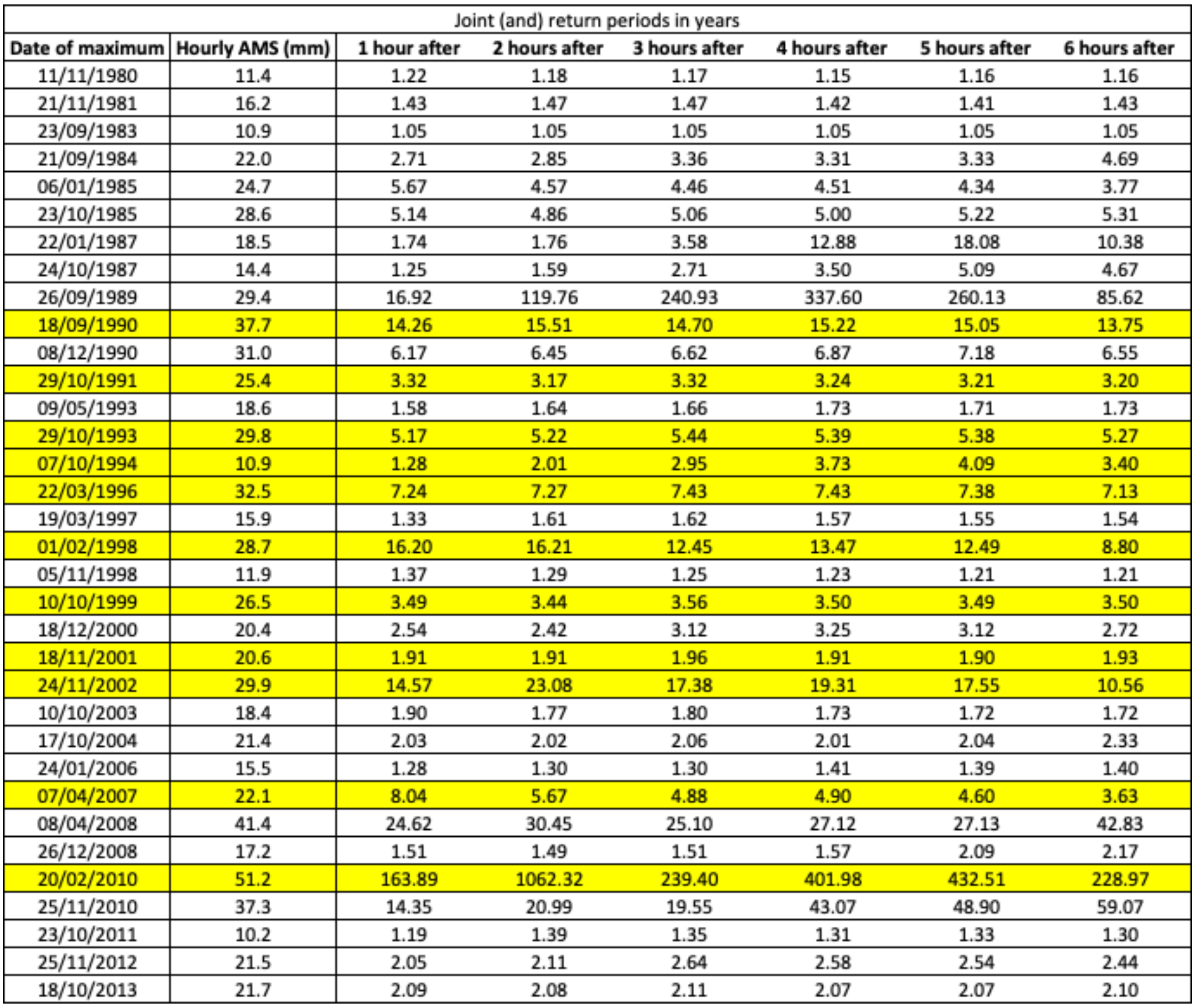
Conditional (cumulative given the maximum) return periods in years							
Date of maximum	**Hourly AMS (mm)**	**1 hour before**	**2 hours before**	**3 hours before**	**4 hours before**	**5 hours before**	**6 hours before**
11/11/1980	11.4	1.13	1.14	1.13	1.13	1.13	1.13
21/11/1981	16.2	2.00	2.14	2.17	2.11	2.07	2.05
23/09/1983	10.9	1.14	1.14	1.12	1.12	1.12	1.12
21/09/1984	22.0	4.40	4.43	4.46	4.45	4.43	4.43
06/01/1985	24.7	13.78	15.72	15.88	14.59	13.80	13.12
23/10/1985	28.6	19.54	19.40	20.87	20.63	20.32	19.98
22/01/1987	18.5	4.95	4.81	4.60	4.39	4.21	4.07
24/10/1987	14.4	1.48	1.63	1.62	1.60	1.58	1.57
26/09/1989	29.4	21.19	21.39	22.56	22.47	22.30	22.13
18/09/1990	37.7	154.43	155.83	168.24	171.01	171.23	167.17
08/12/1990	31.0	40.43	38.26	41.45	41.02	40.28	38.84
29/10/1991	25.4	19.75	16.21	16.29	21.70	20.22	18.85
09/05/1993	18.6	2.47	2.50	4.51	8.88	11.64	11.46
29/10/1993	29.8	24.75	30.23	44.73	64.88	77.09	75.11
07/10/1994	10.9	1.13	1.14	1.13	1.13	1.13	1.13
22/03/1996	32.5	48.87	48.49	53.09	53.65	53.06	51.52
19/03/1997	15.9	1.67	1.68	1.67	1.67	1.66	1.67
01/02/1998	28.7	19.15	19.56	22.51	23.70	23.18	22.64
05/11/1998	11.9	1.36	1.38	1.34	1.33	1.32	1.31
10/10/1999	26.5	19.44	17.01	17.69	16.88	16.28	15.68
18/12/2000	20.4	3.33	3.36	3.36	3.35	3.33	3.33
18/11/2001	20.6	7.26	19.57	21.84	20.66	18.39	16.61
24/11/2002	29.9	42.93	53.46	55.97	54.38	53.35	49.03
10/10/2003	18.4	2.49	2.50	2.47	2.66	2.62	2.60
17/10/2004	21.4	5.61	6.21	6.41	6.29	7.37	8.83
24/01/2006	15.5	1.61	1.62	1.60	1.60	1.60	1.60
07/04/2007	22.1	4.50	4.54	4.57	4.59	5.75	7.07
08/04/2008	41.4	413.40	415.44	447.40	463.45	472.19	509.96
26/12/2008	17.2	2.22	2.21	2.27	2.29	2.25	2.23
20/02/2010	51.2	15130.68	17315.52	14536.86	12585.86	12475.52	10559.88
25/11/2010	37.3	180.37	175.98	185.62	189.17	188.92	178.62
23/10/2011	10.2	1.10	1.11	1.09	1.09	1.10	1.10
25/11/2012	21.5	4.73	7.89	12.07	14.32	16.82	16.91
18/10/2013	21.7	4.16	4.19	4.21	4.20	4.18	4.18

Return periods of annual maximum hourly rainfalls and cumulative hourly rainfalls in hours after the annual maximum.



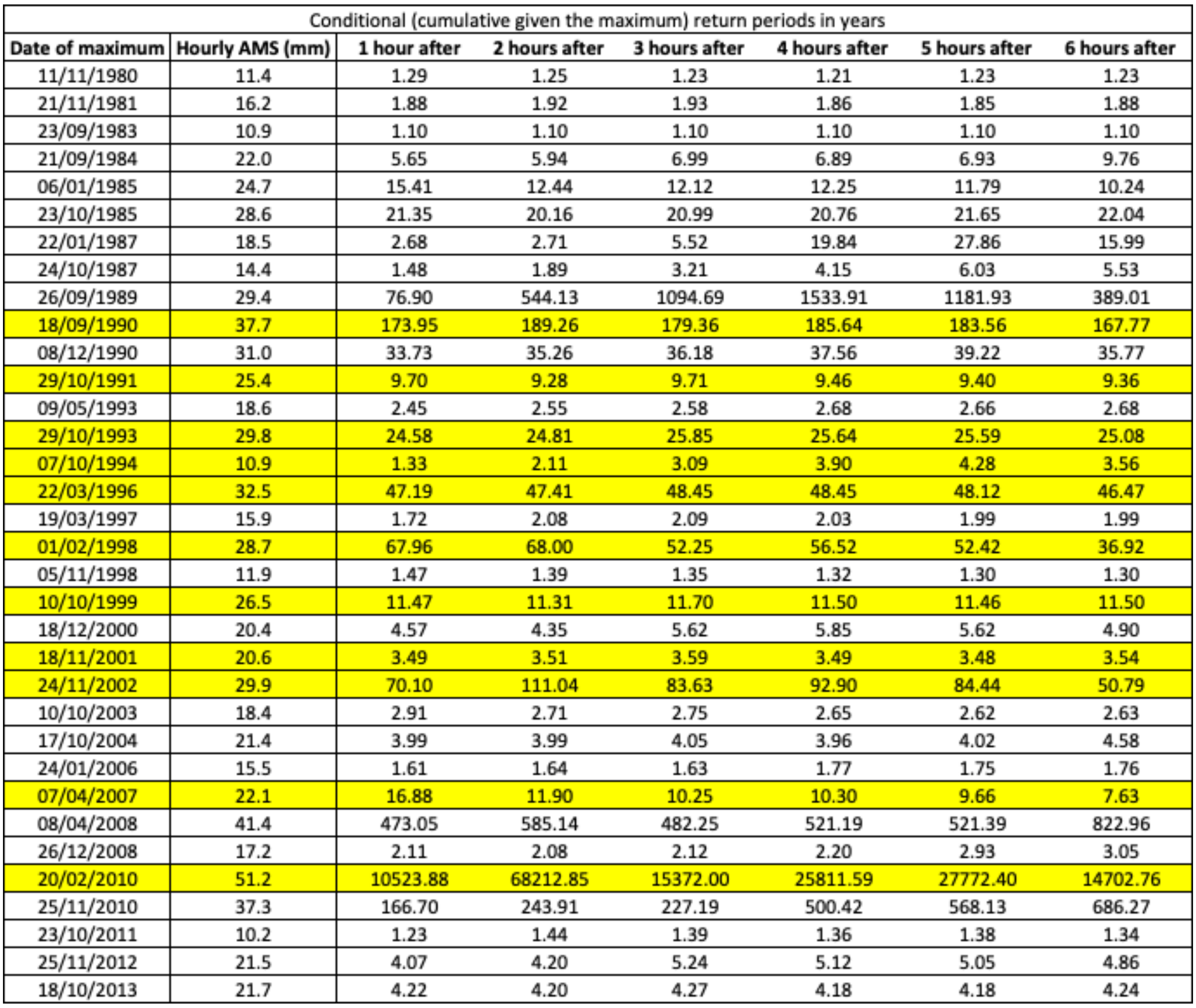
		Univariate return periods in years						
Date of maximum	Hourly AMS (mm)	On AMS	1 hour after	2 hours after	3 hours after	4 hours after	5 hours after	6 hours after
11/11/1980	11.4	1.06	1.21	1.15	1.14	1.12	1.13	1.13
21/11/1981	16.2	1.31	1.31	1.30	1.26	1.23	1.21	1.19
23/09/1983	10.9	1.05	1.01	1.01	1.01	1.01	1.01	1.01
21/09/1984	22.0	2.08	2.31	2.42	2.60	2.33	2.30	3.79
06/01/1985	24.7	2.72	5.23	3.77	3.08	2.74	2.55	2.25
23/10/1985	28.6	4.15	3.38	2.60	2.25	2.05	2.13	2.29
22/01/1987	18.5	1.54	1.52	1.50	3.32	10.87	15.07	10.03
24/10/1987	14.4	1.19	1.16	1.54	2.66	3.28	4.74	4.61
26/09/1989	29.4	4.54	15.90	94.63	227.96	183.41	134.56	72.76
18/09/1990	37.7	12.20	5.75	4.04	3.27	2.86	2.65	2.32
08/12/1990	31.0	5.46	3.19	2.89	2.46	2.38	2.46	2.18
29/10/1991	25.4	2.92	2.24	1.86	1.69	1.59	1.53	1.47
09/05/1993	18.6	1.55	1.20	1.27	1.23	1.35	1.32	1.29
29/10/1993	29.8	4.76	2.60	2.26	2.02	1.87	1.80	1.72
07/10/1994	10.9	1.05	1.27	2.01	2.95	3.67	4.01	3.40
22/03/1996	32.5	6.52	3.35	2.58	2.23	2.03	1.93	1.78
19/03/1997	15.9	1.29	1.17	1.51	1.47	1.40	1.36	1.35
01/02/1998	28.7	4.20	15.36	12.55	8.83	6.96	6.15	5.10
05/11/1998	11.9	1.07	1.36	1.26	1.22	1.19	1.18	1.17
10/10/1999	26.5	3.29	1.96	1.67	1.55	1.48	1.44	1.39
18/12/2000	20.4	1.80	2.31	2.13	2.62	2.50	2.35	2.12
18/11/2001	20.6	1.83	1.39	1.33	1.28	1.25	1.23	1.21
24/11/2002	29.9	4.81	13.26	17.03	12.40	9.46	8.15	5.84
10/10/2003	18.4	1.53	1.74	1.53	1.44	1.38	1.34	1.31
17/10/2004	21.4	1.97	1.38	1.28	1.24	1.21	1.24	1.54
24/01/2006	15.5	1.26	1.12	1.10	1.09	1.25	1.23	1.22
07/04/2007	22.1	2.10	7.94	5.30	4.12	3.54	3.23	2.73
08/04/2008	41.4	19.22	10.02	6.45	4.87	4.08	3.82	12.02
26/12/2008	17.2	1.40	1.32	1.23	1.22	1.31	1.79	1.93
20/02/2010	51.2	64.21	92.51	109.80	67.34	48.44	47.09	48.51
25/11/2010	37.3	11.62	6.53	7.30	6.76	12.89	13.90	30.46
23/10/2011	10.2	1.03	1.19	1.38	1.34	1.30	1.32	1.29
25/11/2012	21.5	1.99	1.39	1.47	1.93	1.80	1.74	1.65
18/10/2013	21.7	2.02	1.40	1.28	1.24	1.21	1.19	1.18

Joint (or) return periods in years							
Date of maximum	**Hourly AMS (mm)**	**1 hour after**	**2 hours after**	**3 hours after**	**4 hours after**	**5 hours after**	**6 hours after**
11/11/1980	11.4	1.05	1.03	1.03	1.04	1.03	1.03
21/11/1981	16.2	1.20	1.18	1.14	1.14	1.13	1.11
23/09/1983	10.9	1.01	1.00	1.00	1.01	1.01	1.00
21/09/1984	22.0	1.84	1.84	1.76	1.65	1.62	1.88
06/01/1985	24.7	2.61	2.41	2.14	1.96	1.89	1.83
23/10/1985	28.6	2.92	2.38	2.05	1.89	1.92	2.05
22/01/1987	18.5	1.36	1.34	1.49	1.51	1.51	1.53
24/10/1987	14.4	1.11	1.16	1.18	1.16	1.17	1.18
26/09/1989	29.4	4.47	4.50	4.54	4.49	4.47	4.50
18/09/1990	37.7	5.38	3.77	3.13	2.73	2.54	2.27
08/12/1990	31.0	2.99	2.67	2.28	2.18	2.22	2.04
29/10/1991	25.4	2.05	1.77	1.58	1.51	1.46	1.41
09/05/1993	18.6	1.18	1.22	1.17	1.24	1.22	1.19
29/10/1993	29.8	2.49	2.17	1.92	1.79	1.73	1.66
07/10/1994	10.9	1.04	1.04	1.05	1.04	1.04	1.05
22/03/1996	32.5	3.18	2.48	2.14	1.96	1.86	1.74
19/03/1997	15.9	1.14	1.22	1.19	1.17	1.16	1.15
01/02/1998	28.7	4.14	3.90	3.69	3.25	3.12	3.12
05/11/1998	11.9	1.07	1.05	1.05	1.05	1.04	1.04
10/10/1999	26.5	1.89	1.63	1.49	1.44	1.40	1.36
18/12/2000	20.4	1.69	1.63	1.62	1.54	1.52	1.52
18/11/2001	20.6	1.35	1.29	1.23	1.22	1.20	1.17
24/11/2002	29.9	4.66	4.48	4.33	3.82	3.65	3.52
10/10/2003	18.4	1.42	1.35	1.26	1.24	1.22	1.20
17/10/2004	21.4	1.35	1.26	1.20	1.19	1.21	1.37
24/01/2006	15.5	1.10	1.07	1.06	1.13	1.12	1.11
07/04/2007	22.1	2.09	2.05	1.95	1.80	1.76	1.77
08/04/2008	41.4	8.99	5.74	4.60	3.84	3.61	8.94
26/12/2008	17.2	1.24	1.17	1.14	1.19	1.26	1.30
20/02/2010	51.2	49.31	42.12	38.10	29.65	28.99	31.43
25/11/2010	37.3	5.90	5.70	5.47	7.12	7.27	9.81
23/10/2011	10.2	1.03	1.03	1.03	1.02	1.02	1.03
25/11/2012	21.5	1.36	1.41	1.56	1.49	1.46	1.43
18/10/2013	21.7	1.37	1.26	1.21	1.19	1.17	1.15



Joint (and) return periods in years							
Date of maximum	**Hourly AMS (mm)**	**1 hour after**	**2 hours after**	**3 hours after**	**4 hours after**	**5 hours after**	**6 hours after**
11/11/1980	11.4	1.22	1.18	1.17	1.15	1.16	1.16
21/11/1981	16.2	1.43	1.47	1.47	1.42	1.41	1.43
23/09/1983	10.9	1.05	1.05	1.05	1.05	1.05	1.05
21/09/1984	22.0	2.71	2.85	3.36	3.31	3.33	4.69
06/01/1985	24.7	5.67	4.57	4.46	4.51	4.34	3.77
23/10/1985	28.6	5.14	4.86	5.06	5.00	5.22	5.31
22/01/1987	18.5	1.74	1.76	3.58	12.88	18.08	10.38
24/10/1987	14.4	1.25	1.59	2.71	3.50	5.09	4.67
26/09/1989	29.4	16.92	119.76	240.93	337.60	260.13	85.62
18/09/1990	37.7	14.26	15.51	14.70	15.22	15.05	13.75
08/12/1990	31.0	6.17	6.45	6.62	6.87	7.18	6.55
29/10/1991	25.4	3.32	3.17	3.32	3.24	3.21	3.20
09/05/1993	18.6	1.58	1.64	1.66	1.73	1.71	1.73
29/10/1993	29.8	5.17	5.22	5.44	5.39	5.38	5.27
07/10/1994	10.9	1.28	2.01	2.95	3.73	4.09	3.40
22/03/1996	32.5	7.24	7.27	7.43	7.43	7.38	7.13
19/03/1997	15.9	1.33	1.61	1.62	1.57	1.55	1.54
01/02/1998	28.7	16.20	16.21	12.45	13.47	12.49	8.80
05/11/1998	11.9	1.37	1.29	1.25	1.23	1.21	1.21
10/10/1999	26.5	3.49	3.44	3.56	3.50	3.49	3.50
18/12/2000	20.4	2.54	2.42	3.12	3.25	3.12	2.72
18/11/2001	20.6	1.91	1.91	1.96	1.91	1.90	1.93
24/11/2002	29.9	14.57	23.08	17.38	19.31	17.55	10.56
10/10/2003	18.4	1.90	1.77	1.80	1.73	1.72	1.72
17/10/2004	21.4	2.03	2.02	2.06	2.01	2.04	2.33
24/01/2006	15.5	1.28	1.30	1.30	1.41	1.39	1.40
07/04/2007	22.1	8.04	5.67	4.88	4.90	4.60	3.63
08/04/2008	41.4	24.62	30.45	25.10	27.12	27.13	42.83
26/12/2008	17.2	1.51	1.49	1.51	1.57	2.09	2.17
20/02/2010	51.2	163.89	1062.32	239.40	401.98	432.51	228.97
25/11/2010	37.3	14.35	20.99	19.55	43.07	48.90	59.07
23/10/2011	10.2	1.19	1.39	1.35	1.31	1.33	1.30
25/11/2012	21.5	2.05	2.11	2.64	2.58	2.54	2.44
18/10/2013	21.7	2.09	2.08	2.11	2.07	2.07	2.10

Conditional (maximum given the cumulative) return periods in years							
Date of maximum	**Hourly AMS (mm)**	**1 hour after**	**2 hours after**	**3 hours after**	**4 hours after**	**5 hours after**	**6 hours after**
11/11/1980	11.4	1.48	1.36	1.32	1.28	1.31	1.31
21/11/1981	16.2	1.87	1.91	1.85	1.74	1.70	1.71
23/09/1983	10.9	1.06	1.06	1.06	1.05	1.05	1.06
21/09/1984	22.0	6.28	6.91	8.75	7.71	7.64	17.76
06/01/1985	24.7	29.63	17.23	13.73	12.36	11.05	8.45
23/10/1985	28.6	17.38	12.64	11.38	10.24	11.09	12.18
22/01/1987	18.5	2.64	2.63	11.89	140.00	272.59	104.13
24/10/1987	14.4	1.45	2.45	7.20	11.47	24.09	21.53
26/09/1989	29.4	269.01	11333.22	54923.87	61918.21	35003.39	6229.17
18/09/1990	37.7	81.95	62.69	48.08	43.46	39.83	31.86
08/12/1990	31.0	19.68	18.65	16.29	16.33	17.63	14.25
29/10/1991	25.4	7.41	5.89	5.61	5.14	4.93	4.70
09/05/1993	18.6	1.89	2.09	2.05	2.33	2.25	2.22
29/10/1993	29.8	13.42	11.79	10.99	10.09	9.71	9.05
07/10/1994	10.9	1.62	4.04	8.69	13.67	16.40	11.55
22/03/1996	32.5	24.23	18.77	16.61	15.12	14.23	12.69
19/03/1997	15.9	1.56	2.44	2.38	2.21	2.11	2.09
01/02/1998	28.7	248.81	203.31	109.94	93.81	76.84	44.84
05/11/1998	11.9	1.87	1.63	1.53	1.47	1.43	1.41
10/10/1999	26.5	6.83	5.74	5.50	5.18	5.01	4.86
18/12/2000	20.4	5.87	5.14	8.18	8.13	7.34	5.77
18/11/2001	20.6	2.65	2.55	2.51	2.38	2.33	2.35
24/11/2002	29.9	193.19	393.14	215.53	182.64	142.98	61.68
10/10/2003	18.4	3.32	2.72	2.59	2.39	2.30	2.26
17/10/2004	21.4	2.80	2.59	2.54	2.43	2.53	3.58
24/01/2006	15.5	1.43	1.43	1.42	1.76	1.71	1.70
07/04/2007	22.1	63.84	30.05	20.12	17.34	14.87	9.92
08/04/2008	41.4	246.62	196.41	122.27	110.69	103.77	514.84
26/12/2008	17.2	1.99	1.82	1.84	2.06	3.73	4.20
20/02/2010	51.2	15162.02	116642.50	16119.82	19469.92	20367.54	11106.89
25/11/2010	37.3	93.75	153.15	132.13	555.29	679.73	1799.47
23/10/2011	10.2	1.41	1.93	1.82	1.70	1.75	1.68
25/11/2012	21.5	2.84	3.11	5.10	4.63	4.42	4.03
18/10/2013	21.7	2.91	2.66	2.61	2.49	2.45	2.47



Conditional (cumulative given the maximum) return periods in years							
Date of maximum	**Hourly AMS (mm)**	**1 hour after**	**2 hours after**	**3 hours after**	**4 hours after**	**5 hours after**	**6 hours after**
11/11/1980	11.4	1.29	1.25	1.23	1.21	1.23	1.23
21/11/1981	16.2	1.88	1.92	1.93	1.86	1.85	1.88
23/09/1983	10.9	1.10	1.10	1.10	1.10	1.10	1.10
21/09/1984	22.0	5.65	5.94	6.99	6.89	6.93	9.76
06/01/1985	24.7	15.41	12.44	12.12	12.25	11.79	10.24
23/10/1985	28.6	21.35	20.16	20.99	20.76	21.65	22.04
22/01/1987	18.5	2.68	2.71	5.52	19.84	27.86	15.99
24/10/1987	14.4	1.48	1.89	3.21	4.15	6.03	5.53
26/09/1989	29.4	76.90	544.13	1094.69	1533.91	1181.93	389.01
18/09/1990	37.7	173.95	189.26	179.36	185.64	183.56	167.77
08/12/1990	31.0	33.73	35.26	36.18	37.56	39.22	35.77
29/10/1991	25.4	9.70	9.28	9.71	9.46	9.40	9.36
09/05/1993	18.6	2.45	2.55	2.58	2.68	2.66	2.68
29/10/1993	29.8	24.58	24.81	25.85	25.64	25.59	25.08
07/10/1994	10.9	1.33	2.11	3.09	3.90	4.28	3.56
22/03/1996	32.5	47.19	47.41	48.45	48.45	48.12	46.47
19/03/1997	15.9	1.72	2.08	2.09	2.03	1.99	1.99
01/02/1998	28.7	67.96	68.00	52.25	56.52	52.42	36.92
05/11/1998	11.9	1.47	1.39	1.35	1.32	1.30	1.30
10/10/1999	26.5	11.47	11.31	11.70	11.50	11.46	11.50
18/12/2000	20.4	4.57	4.35	5.62	5.85	5.62	4.90
18/11/2001	20.6	3.49	3.51	3.59	3.49	3.48	3.54
24/11/2002	29.9	70.10	111.04	83.63	92.90	84.44	50.79
10/10/2003	18.4	2.91	2.71	2.75	2.65	2.62	2.63
17/10/2004	21.4	3.99	3.99	4.05	3.96	4.02	4.58
24/01/2006	15.5	1.61	1.64	1.63	1.77	1.75	1.76
07/04/2007	22.1	16.88	11.90	10.25	10.30	9.66	7.63
08/04/2008	41.4	473.05	585.14	482.25	521.19	521.39	822.96
26/12/2008	17.2	2.11	2.08	2.12	2.20	2.93	3.05
20/02/2010	51.2	10523.88	68212.85	15372.00	25811.59	27772.40	14702.76
25/11/2010	37.3	166.70	243.91	227.19	500.42	568.13	686.27
23/10/2011	10.2	1.23	1.44	1.39	1.36	1.38	1.34
25/11/2012	21.5	4.07	4.20	5.24	5.12	5.05	4.86
18/10/2013	21.7	4.22	4.20	4.27	4.18	4.18	4.24

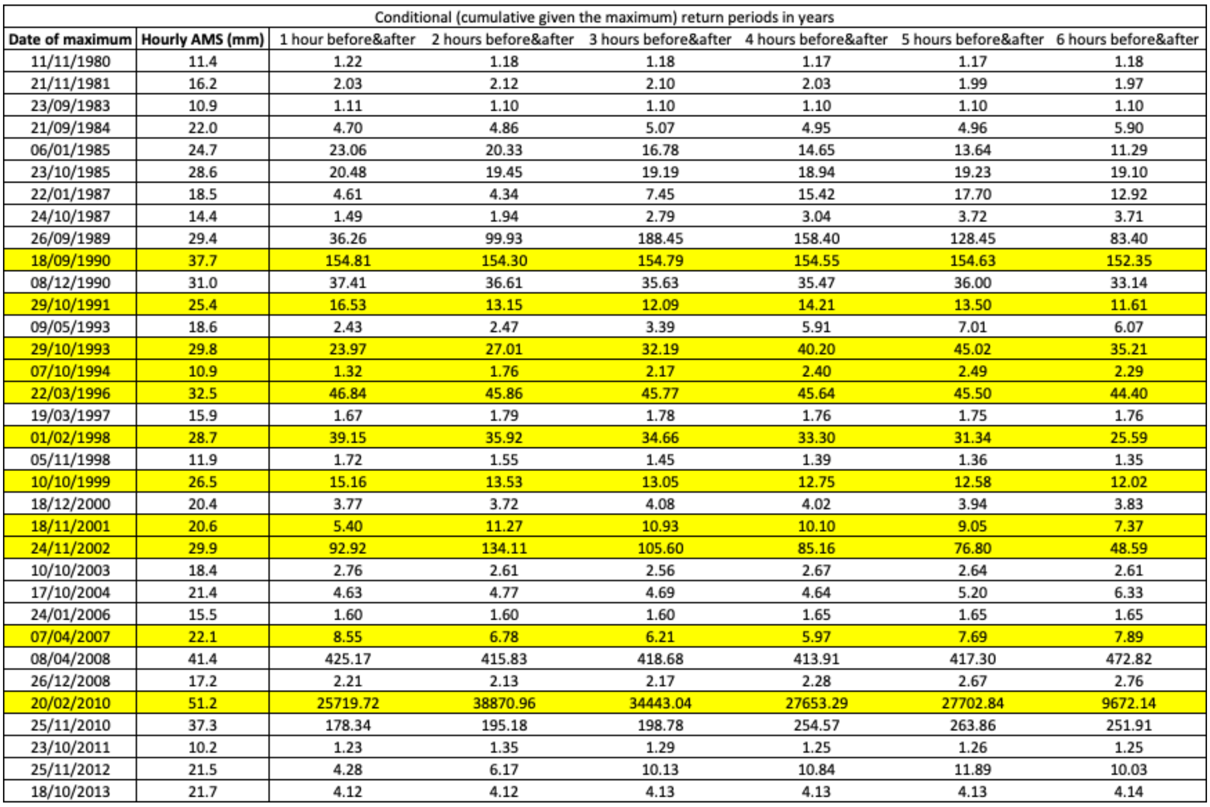
Return periods of annual maximum hourly rainfalls and cumulative hourly rainfalls in hours before and after the annual maximum.

		Univariate return periods in years						
Date of maximum	**Hourly AMS (mm)**	**On AMS**	1 hour before&after	2 hours before&after	3 hours before&after	4 hours before&after	5 hours before&after	6 hours before&after
11/11/1980	11.4	1.06	1.14	1.09	1.07	1.06	1.06	1.06
21/11/1981	16.2	1.31	1.44	1.47	1.42	1.34	1.29	1.26
23/09/1983	10.9	1.05	1.03	1.02	1.01	1.01	1.01	1.01
21/09/1984	22.0	2.08	1.59	1.57	1.61	1.48	1.46	2.01
06/01/1985	24.7	2.72	7.99	6.46	4.76	3.81	3.35	2.84
23/10/1985	28.6	4.15	2.84	2.11	1.81	1.65	1.65	1.74
22/01/1987	18.5	1.54	2.90	2.62	4.60	9.69	11.08	8.08
24/10/1987	14.4	1.19	1.16	1.58	2.30	2.50	3.06	3.04
26/09/1989	29.4	4.54	5.96	18.68	35.11	27.29	20.51	15.72
18/09/1990	37.7	12.20	2.90	2.14	1.84	1.67	1.58	1.50
08/12/1990	31.0	5.46	3.75	2.93	2.38	2.18	2.15	1.95
29/10/1991	25.4	2.92	4.86	3.19	2.56	3.10	2.77	2.42
09/05/1993	18.6	1.55	1.11	1.15	1.86	3.48	4.14	3.59
29/10/1993	29.8	4.76	2.13	2.58	3.25	4.35	4.89	4.35
07/10/1994	10.9	1.05	1.26	1.67	2.07	2.29	2.37	2.17
22/03/1996	32.5	6.52	2.90	2.15	1.86	1.71	1.61	1.52
19/03/1997	15.9	1.29	1.07	1.21	1.17	1.14	1.13	1.13
01/02/1998	28.7	4.20	7.72	6.03	5.11	4.48	3.91	3.48
05/11/1998	11.9	1.07	1.59	1.43	1.32	1.26	1.23	1.21
10/10/1999	26.5	3.29	3.36	2.40	2.02	1.82	1.71	1.60
18/12/2000	20.4	1.80	1.70	1.54	1.70	1.62	1.55	1.48
18/11/2001	20.6	1.83	2.70	5.86	5.48	4.90	4.26	3.48
24/11/2002	29.9	4.81	17.50	24.03	16.53	11.84	9.88	7.17
10/10/2003	18.4	1.53	1.58	1.37	1.28	1.35	1.31	1.27
17/10/2004	21.4	1.97	1.87	1.81	1.67	1.59	1.85	2.53
24/01/2006	15.5	1.26	1.07	1.05	1.04	1.11	1.10	1.09
07/04/2007	22.1	2.10	3.75	2.61	2.16	1.97	2.73	2.99
08/04/2008	41.4	19.22	6.01	3.89	3.16	2.66	2.53	7.94
26/12/2008	17.2	1.40	1.40	1.26	1.27	1.34	1.64	1.70
20/02/2010	51.2	64.21	275.62	344.25	220.65	133.77	116.90	98.35
25/11/2010	37.3	11.62	6.70	6.19	5.23	7.37	7.22	12.93
23/10/2011	10.2	1.03	1.19	1.30	1.24	1.20	1.20	1.19
25/11/2012	21.5	1.99	1.54	2.58	4.46	4.67	5.09	4.41
18/10/2013	21.7	2.02	1.18	1.11	1.08	1.07	1.06	1.06

		Joint (or) return periods in years					
Date of maximum	**Hourly AMS (mm)**	1 hour before&after	2 hours before&after	3 hours before&after	4 hours before&after	5 hours before&after	6 hours before&after
11/11/1980	11.4	1.05	1.03	1.03	1.02	1.02	1.02
21/11/1981	16.2	1.23	1.21	1.19	1.16	1.14	1.12
23/09/1983	10.9	1.02	1.01	1.01	1.01	1.00	1.00
21/09/1984	22.0	1.50	1.45	1.44	1.36	1.34	1.60
06/01/1985	24.7	2.67	2.57	2.40	2.25	2.14	2.09
23/10/1985	28.6	2.56	1.99	1.74	1.59	1.59	1.67
22/01/1987	18.5	1.51	1.48	1.52	1.53	1.53	1.53
24/10/1987	14.4	1.10	1.16	1.17	1.17	1.18	1.17
26/09/1989	29.4	3.81	4.38	4.46	4.39	4.28	4.36
18/09/1990	37.7	2.87	2.13	1.83	1.66	1.58	1.50
08/12/1990	31.0	3.29	2.66	2.22	2.05	2.01	1.88
29/10/1991	25.4	2.70	2.31	2.04	2.18	2.06	1.99
09/05/1993	18.6	1.11	1.13	1.38	1.49	1.50	1.50
29/10/1993	29.8	2.08	2.37	2.70	3.11	3.24	3.28
07/10/1994	10.9	1.04	1.04	1.05	1.04	1.04	1.04
22/03/1996	32.5	2.78	2.10	1.82	1.68	1.59	1.51
19/03/1997	15.9	1.06	1.13	1.11	1.09	1.08	1.07
01/02/1998	28.7	3.84	3.48	3.19	2.98	2.77	2.77
05/11/1998	11.9	1.07	1.07	1.06	1.05	1.05	1.04
10/10/1999	26.5	2.60	2.09	1.83	1.68	1.59	1.53
18/12/2000	20.4	1.50	1.39	1.43	1.38	1.34	1.31
18/11/2001	20.6	1.73	1.81	1.78	1.76	1.73	1.71
24/11/2002	29.9	4.69	4.68	4.49	4.24	4.06	4.03
10/10/2003	18.4	1.36	1.25	1.19	1.21	1.19	1.17
17/10/2004	21.4	1.62	1.55	1.45	1.40	1.49	1.69
24/01/2006	15.5	1.06	1.04	1.03	1.07	1.06	1.05
07/04/2007	22.1	2.01	1.82	1.67	1.58	1.75	1.84
08/04/2008	41.4	5.78	3.81	3.10	2.62	2.49	7.28
26/12/2008	17.2	1.26	1.18	1.17	1.18	1.25	1.26
20/02/2010	51.2	59.86	59.43	54.82	48.25	45.85	52.35
25/11/2010	37.3	5.88	5.32	4.57	5.68	5.54	8.52
23/10/2011	10.2	1.03	1.03	1.03	1.02	1.02	1.02
25/11/2012	21.5	1.46	1.76	1.88	1.87	1.88	1.88
18/10/2013	21.7	1.17	1.11	1.08	1.06	1.06	1.05

Joint (and) return periods in years							
Date of maximum	**Hourly AMS (mm)**	1 hour before&after	2 hours before&after	3 hours before&after	4 hours before&after	5 hours before&after	6 hours before&after
11/11/1980	11.4	1.16	1.12	1.11	1.10	1.11	1.11
21/11/1981	16.2	1.55	1.62	1.60	1.54	1.52	1.50
23/09/1983	10.9	1.06	1.05	1.05	1.05	1.05	1.05
21/09/1984	22.0	2.26	2.33	2.44	2.38	2.38	2.84
06/01/1985	24.7	8.48	7.48	6.17	5.39	5.02	4.15
23/10/1985	28.6	4.94	4.69	4.63	4.56	4.63	4.60
22/01/1987	18.5	2.99	2.82	4.83	10.01	11.49	8.39
24/10/1987	14.4	1.26	1.64	2.35	2.56	3.14	3.12
26/09/1989	29.4	7.98	21.99	41.48	34.86	28.27	18.35
18/09/1990	37.7	12.69	12.65	12.69	12.67	12.67	12.49
08/12/1990	31.0	6.85	6.70	6.52	6.49	6.59	6.06
29/10/1991	25.4	5.65	4.50	4.14	4.86	4.62	3.97
09/05/1993	18.6	1.56	1.59	2.18	3.80	4.51	3.91
29/10/1993	29.8	5.04	5.68	6.77	8.45	9.47	7.40
07/10/1994	10.9	1.26	1.68	2.07	2.30	2.38	2.19
22/03/1996	32.5	7.19	7.04	7.02	7.00	6.98	6.81
19/03/1997	15.9	1.30	1.39	1.38	1.37	1.36	1.37
01/02/1998	28.7	9.33	8.56	8.26	7.93	7.47	6.10
05/11/1998	11.9	1.60	1.44	1.35	1.30	1.27	1.26
10/10/1999	26.5	4.61	4.11	3.97	3.87	3.82	3.65
18/12/2000	20.4	2.10	2.06	2.26	2.23	2.19	2.13
18/11/2001	20.6	2.95	6.15	5.97	5.51	4.94	4.02
24/11/2002	29.9	19.31	27.87	21.95	17.70	15.96	10.10
10/10/2003	18.4	1.80	1.70	1.67	1.75	1.72	1.71
17/10/2004	21.4	2.35	2.42	2.39	2.36	2.64	3.22
24/01/2006	15.5	1.27	1.27	1.27	1.32	1.31	1.32
07/04/2007	22.1	4.07	3.23	2.95	2.84	3.66	3.76
08/04/2008	41.4	22.13	21.64	21.79	21.54	21.72	24.60
26/12/2008	17.2	1.58	1.52	1.55	1.63	1.91	1.97
20/02/2010	51.2	400.55	605.36	536.40	430.66	431.43	150.63
25/11/2010	37.3	15.35	16.80	17.11	21.91	22.71	21.68
23/10/2011	10.2	1.19	1.31	1.25	1.21	1.22	1.21
25/11/2012	21.5	2.15	3.10	5.10	5.45	5.99	5.05
18/10/2013	21.7	2.04	2.04	2.04	2.04	2.04	2.05

Conditional (maximum given the cumulative) return periods in years							
Date of maximum	**Hourly AMS (mm)**	1 hour before&after	2 hours before&after	3 hours before&after	4 hours before&after	5 hours before&after	6 hours before&after
11/11/1980	11.4	1.32	1.21	1.19	1.17	1.18	1.18
21/11/1981	16.2	2.23	2.38	2.26	2.06	1.97	1.89
23/09/1983	10.9	1.09	1.07	1.07	1.06	1.06	1.07
21/09/1984	22.0	3.58	3.66	3.91	3.53	3.48	5.70
06/01/1985	24.7	67.77	48.27	29.38	20.51	16.79	11.79
23/10/1985	28.6	13.99	9.87	8.39	7.52	7.66	8.00
22/01/1987	18.5	8.67	7.39	22.21	97.05	127.32	67.76
24/10/1987	14.4	1.46	2.59	5.40	6.41	9.61	9.49
26/09/1989	29.4	47.59	410.94	1456.18	951.49	579.95	288.59
18/09/1990	37.7	36.77	27.08	23.34	21.10	20.08	18.74
08/12/1990	31.0	25.64	19.60	15.52	14.14	14.16	11.81
29/10/1991	25.4	27.49	14.36	10.58	15.07	12.81	9.61
09/05/1993	18.6	1.74	1.83	4.06	13.22	18.67	14.02
29/10/1993	29.8	10.75	14.63	21.97	36.75	46.33	32.23
07/10/1994	10.9	1.59	2.81	4.29	5.26	5.63	4.75
22/03/1996	32.5	20.82	15.15	13.04	11.94	11.26	10.38
19/03/1997	15.9	1.39	1.67	1.62	1.56	1.53	1.54
01/02/1998	28.7	72.07	51.57	42.18	35.58	29.17	21.25
05/11/1998	11.9	2.55	2.07	1.79	1.64	1.56	1.52
10/10/1999	26.5	15.50	9.87	8.02	7.05	6.54	5.85
18/12/2000	20.4	3.56	3.18	3.86	3.62	3.39	3.14
18/11/2001	20.6	7.95	36.07	32.71	27.00	21.03	14.01
24/11/2002	29.9	337.93	669.79	362.90	209.65	157.64	72.40
10/10/2003	18.4	2.85	2.33	2.14	2.35	2.25	2.17
17/10/2004	21.4	4.39	4.39	3.98	3.74	4.89	8.15
24/01/2006	15.5	1.36	1.33	1.33	1.46	1.44	1.43
07/04/2007	22.1	15.24	8.41	6.39	5.60	9.98	11.23
08/04/2008	41.4	133.05	84.28	68.79	57.22	54.89	195.42
26/12/2008	17.2	2.20	1.91	1.97	2.19	3.12	3.36
20/02/2010	51.2	110397.90	208395.70	118355.60	57608.41	50433.48	14813.79
25/11/2010	37.3	102.82	104.05	89.46	161.41	163.86	280.27
23/10/2011	10.2	1.42	1.70	1.56	1.45	1.47	1.44
25/11/2012	21.5	3.32	7.99	22.76	25.50	30.46	22.26
18/10/2013	21.7	2.39	2.26	2.21	2.18	2.16	2.17

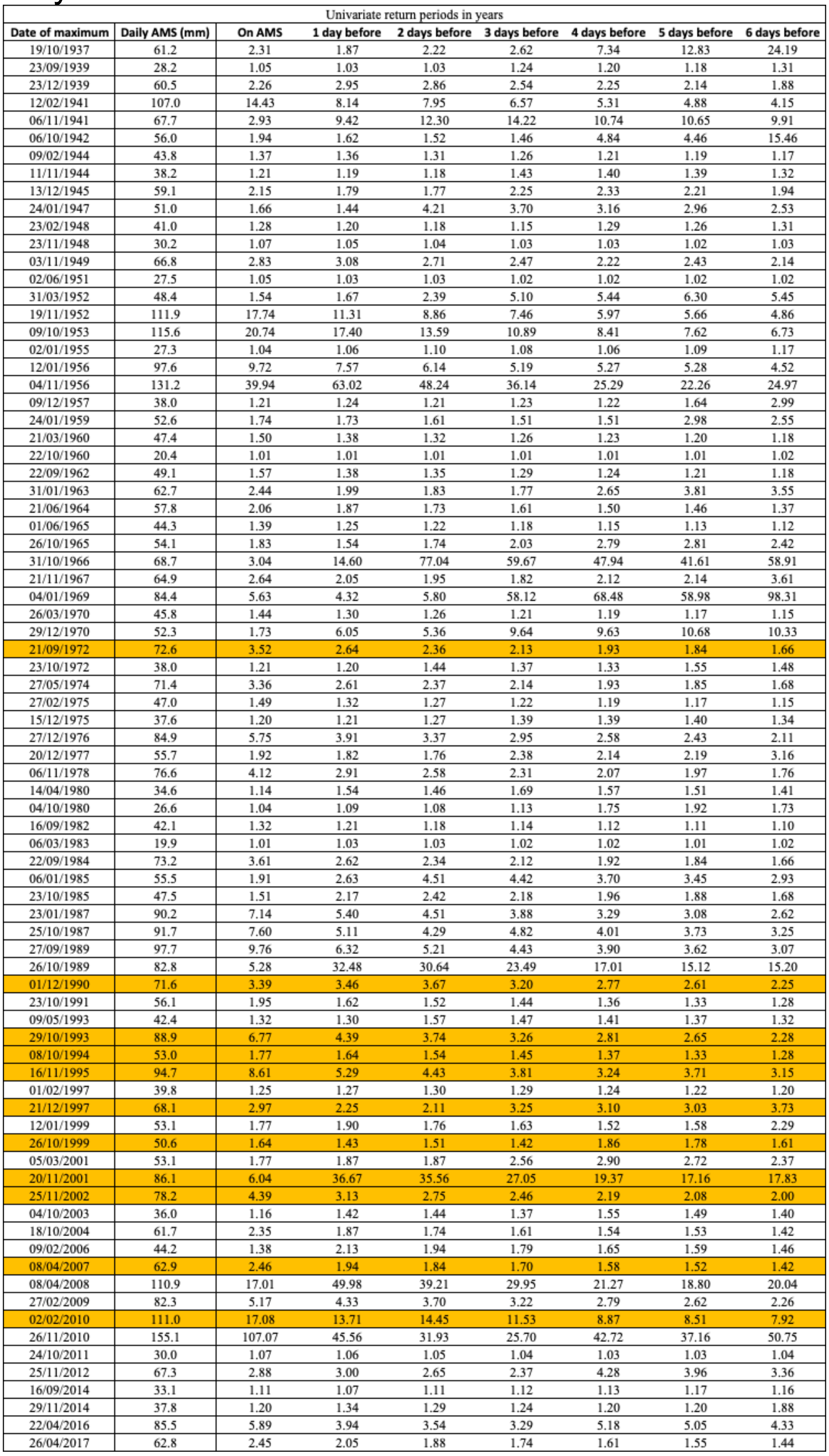


Conditional (cumulative given the maximum) return periods in years							
Date of maximum	**Hourly AMS (mm)**	1 hour before&after	2 hours before&after	3 hours before&after	4 hours before&after	5 hours before&after	6 hours before&after
11/11/1980	11.4	1.22	1.18	1.18	1.17	1.17	1.18
21/11/1981	16.2	2.03	2.12	2.10	2.03	1.99	1.97
23/09/1983	10.9	1.11	1.10	1.10	1.10	1.10	1.10
21/09/1984	22.0	4.70	4.86	5.07	4.95	4.96	5.90
06/01/1985	24.7	23.06	20.33	16.78	14.65	13.64	11.29
23/10/1985	28.6	20.48	19.45	19.19	18.94	19.23	19.10
22/01/1987	18.5	4.61	4.34	7.45	15.42	17.70	12.92
24/10/1987	14.4	1.49	1.94	2.79	3.04	3.72	3.71
26/09/1989	29.4	36.26	99.93	188.45	158.40	128.45	83.40
18/09/1990	37.7	154.81	154.30	154.79	154.55	154.63	152.35
08/12/1990	31.0	37.41	36.61	35.63	35.47	36.00	33.14
29/10/1991	25.4	16.53	13.15	12.09	14.21	13.50	11.61
09/05/1993	18.6	2.43	2.47	3.39	5.91	7.01	6.07
29/10/1993	29.8	23.97	27.01	32.19	40.20	45.02	35.21
07/10/1994	10.9	1.32	1.76	2.17	2.40	2.49	2.29
22/03/1996	32.5	46.84	45.86	45.77	45.64	45.50	44.40
19/03/1997	15.9	1.67	1.79	1.78	1.76	1.75	1.76
01/02/1998	28.7	39.15	35.92	34.66	33.30	31.34	25.59
05/11/1998	11.9	1.72	1.55	1.45	1.39	1.36	1.35
10/10/1999	26.5	15.16	13.53	13.05	12.75	12.58	12.02
18/12/2000	20.4	3.77	3.72	4.08	4.02	3.94	3.83
18/11/2001	20.6	5.40	11.27	10.93	10.10	9.05	7.37
24/11/2002	29.9	92.92	134.11	105.60	85.16	76.80	48.59
10/10/2003	18.4	2.76	2.61	2.56	2.67	2.64	2.61
17/10/2004	21.4	4.63	4.77	4.69	4.64	5.20	6.33
24/01/2006	15.5	1.60	1.60	1.60	1.65	1.65	1.65
07/04/2007	22.1	8.55	6.78	6.21	5.97	7.69	7.89
08/04/2008	41.4	425.17	415.83	418.68	413.91	417.30	472.82
26/12/2008	17.2	2.21	2.13	2.17	2.28	2.67	2.76
20/02/2010	51.2	25719.72	38870.96	34443.04	27653.29	27702.84	9672.14
25/11/2010	37.3	178.34	195.18	198.78	254.57	263.86	251.91
23/10/2011	10.2	1.23	1.35	1.29	1.25	1.26	1.25
25/11/2012	21.5	4.28	6.17	10.13	10.84	11.89	10.03
18/10/2013	21.7	4.12	4.12	4.13	4.13	4.13	4.14

Annex IV – Return periods for daily rainfall

Note: The cells highlighted in orange identify the daily extreme rainfall events that are associated with alluvium flood events.

Return periods of annual maximum daily rainfalls and cumulative daily rainfalls in days before the annual maximum.



Univariate return periods in years								
Date of maximum	Daily AMS (mm)	On AMS	1 day before	2 days before	3 days before	4 days before	5 days before	6 days before
19/10/1937	61.2	2.31	1.87	2.22	2.62	7.34	12.83	24.19
23/09/1939	28.2	1.05	1.03	1.03	1.24	1.20	1.18	1.31
23/12/1939	60.5	2.26	2.95	2.86	2.54	2.25	2.14	1.88
12/02/1941	107.0	14.43	8.14	7.95	6.57	5.31	4.88	4.15
06/11/1941	67.7	2.93	9.42	12.30	14.22	10.74	10.65	9.91
06/10/1942	56.0	1.94	1.62	1.52	1.46	4.84	4.46	15.46
09/02/1944	43.8	1.37	1.36	1.31	1.26	1.21	1.19	1.17
11/11/1944	38.2	1.21	1.19	1.18	1.43	1.40	1.39	1.32
13/12/1945	59.1	2.15	1.79	1.77	2.25	2.33	2.21	1.94
24/01/1947	51.0	1.66	1.44	4.21	3.70	3.16	2.96	2.53
23/02/1948	41.0	1.28	1.20	1.18	1.15	1.29	1.26	1.31
23/11/1948	30.2	1.07	1.05	1.04	1.03	1.03	1.02	1.03
03/11/1949	66.8	2.83	3.08	2.71	2.47	2.22	2.43	2.14
02/06/1951	27.5	1.05	1.03	1.03	1.02	1.02	1.02	1.02
31/03/1952	48.4	1.54	1.67	2.39	5.10	5.44	6.30	5.45
19/11/1952	111.9	17.74	11.31	8.86	7.46	5.97	5.66	4.86
09/10/1953	115.6	20.74	17.40	13.59	10.89	8.41	7.62	6.73
02/01/1955	27.3	1.04	1.06	1.10	1.08	1.06	1.09	1.17
12/01/1956	97.6	9.72	7.57	6.14	5.19	5.27	5.28	4.52
04/11/1956	131.2	39.94	63.02	48.24	36.14	25.29	22.26	24.97
09/12/1957	38.0	1.21	1.24	1.21	1.23	1.22	1.64	2.99
24/01/1959	52.6	1.74	1.73	1.61	1.51	1.51	2.98	2.55
21/03/1960	47.4	1.50	1.38	1.32	1.26	1.23	1.20	1.18
22/10/1960	20.4	1.01	1.01	1.01	1.01	1.01	1.01	1.02
22/09/1962	49.1	1.57	1.38	1.35	1.29	1.24	1.21	1.18
31/01/1963	62.7	2.44	1.99	1.83	1.77	2.65	3.81	3.55
21/06/1964	57.8	2.06	1.87	1.73	1.61	1.50	1.46	1.37
01/06/1965	44.3	1.39	1.25	1.22	1.18	1.15	1.13	1.12
26/10/1965	54.1	1.83	1.54	1.74	2.03	2.79	2.81	2.42
31/10/1966	68.7	3.04	14.60	77.04	59.67	47.94	41.61	58.91
21/11/1967	64.9	2.64	2.05	1.95	1.82	2.12	2.14	3.61
04/01/1969	84.4	5.63	4.32	5.80	58.12	68.48	58.98	98.31
26/03/1970	45.8	1.44	1.30	1.26	1.21	1.19	1.17	1.15
29/12/1970	52.3	1.73	6.05	5.36	9.64	9.63	10.68	10.33
21/09/1972	72.6	3.52	2.64	2.36	2.13	1.93	1.84	1.66
23/10/1972	38.0	1.21	1.20	1.44	1.37	1.33	1.55	1.48
27/05/1974	71.4	3.36	2.61	2.37	2.14	1.93	1.85	1.68
27/02/1975	47.0	1.49	1.32	1.27	1.22	1.19	1.17	1.15
15/12/1975	37.6	1.20	1.21	1.27	1.39	1.39	1.40	1.34
27/12/1976	84.9	5.75	3.91	3.37	2.95	2.58	2.43	2.11
20/12/1977	55.7	1.92	1.82	1.76	2.38	2.14	2.19	3.16
06/11/1978	76.6	4.12	2.91	2.58	2.31	2.07	1.97	1.76
14/04/1980	34.6	1.14	1.54	1.46	1.69	1.57	1.51	1.41
04/10/1980	26.6	1.04	1.09	1.08	1.13	1.75	1.92	1.73
16/09/1982	42.1	1.32	1.21	1.18	1.14	1.12	1.11	1.10
06/03/1983	19.9	1.01	1.03	1.03	1.02	1.02	1.01	1.02
22/09/1984	73.2	3.61	2.62	2.34	2.12	1.92	1.84	1.66
06/01/1985	55.5	1.91	2.63	4.51	4.42	3.70	3.45	2.93
23/10/1985	47.5	1.51	2.17	2.42	2.18	1.96	1.88	1.68
23/01/1987	90.2	7.14	5.40	4.51	3.88	3.29	3.08	2.62
25/10/1987	91.7	7.60	5.11	4.29	4.82	4.01	3.73	3.25
27/09/1989	97.7	9.76	6.32	5.21	4.43	3.90	3.62	3.07
26/10/1989	82.8	5.28	32.48	30.64	23.49	17.01	15.12	15.20
01/12/1990	71.6	3.39	3.46	3.67	3.20	2.77	2.61	2.25
23/10/1991	56.1	1.95	1.62	1.52	1.44	1.36	1.33	1.28
09/05/1993	42.4	1.32	1.30	1.57	1.47	1.41	1.37	1.32
29/10/1993	88.9	6.77	4.39	3.74	3.26	2.81	2.65	2.28
08/10/1994	53.0	1.77	1.64	1.54	1.45	1.37	1.33	1.28
16/11/1995	94.7	8.61	5.29	4.43	3.81	3.24	3.71	3.15
01/02/1997	39.8	1.25	1.27	1.30	1.29	1.24	1.22	1.20
21/12/1997	68.1	2.97	2.25	2.11	3.25	3.10	3.03	3.73
12/01/1999	53.1	1.77	1.90	1.76	1.63	1.52	1.58	2.29
26/10/1999	50.6	1.64	1.43	1.51	1.42	1.86	1.78	1.61
05/03/2001	53.1	1.77	1.87	1.87	2.56	2.90	2.72	2.37
20/11/2001	86.1	6.04	36.67	35.56	27.05	19.37	17.16	17.83
25/11/2002	78.2	4.39	3.13	2.75	2.46	2.19	2.08	2.00
04/10/2003	36.0	1.16	1.42	1.44	1.37	1.55	1.49	1.40
18/10/2004	61.7	2.35	1.87	1.74	1.61	1.54	1.53	1.42
09/02/2006	44.2	1.38	2.13	1.94	1.79	1.65	1.59	1.46
08/04/2007	62.9	2.46	1.94	1.84	1.70	1.58	1.52	1.42
08/04/2008	110.9	17.01	49.98	39.21	29.95	21.27	18.80	20.04
27/02/2009	82.3	5.17	4.33	3.70	3.22	2.79	2.62	2.26
02/02/2010	111.0	17.08	13.71	14.45	11.53	8.87	8.51	7.92
26/11/2010	155.1	107.07	45.56	31.93	25.70	42.72	37.16	50.75
24/10/2011	30.0	1.07	1.06	1.05	1.04	1.03	1.03	1.04
25/11/2012	67.3	2.88	3.00	2.65	2.37	4.28	3.96	3.36
16/09/2014	33.1	1.11	1.07	1.11	1.12	1.13	1.17	1.16
29/11/2014	37.8	1.20	1.34	1.29	1.24	1.20	1.20	1.88
22/04/2016	85.5	5.89	3.94	3.54	3.29	5.18	5.05	4.33
26/04/2017	62.8	2.45	2.05	1.88	1.74	1.61	1.55	1.44

Joint "or" return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day before**	**2 days before**	**3 days before**	**4 days before**	**5 days before**	**6 days before**
19/10/1937	61.2	1.84	1.91	2.00	2.20	2.28	2.29
23/09/1939	28.2	1.03	1.03	1.05	1.04	1.05	1.05
23/12/1939	60.5	2.03	1.96	1.96	1.82	1.77	1.63
12/02/1941	107.0	7.64	7.17	5.84	4.87	4.47	3.84
06/11/1941	67.7	2.77	2.76	2.88	2.77	2.81	2.76
06/10/1942	56.0	1.60	1.51	1.41	1.85	1.87	1.92
09/02/1944	43.8	1.29	1.26	1.21	1.18	1.16	1.13
11/11/1944	38.2	1.16	1.15	1.19	1.17	1.17	1.15
13/12/1945	59.1	1.75	1.71	1.84	1.80	1.76	1.63
24/01/1947	51.0	1.43	1.58	1.64	1.58	1.60	1.54
23/02/1948	41.0	1.20	1.17	1.13	1.19	1.18	1.18
23/11/1948	30.2	1.05	1.04	1.03	1.02	1.02	1.03
03/11/1949	66.8	2.42	2.25	2.12	1.96	2.03	1.85
02/06/1951	27.5	1.03	1.03	1.02	1.02	1.01	1.02
31/03/1952	48.4	1.44	1.44	1.54	1.51	1.53	1.52
19/11/1952	111.9	10.03	8.11	6.66	5.49	5.17	4.47
09/10/1953	115.6	13.31	11.03	9.07	7.36	6.70	5.95
02/01/1955	27.3	1.04	1.03	1.04	1.03	1.04	1.04
12/01/1956	97.6	6.46	5.46	4.58	4.52	4.45	3.88
04/11/1956	131.2	30.19	26.30	23.15	18.33	16.69	17.46
09/12/1957	38.0	1.17	1.15	1.16	1.14	1.19	1.20
24/01/1959	52.6	1.57	1.51	1.42	1.40	1.66	1.60
21/03/1960	47.4	1.35	1.30	1.23	1.20	1.18	1.15
22/10/1960	20.4	1.01	1.01	1.01	1.01	1.01	1.01
22/09/1962	49.1	1.37	1.33	1.26	1.22	1.19	1.16
31/01/1963	62.7	1.94	1.79	1.67	1.99	2.18	2.10
21/06/1964	57.8	1.77	1.66	1.53	1.44	1.39	1.32
01/06/1965	44.3	1.25	1.21	1.16	1.14	1.12	1.11
26/10/1965	54.1	1.53	1.58	1.64	1.68	1.70	1.63
31/10/1966	68.7	2.92	3.01	3.03	3.00	3.02	3.02
21/11/1967	64.9	2.01	1.90	1.72	1.87	1.86	2.21
04/01/1969	84.4	3.93	4.14	5.57	5.49	5.52	5.55
26/03/1970	45.8	1.29	1.25	1.19	1.17	1.15	1.13
29/12/1970	52.3	1.68	1.66	1.72	1.70	1.72	1.71
21/09/1972	72.6	2.55	2.30	2.02	1.85	1.76	1.59
23/10/1972	38.0	1.16	1.16	1.18	1.16	1.18	1.17
27/05/1974	71.4	2.50	2.28	2.01	1.84	1.75	1.60
27/02/1975	47.0	1.31	1.27	1.20	1.17	1.15	1.13
15/12/1975	37.6	1.16	1.15	1.18	1.16	1.17	1.15
27/12/1976	84.9	3.73	3.24	2.76	2.45	2.30	2.01
20/12/1977	55.7	1.69	1.62	1.76	1.66	1.67	1.76
06/11/1978	76.6	2.82	2.52	2.19	1.99	1.88	1.69
14/04/1980	34.6	1.12	1.11	1.14	1.12	1.13	1.12
04/10/1980	26.6	1.03	1.03	1.04	1.03	1.04	1.04
16/09/1982	42.1	1.20	1.17	1.13	1.11	1.10	1.09
06/03/1983	19.9	1.01	1.01	1.01	1.01	1.01	1.01
22/09/1984	73.2	2.55	2.29	2.01	1.84	1.76	1.59
06/01/1985	55.5	1.76	1.79	1.87	1.79	1.80	1.73
23/10/1985	47.5	1.43	1.42	1.46	1.40	1.41	1.35
23/01/1987	90.2	4.83	4.15	3.50	3.05	2.84	2.45
25/10/1987	91.7	4.77	4.08	4.13	3.56	3.32	2.92
27/09/1989	97.7	5.86	4.92	4.06	3.62	3.35	2.87
26/10/1989	82.8	5.06	4.97	5.09	4.79	4.79	4.69
01/12/1990	71.6	2.80	2.70	2.56	2.32	2.21	1.98
23/10/1991	56.1	1.60	1.51	1.40	1.33	1.30	1.24
09/05/1993	42.4	1.25	1.25	1.27	1.23	1.22	1.19
29/10/1993	88.9	4.19	3.61	3.04	2.67	2.50	2.17
08/10/1994	53.0	1.56	1.49	1.39	1.33	1.29	1.23
16/11/1995	94.7	5.03	4.26	3.54	3.07	3.37	2.90
01/02/1997	39.8	1.20	1.19	1.19	1.16	1.15	1.13
21/12/1997	68.1	2.20	2.05	2.44	2.31	2.27	2.37
12/01/1999	53.1	1.61	1.55	1.49	1.41	1.43	1.58
26/10/1999	50.6	1.42	1.43	1.35	1.47	1.46	1.38
05/03/2001	53.1	1.61	1.56	1.69	1.65	1.66	1.59
20/11/2001	86.1	5.76	5.67	5.80	5.44	5.42	5.33
25/11/2002	78.2	3.01	2.67	2.31	2.09	1.97	1.88
04/10/2003	36.0	1.14	1.13	1.15	1.14	1.15	1.14
18/10/2004	61.7	1.84	1.71	1.56	1.49	1.46	1.37
09/02/2006	44.2	1.33	1.31	1.34	1.30	1.30	1.25
08/04/2007	62.9	1.91	1.80	1.63	1.53	1.47	1.37
08/04/2008	110.9	14.90	13.85	13.48	11.54	10.93	10.87
27/02/2009	82.3	3.80	3.35	2.89	2.57	2.41	2.11
02/02/2010	111.0	10.93	10.43	8.95	7.34	7.01	6.49
26/11/2010	155.1	41.16	29.74	23.37	34.36	30.55	37.46
24/10/2011	30.0	1.05	1.05	1.03	1.03	1.02	1.03
25/11/2012	67.3	2.44	2.26	2.08	2.47	2.44	2.26
16/09/2014	33.1	1.07	1.08	1.08	1.08	1.09	1.08
29/11/2014	37.8	1.17	1.15	1.16	1.13	1.13	1.18
22/04/2016	85.5	3.76	3.38	3.01	3.85	3.75	3.35
26/04/2017	62.8	1.97	1.83	1.65	1.55	1.49	1.39

		Joint "and" return periods in years					
Date of maximum	**Daily AMS (mm)**	**1 day before**	**2 days before**	**3 days before**	**4 days before**	**5 days before**	**6 days before**
19/10/1937	61.2	2.37	2.79	3.18	8.75	13.92	26.72
23/09/1939	28.2	1.05	1.05	1.24	1.21	1.18	1.31
23/12/1939	60.5	3.44	3.54	3.07	2.97	2.89	2.78
12/02/1941	107.0	16.31	17.96	19.87	19.15	19.86	20.22
06/11/1941	67.7	11.54	16.30	15.28	13.51	12.45	12.41
06/10/1942	56.0	1.97	1.97	2.03	5.56	4.90	16.61
09/02/1944	43.8	1.45	1.43	1.43	1.41	1.41	1.42
11/11/1944	38.2	1.24	1.25	1.46	1.47	1.44	1.39
13/12/1945	59.1	2.21	2.26	2.75	2.96	2.86	2.73
24/01/1947	51.0	1.68	4.82	3.82	3.52	3.19	2.86
23/02/1948	41.0	1.29	1.29	1.30	1.40	1.39	1.44
23/11/1948	30.2	1.07	1.07	1.08	1.08	1.08	1.08
03/11/1949	66.8	3.78	3.60	3.49	3.41	3.69	3.60
02/06/1951	27.5	1.05	1.05	1.05	1.05	1.05	1.05
31/03/1952	48.4	1.81	2.68	5.17	5.91	6.47	5.73
19/11/1952	111.9	22.16	21.75	24.84	23.94	25.31	26.07
09/10/1953	115.6	32.72	32.14	33.49	32.05	33.14	35.04
02/01/1955	27.3	1.07	1.11	1.08	1.08	1.09	1.18
12/01/1956	97.6	12.46	12.11	13.01	13.95	14.85	15.01
04/11/1956	131.2	128.46	129.19	105.12	99.67	99.64	128.24
09/12/1957	38.0	1.29	1.28	1.29	1.29	1.68	3.04
24/01/1959	52.6	1.93	1.89	1.88	1.91	3.28	2.95
21/03/1960	47.4	1.53	1.52	1.55	1.54	1.54	1.55
22/10/1960	20.4	1.01	1.01	1.01	1.01	1.01	1.02
22/09/1962	49.1	1.59	1.59	1.62	1.61	1.62	1.62
31/01/1963	62.7	2.53	2.51	2.65	3.51	4.67	4.66
21/06/1964	57.8	2.20	2.17	2.22	2.18	2.20	2.19
01/06/1965	44.3	1.39	1.39	1.41	1.40	1.41	1.41
26/10/1965	54.1	1.85	2.06	2.32	3.23	3.17	2.89
31/10/1966	68.7	18.01	103.13	61.91	59.33	45.79	67.50
21/11/1967	64.9	2.71	2.73	2.86	3.15	3.25	4.94
04/01/1969	84.4	6.46	9.22	65.99	97.97	74.40	131.77
26/03/1970	45.8	1.45	1.45	1.47	1.47	1.47	1.48
29/12/1970	52.3	6.70	6.19	9.79	10.68	11.04	10.95
21/09/1972	72.6	3.70	3.68	3.89	3.82	3.88	3.86
23/10/1972	38.0	1.25	1.51	1.40	1.40	1.59	1.54
27/05/1974	71.4	3.57	3.56	3.75	3.67	3.73	3.71
27/02/1975	47.0	1.50	1.49	1.52	1.51	1.51	1.52
15/12/1975	37.6	1.26	1.33	1.42	1.45	1.44	1.41
27/12/1976	84.9	6.20	6.14	6.68	6.51	6.67	6.63
20/12/1977	55.7	2.09	2.12	2.69	2.60	2.65	3.73
06/11/1978	76.6	4.32	4.29	4.59	4.50	4.58	4.55
14/04/1980	34.6	1.57	1.51	1.69	1.61	1.53	1.44
04/10/1980	26.6	1.10	1.09	1.13	1.76	1.92	1.73
16/09/1982	42.1	1.32	1.32	1.33	1.33	1.33	1.34
06/03/1983	19.9	1.03	1.03	1.02	1.02	1.02	1.02
22/09/1984	73.2	3.76	3.73	3.96	3.89	3.96	3.94
06/01/1985	55.5	2.97	5.35	4.64	4.27	3.86	3.47
23/10/1985	47.5	2.34	2.69	2.27	2.17	2.06	1.93
23/01/1987	90.2	8.47	8.29	8.92	8.65	8.87	8.82
25/10/1987	91.7	8.50	8.40	10.35	9.99	10.19	10.27
27/09/1989	97.7	11.13	10.99	12.22	12.08	12.46	12.49
26/10/1989	82.8	44.47	47.41	28.01	25.28	21.39	23.74
01/12/1990	71.6	4.42	5.09	4.60	4.44	4.41	4.28
23/10/1991	56.1	1.98	1.97	2.03	2.01	2.03	2.03
09/05/1993	42.4	1.38	1.69	1.55	1.53	1.50	1.48
29/10/1993	88.9	7.32	7.26	7.97	7.76	7.97	7.94
08/10/1994	53.0	1.86	1.84	1.87	1.84	1.85	1.85
16/11/1995	94.7	9.40	9.33	10.37	10.08	11.30	11.29
01/02/1997	39.8	1.33	1.37	1.36	1.34	1.33	1.33
21/12/1997	68.1	3.07	3.08	4.27	4.42	4.40	5.44
12/01/1999	53.1	2.12	2.05	1.98	1.94	2.01	2.72
26/10/1999	50.6	1.66	1.74	1.75	2.15	2.07	1.98
05/03/2001	53.1	2.09	2.18	2.77	3.31	3.04	2.80
20/11/2001	86.1	51.48	57.00	33.09	29.94	25.32	29.13
25/11/2002	78.2	4.65	4.62	4.95	4.84	4.94	5.07
04/10/2003	36.0	1.46	1.50	1.39	1.59	1.52	1.44
18/10/2004	61.7	2.41	2.40	2.49	2.47	2.52	2.51
09/02/2006	44.2	2.26	2.12	1.86	1.79	1.72	1.64
08/04/2007	62.9	2.52	2.53	2.63	2.59	2.62	2.61
08/04/2008	110.9	85.49	82.71	55.57	52.25	48.94	59.80
27/02/2009	82.3	6.21	6.04	6.33	6.15	6.26	6.19
02/02/2010	111.0	25.01	31.40	29.88	28.53	29.99	32.64
26/11/2010	155.1	142.95	142.26	183.51	274.39	284.12	426.15
24/10/2011	30.0	1.08	1.07	1.08	1.07	1.07	1.08
25/11/2012	67.3	3.69	3.54	3.46	5.68	5.26	4.93
16/09/2014	33.1	1.11	1.14	1.15	1.17	1.20	1.20
29/11/2014	37.8	1.39	1.36	1.29	1.28	1.28	1.93
22/04/2016	85.5	6.32	6.40	7.11	9.74	9.88	9.80
26/04/2017	62.8	2.57	2.55	2.64	2.60	2.63	2.61

Conditional (maximum given the cumulative) return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day before**	**2 days before**	**3 days before**	**4 days before**	**5 days before**	**6 days before**
19/10/1937	61.2	4.45	6.19	8.33	64.26	178.59	646.38
23/09/1939	28.2	1.09	1.09	1.54	1.45	1.40	1.72
23/12/1939	60.5	10.16	10.14	7.81	6.69	6.19	5.24
12/02/1941	107.0	132.78	142.73	130.64	101.69	96.88	84.01
06/11/1941	67.7	108.78	200.50	217.32	145.01	132.59	122.99
06/10/1942	56.0	3.19	2.99	2.97	26.93	21.88	256.80
09/02/1944	43.8	1.98	1.87	1.79	1.71	1.68	1.65
11/11/1944	38.2	1.48	1.47	2.08	2.06	2.00	1.84
13/12/1945	59.1	3.95	4.01	6.19	6.91	6.32	5.29
24/01/1947	51.0	2.42	20.30	14.14	11.11	9.44	7.22
23/02/1948	41.0	1.56	1.53	1.50	1.82	1.75	1.90
23/11/1948	30.2	1.13	1.12	1.11	1.10	1.10	1.11
03/11/1949	66.8	11.65	9.78	8.61	7.58	8.98	7.71
02/06/1951	27.5	1.08	1.07	1.07	1.07	1.06	1.08
31/03/1952	48.4	3.01	6.40	26.39	32.15	40.78	31.26
19/11/1952	111.9	250.53	192.74	185.26	142.99	143.24	126.68
09/10/1953	115.6	569.35	436.76	364.64	269.59	252.51	235.96
02/01/1955	27.3	1.13	1.22	1.17	1.15	1.19	1.38
12/01/1956	97.6	94.32	74.30	67.58	73.49	78.42	67.77
04/11/1956	131.2	8096.13	6231.58	3799.33	2520.44	2218.36	3202.42
09/12/1957	38.0	1.59	1.55	1.59	1.58	2.76	9.09
24/01/1959	52.6	3.34	3.05	2.84	2.89	9.78	7.52
21/03/1960	47.4	2.10	2.01	1.95	1.89	1.86	1.82
22/10/1960	20.4	1.03	1.02	1.03	1.02	1.02	1.04
22/09/1962	49.1	2.20	2.14	2.09	1.99	1.96	1.92
31/01/1963	62.7	5.04	4.60	4.68	9.29	17.79	16.56
21/06/1964	57.8	4.12	3.76	3.57	3.28	3.20	2.99
01/06/1965	44.3	1.75	1.69	1.66	1.61	1.59	1.58
26/10/1965	54.1	2.86	3.59	4.70	9.01	8.91	6.99
31/10/1966	68.7	262.96	7945.37	3694.33	2844.45	1905.10	3976.21
21/11/1967	64.9	5.56	5.34	5.20	6.66	6.95	17.83
04/01/1969	84.4	27.91	53.46	3835.32	6708.19	4387.95	12954.71
26/03/1970	45.8	1.89	1.82	1.78	1.75	1.72	1.70
29/12/1970	52.3	40.53	33.15	94.38	102.85	117.90	113.14
21/09/1972	72.6	9.80	8.69	8.31	7.37	7.16	6.40
23/10/1972	38.0	1.50	2.18	1.91	1.87	2.45	2.28
27/05/1974	71.4	9.32	8.43	8.02	7.10	6.89	6.22
27/02/1975	47.0	1.98	1.90	1.86	1.79	1.76	1.74
15/12/1975	37.6	1.52	1.69	1.96	2.03	2.02	1.88
27/12/1976	84.9	24.23	20.67	19.72	16.79	16.22	14.00
20/12/1977	55.7	3.81	3.72	6.40	5.57	5.82	11.79
06/11/1978	76.6	12.57	11.06	10.60	9.31	9.04	8.00
14/04/1980	34.6	2.42	2.20	2.86	2.52	2.32	2.03
04/10/1980	26.6	1.20	1.18	1.27	3.09	3.68	3.00
16/09/1982	42.1	1.60	1.55	1.52	1.49	1.47	1.47
06/03/1983	19.9	1.07	1.06	1.04	1.04	1.03	1.05
22/09/1984	73.2	9.84	8.75	8.40	7.46	7.29	6.52
06/01/1985	55.5	7.81	24.13	20.50	15.83	13.28	10.17
23/10/1985	47.5	5.09	6.50	4.96	4.26	3.86	3.24
23/01/1987	90.2	45.73	37.40	34.57	28.47	27.28	23.15
25/10/1987	91.7	43.47	36.06	49.94	40.06	38.02	33.34
27/09/1989	97.7	70.37	57.24	54.11	47.04	45.06	38.32
26/10/1989	82.8	1444.42	1452.75	657.96	430.10	323.49	360.77
01/12/1990	71.6	15.29	18.68	14.74	12.31	11.50	9.63
23/10/1991	56.1	3.20	3.01	2.91	2.73	2.70	2.59
09/05/1993	42.4	1.79	2.65	2.28	2.15	2.05	1.94
29/10/1993	88.9	32.15	27.16	25.94	21.85	21.09	18.10
08/10/1994	53.0	3.04	2.83	2.70	2.53	2.47	2.36
16/11/1995	94.7	49.73	41.31	39.51	32.68	41.94	35.54
01/02/1997	39.8	1.68	1.78	1.76	1.67	1.63	1.59
21/12/1997	68.1	6.89	6.50	13.87	13.72	13.33	20.28
12/01/1999	53.1	4.03	3.60	3.23	2.95	3.17	6.22
26/10/1999	50.6	2.38	2.63	2.48	3.99	3.69	3.19
05/03/2001	53.1	3.93	4.07	7.09	9.60	8.28	6.64
20/11/2001	86.1	1887.71	2026.72	895.12	579.84	434.55	519.25
25/11/2002	78.2	14.59	12.72	12.15	10.59	10.26	10.14
04/10/2003	36.0	2.08	2.16	1.89	2.46	2.27	2.02
18/10/2004	61.7	4.51	4.16	4.02	3.80	3.85	3.57
09/02/2006	44.2	4.81	4.11	3.31	2.95	2.73	2.41
08/04/2007	62.9	4.89	4.66	4.48	4.09	3.99	3.70
08/04/2008	110.9	4272.49	3243.03	1664.17	1111.31	920.31	1198.47
27/02/2009	82.3	26.91	22.33	20.37	17.12	16.40	13.99
02/02/2010	111.0	342.92	453.56	344.56	252.88	255.20	258.57
26/11/2010	155.1	6512.22	4542.19	4716.93	11720.88	10558.58	21629.26
24/10/2011	30.0	1.14	1.13	1.12	1.11	1.10	1.12
25/11/2012	67.3	11.07	9.37	8.18	24.31	20.82	16.54
16/09/2014	33.1	1.20	1.26	1.29	1.31	1.41	1.39
29/11/2014	37.8	1.87	1.76	1.61	1.53	1.54	3.64
22/04/2016	85.5	24.89	22.65	23.41	50.45	49.92	42.42
26/04/2017	62.8	5.28	4.80	4.59	4.18	4.07	3.76

Conditional (cumulative given the maximum) return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day before**	**2 days before**	**3 days before**	**4 days before**	**5 days before**	**6 days before**
19/10/1937	61.2	5.49	6.45	7.36	20.25	32.21	61.81
23/09/1939	28.2	1.11	1.11	1.31	1.28	1.25	1.38
23/12/1939	60.5	7.77	8.00	6.94	6.69	6.54	6.28
12/02/1941	107.0	235.38	259.25	286.83	276.33	286.55	291.79
06/11/1941	67.7	33.76	47.69	44.71	39.51	36.43	36.30
06/10/1942	56.0	3.83	3.82	3.95	10.80	9.52	32.26
09/02/1944	43.8	1.99	1.96	1.95	1.93	1.94	1.94
11/11/1944	38.2	1.50	1.51	1.77	1.78	1.75	1.69
13/12/1945	59.1	4.75	4.87	5.91	6.37	6.16	5.88
24/01/1947	51.0	2.79	8.01	6.35	5.85	5.31	4.75
23/02/1948	41.0	1.66	1.66	1.67	1.80	1.78	1.85
23/11/1948	30.2	1.15	1.15	1.16	1.15	1.16	1.16
03/11/1949	66.8	10.68	10.19	9.87	9.65	10.44	10.17
02/06/1951	27.5	1.09	1.09	1.10	1.10	1.10	1.10
31/03/1952	48.4	2.79	4.13	7.98	9.12	9.99	8.85
19/11/1952	111.9	393.21	386.00	440.77	424.75	449.03	462.58
09/10/1953	115.6	678.68	666.60	694.67	664.83	687.34	726.78
02/01/1955	27.3	1.12	1.16	1.13	1.12	1.14	1.23
12/01/1956	97.6	121.16	117.69	126.51	135.64	144.33	145.90
04/11/1956	131.2	5130.90	5159.97	4198.82	3981.12	3979.88	5122.22
09/12/1957	38.0	1.55	1.54	1.56	1.56	2.03	3.67
24/01/1959	52.6	3.37	3.30	3.28	3.34	5.72	5.15
21/03/1960	47.4	2.30	2.29	2.32	2.31	2.32	2.32
22/10/1960	20.4	1.02	1.02	1.02	1.02	1.02	1.03
22/09/1962	49.1	2.50	2.51	2.55	2.53	2.54	2.55
31/01/1963	62.7	6.17	6.12	6.46	8.55	11.40	11.36
21/06/1964	57.8	4.54	4.47	4.56	4.50	4.53	4.51
01/06/1965	44.3	1.93	1.93	1.95	1.94	1.95	1.96
26/10/1965	54.1	3.38	3.76	4.24	5.89	5.79	5.28
31/10/1966	68.7	54.69	313.16	188.01	180.16	139.04	204.97
21/11/1967	64.9	7.16	7.22	7.56	8.31	8.58	13.03
04/01/1969	84.4	36.37	51.93	371.59	551.63	418.92	742.00
26/03/1970	45.8	2.09	2.08	2.11	2.11	2.12	2.12
29/12/1970	52.3	11.59	10.69	16.92	18.45	19.09	18.92
21/09/1972	72.6	13.05	12.95	13.72	13.46	13.67	13.59
23/10/1972	38.0	1.51	1.83	1.69	1.69	1.91	1.86
27/05/1974	71.4	12.00	11.96	12.60	12.35	12.54	12.49
27/02/1975	47.0	2.22	2.22	2.25	2.24	2.25	2.26
15/12/1975	37.6	1.50	1.60	1.70	1.74	1.73	1.69
27/12/1976	84.9	35.62	35.30	38.36	37.43	38.33	38.11
20/12/1977	55.7	4.02	4.07	5.17	5.01	5.10	7.17
06/11/1978	76.6	17.77	17.66	18.88	18.51	18.86	18.75
14/04/1980	34.6	1.79	1.72	1.93	1.83	1.74	1.64
04/10/1980	26.6	1.14	1.13	1.17	1.83	1.99	1.80
16/09/1982	42.1	1.74	1.74	1.75	1.75	1.75	1.76
06/03/1983	19.9	1.04	1.04	1.03	1.03	1.02	1.03
22/09/1984	73.2	13.54	13.46	14.29	14.03	14.28	14.21
06/01/1985	55.5	5.68	10.22	8.87	8.17	7.37	6.64
23/10/1985	47.5	3.53	4.05	3.43	3.27	3.10	2.90
23/01/1987	90.2	60.51	59.22	63.73	61.80	63.37	63.04
25/10/1987	91.7	64.63	63.84	78.71	75.92	77.49	78.10
27/09/1989	97.7	108.67	107.29	119.26	117.89	121.63	121.90
26/10/1989	82.8	234.63	250.19	147.82	133.41	112.88	125.25
01/12/1990	71.6	14.97	17.24	15.60	15.06	14.94	14.52
23/10/1991	56.1	3.85	3.84	3.95	3.91	3.95	3.95
09/05/1993	42.4	1.83	2.24	2.05	2.02	1.98	1.96
29/10/1993	88.9	49.56	49.16	53.94	52.55	53.98	53.76
08/10/1994	53.0	3.29	3.25	3.30	3.26	3.27	3.27
16/11/1995	94.7	80.95	80.33	89.33	86.84	97.34	97.26
01/02/1997	39.8	1.66	1.72	1.70	1.68	1.67	1.66
21/12/1997	68.1	9.10	9.16	12.68	13.13	13.06	16.15
12/01/1999	53.1	3.76	3.63	3.51	3.44	3.56	4.81
26/10/1999	50.6	2.73	2.86	2.87	3.53	3.40	3.25
05/03/2001	53.1	3.71	3.86	4.90	5.86	5.39	4.96
20/11/2001	86.1	310.72	344.03	199.73	180.69	152.82	175.79
25/11/2002	78.2	20.42	20.26	21.71	21.25	21.67	22.25
04/10/2003	36.0	1.70	1.75	1.61	1.86	1.77	1.68
18/10/2004	61.7	5.67	5.65	5.86	5.82	5.94	5.91
09/02/2006	44.2	3.13	2.93	2.56	2.47	2.37	2.27
08/04/2007	62.9	6.19	6.21	6.46	6.37	6.43	6.41
08/04/2008	110.9	1454.33	1407.02	945.26	888.81	832.56	1017.35
27/02/2009	82.3	32.10	31.25	32.71	31.78	32.37	32.02
02/02/2010	111.0	427.32	536.36	510.38	487.32	512.34	557.58
26/11/2010	155.1	15305.41	15231.49	19648.24	29378.83	30419.78	45627.45
24/10/2011	30.0	1.15	1.15	1.15	1.15	1.15	1.16
25/11/2012	67.3	10.65	10.21	9.96	16.38	15.16	14.21
16/09/2014	33.1	1.24	1.27	1.28	1.30	1.34	1.33
29/11/2014	37.8	1.68	1.63	1.56	1.54	1.54	2.32
22/04/2016	85.5	37.25	37.67	41.85	57.34	58.21	57.69
26/04/2017	62.8	6.29	6.23	6.46	6.36	6.43	6.40

Return periods of annual maximum daily rainfalls and cumulative daily rainfalls in days after the annual maximum.

Univariate return periods in years								
Date of maximum	**Daily AMS (mm)**	**On AMS**	**1 day after**	**2 days after**	**3 days after**	**4 days after**	**5 days after**	**6 days after**
19/10/1937	61.2	2.31	1.72	1.57	1.48	1.46	1.48	1.46
23/09/1939	28.2	1.05	1.05	1.06	1.35	2.10	2.18	2.12
23/12/1939	60.5	2.26	5.02	4.58	5.40	4.88	4.79	4.90
12/02/1941	107.0	14.43	8.41	6.35	6.56	6.59	6.39	6.04
06/11/1941	67.7	2.93	6.30	4.61	3.82	4.24	4.37	4.18
06/10/1942	56.0	1.94	1.84	1.81	1.68	1.63	1.67	1.64
09/02/1944	43.8	1.37	1.23	1.20	1.17	1.16	1.14	1.14
11/11/1944	38.2	1.21	1.15	1.13	1.11	1.10	1.08	1.09
13/12/1945	59.1	2.15	1.64	1.51	1.43	1.57	1.69	2.13
24/01/1947	51.0	1.66	1.39	1.32	1.33	1.32	1.33	1.40
23/02/1948	41.0	1.28	1.26	1.38	1.36	1.34	1.35	1.47
23/11/1948	30.2	1.07	1.06	1.06	1.05	1.06	1.04	1.04
03/11/1949	66.8	2.83	1.97	1.76	1.64	1.59	1.63	1.60
02/06/1951	27.5	1.05	1.10	1.08	1.07	1.07	1.08	1.07
31/03/1952	48.4	1.54	1.34	1.28	1.24	1.22	1.22	1.21
19/11/1952	111.9	17.74	21.45	12.72	9.42	8.25	7.41	6.98
09/10/1953	115.6	20.74	10.39	9.94	8.75	7.72	8.00	7.52
02/01/1955	27.3	1.04	1.04	1.14	1.23	1.21	1.20	1.20
12/01/1956	97.6	9.72	5.17	3.91	4.71	5.14	6.10	5.77
04/11/1956	131.2	39.94	20.99	12.49	9.27	8.13	17.95	16.56
09/12/1957	38.0	1.21	1.15	1.13	1.24	1.45	1.53	1.51
24/01/1959	52.6	1.74	4.31	6.33	5.63	5.09	4.97	4.73
21/03/1960	47.4	1.50	1.36	1.71	1.60	1.55	1.59	1.56
22/10/1960	20.4	1.01	1.01	1.01	1.01	1.02	1.04	1.03
22/09/1962	49.1	1.57	1.65	1.61	1.63	1.59	1.63	1.60
31/01/1963	62.7	2.44	1.86	2.19	3.30	3.92	3.95	5.83
21/06/1964	57.8	2.06	1.60	1.48	1.41	1.39	1.41	1.39
01/06/1965	44.3	1.39	1.46	1.38	1.32	1.30	1.30	1.29
26/10/1965	54.1	1.83	1.57	1.61	1.54	1.50	1.53	1.51
31/10/1966	68.7	3.04	16.20	11.46	9.15	8.03	7.25	11.61
21/11/1967	64.9	2.64	5.94	22.46	16.58	14.06	12.72	13.67
04/01/1969	84.4	5.63	4.28	3.48	6.40	6.83	7.40	6.97
26/03/1970	45.8	1.44	1.41	1.33	1.30	1.56	1.59	2.00
29/12/1970	52.3	1.73	1.42	1.35	1.42	1.39	1.84	1.80
21/09/1972	72.6	3.52	4.89	3.74	9.86	18.06	13.52	12.55
23/10/1972	38.0	1.21	1.27	1.38	1.87	1.80	1.86	1.82
27/05/1974	71.4	3.36	2.23	1.95	1.79	1.73	1.78	1.74
27/02/1975	47.0	1.49	1.41	1.36	1.31	1.29	1.29	1.28
15/12/1975	37.6	1.20	1.14	1.12	1.10	1.10	1.08	1.08
27/12/1976	84.9	5.75	3.34	23.07	25.27	35.45	21.91	20.12
20/12/1977	55.7	1.92	4.19	3.37	2.92	2.73	2.83	2.73
06/11/1978	76.6	4.12	2.77	2.33	2.10	2.00	2.08	2.10
14/04/1980	34.6	1.14	1.10	1.09	1.08	1.08	1.06	1.06
04/10/1980	26.6	1.04	1.37	1.31	1.26	1.24	1.24	1.23
16/09/1982	42.1	1.32	1.36	1.54	1.45	1.42	1.44	1.42
06/03/1983	19.9	1.01	1.02	1.02	1.01	1.01	1.00	1.00
22/09/1984	73.2	3.61	5.18	3.92	3.31	3.08	3.34	3.22
06/01/1985	55.5	1.91	1.69	1.56	1.54	1.50	1.52	1.50
23/10/1985	47.5	1.51	1.38	1.32	1.27	1.25	1.25	1.24
23/01/1987	90.2	7.14	7.87	19.65	29.49	35.32	26.14	25.51
25/10/1987	91.7	7.60	6.23	4.56	4.02	3.69	4.91	4.76
27/09/1989	97.7	9.76	12.08	10.44	9.30	10.74	11.02	10.33
26/10/1989	82.8	5.28	3.12	2.58	2.29	2.18	2.26	2.20
01/12/1990	71.6	3.39	6.19	9.23	8.00	7.16	6.61	6.24
23/10/1991	56.1	1.95	1.53	1.46	1.39	1.37	1.38	1.60
09/05/1993	42.4	1.32	2.17	2.96	2.59	2.44	2.54	2.48
29/10/1993	88.9	6.77	7.69	24.63	16.99	14.39	12.54	11.69
08/10/1994	53.0	1.77	1.44	1.86	2.27	2.16	2.36	2.29
16/11/1995	94.7	8.61	5.02	3.81	3.23	3.01	3.10	2.99
01/02/1997	39.8	1.25	1.17	1.14	1.12	1.12	1.10	1.10
21/12/1997	68.1	2.97	2.17	1.91	1.76	1.70	1.75	1.71
12/01/1999	53.1	1.77	1.72	1.89	1.75	1.69	1.74	1.71
26/10/1999	50.6	1.64	3.24	6.35	5.08	4.61	4.56	4.35
05/03/2001	53.1	1.77	2.73	2.37	2.12	2.03	2.11	2.05
20/11/2001	86.1	6.04	4.84	3.70	3.15	2.94	3.03	2.92
25/11/2002	78.2	4.39	2.71	2.29	2.24	2.13	2.21	2.15
04/10/2003	36.0	1.16	1.12	1.21	1.25	1.23	1.23	1.22
18/10/2004	61.7	2.35	1.90	2.51	2.23	2.13	2.21	2.15
09/02/2006	44.2	1.38	3.16	2.86	2.51	2.37	2.46	2.59
08/04/2007	62.9	2.46	1.79	1.63	2.30	2.19	2.28	2.21
08/04/2008	110.9	17.01	31.43	23.52	16.36	14.25	11.32	10.55
27/02/2009	82.3	5.17	3.24	2.68	3.12	3.56	3.65	3.50
02/02/2010	111.0	17.08	50.64	26.00	22.87	19.05	14.02	15.39
26/11/2010	155.1	107.07	65.88	34.22	141.96	254.33	74.94	66.99
24/10/2011	30.0	1.07	1.06	1.07	1.07	1.07	1.05	1.04
25/11/2012	67.3	2.88	2.28	2.67	2.38	2.25	2.35	2.28
16/09/2014	33.1	1.11	1.09	1.08	1.07	1.06	1.05	1.05
29/11/2014	37.8	1.20	1.14	1.12	1.11	1.10	1.08	1.08
22/04/2016	85.5	5.89	3.41	2.77	2.44	2.31	2.40	2.33
26/04/2017	62.8	2.45	3.61	3.06	3.26	3.04	3.12	3.01

Joint "or" return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day after**	**2 days after**	**3 days after**	**4 days after**	**5 days after**	**6 days after**
19/10/1937	61.2	1.70	1.54	1.46	1.43	1.45	1.43
23/09/1939	28.2	1.04	1.04	1.05	1.05	1.05	1.05
23/12/1939	60.5	2.09	2.09	2.23	2.20	2.20	2.20
12/02/1941	107.0	7.57	5.82	6.14	6.10	5.98	5.69
06/11/1941	67.7	2.65	2.57	2.61	2.65	2.68	2.65
06/10/1942	56.0	1.67	1.62	1.55	1.51	1.54	1.52
09/02/1944	43.8	1.23	1.18	1.15	1.14	1.13	1.12
11/11/1944	38.2	1.14	1.11	1.09	1.08	1.07	1.07
13/12/1945	59.1	1.62	1.49	1.41	1.50	1.58	1.80
24/01/1947	51.0	1.38	1.30	1.29	1.28	1.29	1.33
23/02/1948	41.0	1.21	1.22	1.21	1.20	1.20	1.23
23/11/1948	30.2	1.05	1.05	1.03	1.03	1.03	1.03
03/11/1949	66.8	1.95	1.72	1.61	1.56	1.60	1.57
02/06/1951	27.5	1.04	1.04	1.03	1.03	1.03	1.03
31/03/1952	48.4	1.33	1.26	1.21	1.20	1.20	1.19
19/11/1952	111.9	12.53	9.72	8.47	7.54	6.95	6.59
09/10/1953	115.6	9.55	8.68	8.19	7.29	7.55	7.14
02/01/1955	27.3	1.03	1.04	1.04	1.04	1.04	1.04
12/01/1956	97.6	4.94	3.74	4.44	4.71	5.38	5.15
04/11/1956	131.2	18.10	11.54	9.09	7.98	16.08	15.03
09/12/1957	38.0	1.14	1.11	1.14	1.18	1.19	1.18
24/01/1959	52.6	1.66	1.69	1.74	1.74	1.74	1.73
21/03/1960	47.4	1.33	1.39	1.38	1.35	1.37	1.36
22/10/1960	20.4	1.01	1.01	1.00	1.01	1.01	1.01
22/09/1962	49.1	1.43	1.41	1.42	1.39	1.41	1.40
31/01/1963	62.7	1.82	1.92	2.24	2.29	2.30	2.39
21/06/1964	57.8	1.58	1.46	1.38	1.36	1.38	1.36
01/06/1965	44.3	1.29	1.27	1.23	1.22	1.22	1.21
26/10/1965	54.1	1.53	1.50	1.45	1.41	1.44	1.42
31/10/1966	68.7	2.91	2.88	3.00	2.96	2.95	3.01
21/11/1967	64.9	2.42	2.59	2.64	2.63	2.63	2.63
04/01/1969	84.4	3.78	3.17	4.54	4.58	4.73	4.62
26/03/1970	45.8	1.32	1.28	1.24	1.33	1.34	1.40
29/12/1970	52.3	1.41	1.33	1.36	1.33	1.54	1.53
21/09/1972	72.6	2.97	2.77	3.45	3.50	3.49	3.47
23/10/1972	38.0	1.16	1.17	1.20	1.20	1.20	1.20
27/05/1974	71.4	2.19	1.90	1.76	1.70	1.75	1.71
27/02/1975	47.0	1.35	1.30	1.25	1.23	1.24	1.23
15/12/1975	37.6	1.13	1.11	1.08	1.08	1.07	1.06
27/12/1976	84.9	3.25	5.33	5.68	5.70	5.63	5.60
20/12/1977	55.7	1.80	1.79	1.84	1.81	1.83	1.81
06/11/1978	76.6	2.67	2.25	2.05	1.96	2.03	2.05
14/04/1980	34.6	1.10	1.08	1.06	1.06	1.05	1.05
04/10/1980	26.6	1.03	1.03	1.04	1.04	1.04	1.04
16/09/1982	42.1	1.24	1.25	1.25	1.23	1.24	1.24
06/03/1983	19.9	1.01	1.01	1.00	1.00	1.00	1.00
22/09/1984	73.2	3.05	2.84	2.75	2.62	2.75	2.69
06/01/1985	55.5	1.61	1.49	1.46	1.43	1.45	1.43
23/10/1985	47.5	1.35	1.28	1.23	1.21	1.21	1.21
23/01/1987	90.2	5.31	6.33	7.02	7.03	6.96	6.93
25/10/1987	91.7	5.09	4.06	3.77	3.49	4.36	4.25
27/09/1989	97.7	7.27	6.80	6.99	7.33	7.47	7.23
26/10/1989	82.8	3.05	2.50	2.25	2.14	2.22	2.16
01/12/1990	71.6	2.98	3.13	3.29	3.23	3.21	3.18
23/10/1991	56.1	1.52	1.43	1.36	1.34	1.35	1.50
09/05/1993	42.4	1.27	1.29	1.32	1.32	1.32	1.32
29/10/1993	88.9	5.10	6.19	6.44	6.24	6.12	6.02
08/10/1994	53.0	1.43	1.56	1.66	1.63	1.67	1.65
16/11/1995	94.7	4.73	3.63	3.17	2.95	3.04	2.93
01/02/1997	39.8	1.16	1.13	1.10	1.10	1.09	1.08
21/12/1997	68.1	2.11	1.85	1.72	1.66	1.70	1.67
12/01/1999	53.1	1.56	1.57	1.53	1.50	1.52	1.51
26/10/1999	50.6	1.56	1.60	1.64	1.64	1.64	1.64
05/03/2001	53.1	1.64	1.63	1.64	1.60	1.63	1.61
20/11/2001	86.1	4.12	3.35	3.01	2.81	2.90	2.80
25/11/2002	78.2	2.66	2.23	2.18	2.08	2.15	2.10
04/10/2003	36.0	1.11	1.13	1.13	1.12	1.12	1.12
18/10/2004	61.7	1.83	1.98	1.92	1.85	1.90	1.87
09/02/2006	44.2	1.34	1.34	1.37	1.37	1.37	1.37
08/04/2007	62.9	1.77	1.59	1.98	1.91	1.96	1.92
08/04/2008	110.9	13.43	12.36	11.81	10.80	9.47	8.99
27/02/2009	82.3	3.13	2.58	2.92	3.17	3.24	3.14
02/02/2010	111.0	14.65	12.77	13.60	12.46	10.81	11.30
26/11/2010	155.1	50.12	30.15	78.62	91.34	56.65	52.49
24/10/2011	30.0	1.05	1.05	1.04	1.04	1.03	1.03
25/11/2012	67.3	2.16	2.23	2.13	2.04	2.10	2.06
16/09/2014	33.1	1.08	1.07	1.05	1.05	1.04	1.04
29/11/2014	37.8	1.13	1.11	1.09	1.08	1.07	1.07
22/04/2016	85.5	3.31	2.68	2.40	2.27	2.36	2.29
26/04/2017	62.8	2.17	2.12	2.24	2.17	2.20	2.17

Joint "and" return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day after**	**2 days after**	**3 days after**	**4 days after**	**5 days after**	**6 days after**
19/10/1937	61.2	2.34	2.38	2.38	2.39	2.39	2.39
23/09/1939	28.2	1.07	1.07	1.36	2.10	2.18	2.12
23/12/1939	60.5	6.09	5.44	5.60	5.17	5.05	5.17
12/02/1941	107.0	17.82	18.17	16.93	17.47	17.06	16.90
06/11/1941	67.7	8.14	5.89	4.52	4.99	5.06	4.91
06/10/1942	56.0	2.17	2.22	2.15	2.14	2.16	2.15
09/02/1944	43.8	1.38	1.39	1.40	1.40	1.39	1.39
11/11/1944	38.2	1.22	1.23	1.24	1.24	1.23	1.23
13/12/1945	59.1	2.18	2.21	2.22	2.29	2.34	2.65
24/01/1947	51.0	1.68	1.69	1.73	1.74	1.74	1.77
23/02/1948	41.0	1.34	1.46	1.45	1.44	1.45	1.55
23/11/1948	30.2	1.08	1.08	1.09	1.10	1.09	1.08
03/11/1949	66.8	2.88	2.93	2.92	2.93	2.93	2.93
02/06/1951	27.5	1.11	1.09	1.09	1.09	1.09	1.09
31/03/1952	48.4	1.56	1.57	1.59	1.59	1.58	1.58
19/11/1952	111.9	43.16	31.19	22.52	22.22	21.12	20.92
09/10/1953	115.6	25.15	29.70	24.78	24.63	24.54	24.31
02/01/1955	27.3	1.06	1.15	1.23	1.22	1.21	1.20
12/01/1956	97.6	10.62	10.90	11.10	11.73	12.37	12.21
04/11/1956	131.2	57.31	54.24	43.86	43.87	53.83	52.92
09/12/1957	38.0	1.22	1.22	1.32	1.49	1.57	1.55
24/01/1959	52.6	4.92	7.08	5.68	5.17	5.04	4.81
21/03/1960	47.4	1.53	1.88	1.77	1.75	1.77	1.75
22/10/1960	20.4	1.02	1.02	1.02	1.02	1.04	1.04
22/09/1962	49.1	1.84	1.82	1.84	1.83	1.85	1.83
31/01/1963	62.7	2.50	2.89	3.76	4.37	4.37	6.14
21/06/1964	57.8	2.08	2.11	2.12	2.13	2.13	2.12
01/06/1965	44.3	1.58	1.51	1.49	1.49	1.49	1.48
26/10/1965	54.1	1.88	1.98	1.97	1.97	1.98	1.97
31/10/1966	68.7	21.12	14.42	9.54	8.59	7.79	12.03
21/11/1967	64.9	7.48	27.32	16.70	14.29	12.93	13.89
04/01/1969	84.4	6.80	6.70	8.81	9.47	9.85	9.55
26/03/1970	45.8	1.54	1.51	1.53	1.71	1.74	2.09
29/12/1970	52.3	1.74	1.76	1.83	1.83	2.12	2.09
21/09/1972	72.6	6.62	5.26	10.47	18.63	14.11	13.22
23/10/1972	38.0	1.33	1.43	1.88	1.82	1.88	1.84
27/05/1974	71.4	3.44	3.51	3.48	3.49	3.49	3.49
27/02/1975	47.0	1.56	1.56	1.57	1.57	1.56	1.56
15/12/1975	37.6	1.21	1.21	1.22	1.22	1.21	1.21
27/12/1976	84.9	6.02	33.53	26.75	37.26	23.75	22.15
20/12/1977	55.7	4.90	3.88	3.13	3.00	3.07	2.99
06/11/1978	76.6	4.34	4.42	4.31	4.32	4.33	4.36
14/04/1980	34.6	1.15	1.15	1.16	1.16	1.15	1.15
04/10/1980	26.6	1.38	1.32	1.26	1.25	1.24	1.23
16/09/1982	42.1	1.45	1.63	1.54	1.53	1.54	1.53
06/03/1983	19.9	1.02	1.02	1.02	1.02	1.01	1.01
22/09/1984	73.2	7.05	5.52	4.62	4.55	4.70	4.64
06/01/1985	55.5	2.02	2.01	2.04	2.04	2.05	2.04
23/10/1985	47.5	1.55	1.55	1.56	1.57	1.56	1.56
23/01/1987	90.2	12.71	30.50	31.89	38.37	29.01	28.61
25/10/1987	91.7	10.48	9.57	8.65	8.62	9.45	9.40
27/09/1989	97.7	20.98	19.52	14.96	16.90	16.87	16.40
26/10/1989	82.8	5.50	5.65	5.49	5.50	5.51	5.50
01/12/1990	71.6	8.28	11.97	8.63	7.99	7.41	7.11
23/10/1991	56.1	1.97	2.00	2.01	2.01	2.01	2.13
09/05/1993	42.4	2.32	3.14	2.61	2.47	2.56	2.51
29/10/1993	88.9	12.24	37.31	19.53	17.59	15.59	14.93
08/10/1994	53.0	1.78	2.16	2.47	2.41	2.57	2.52
16/11/1995	94.7	9.62	9.76	9.12	9.14	9.13	9.10
01/02/1997	39.8	1.26	1.27	1.28	1.28	1.27	1.27
21/12/1997	68.1	3.08	3.13	3.10	3.10	3.11	3.10
12/01/1999	53.1	1.99	2.20	2.07	2.05	2.07	2.06
26/10/1999	50.6	3.65	7.02	5.11	4.66	4.61	4.40
05/03/2001	53.1	3.12	2.69	2.35	2.31	2.36	2.32
20/11/2001	86.1	7.73	7.27	6.65	6.64	6.64	6.61
25/11/2002	78.2	4.53	4.65	4.63	4.63	4.65	4.64
04/10/2003	36.0	1.17	1.26	1.30	1.29	1.28	1.28
18/10/2004	61.7	2.46	3.15	2.84	2.81	2.85	2.82
09/02/2006	44.2	3.42	3.05	2.54	2.42	2.50	2.63
08/04/2007	62.9	2.49	2.53	2.97	2.94	2.98	2.95
08/04/2008	110.9	62.05	49.07	28.35	27.51	24.08	23.61
27/02/2009	82.3	5.49	5.62	5.84	6.28	6.28	6.21
02/02/2010	111.0	99.80	53.56	34.78	32.51	26.81	28.53
26/11/2010	155.1	218.98	185.57	272.91	430.45	198.75	191.73
24/10/2011	30.0	1.08	1.09	1.10	1.10	1.09	1.09
25/11/2012	67.3	3.10	3.66	3.36	3.34	3.38	3.35
16/09/2014	33.1	1.12	1.12	1.13	1.13	1.13	1.12
29/11/2014	37.8	1.21	1.22	1.23	1.23	1.22	1.22
22/04/2016	85.5	6.18	6.35	6.14	6.15	6.16	6.15
26/04/2017	62.8	4.48	3.80	3.73	3.60	3.65	3.57

Conditional (maximum given the cumulative) return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day after**	**2 days after**	**3 days after**	**4 days after**	**5 days after**	**6 days after**
19/10/1937	61.2	4.02	3.74	3.54	3.49	3.55	3.49
23/09/1939	28.2	1.12	1.13	1.84	4.41	4.75	4.50
23/12/1939	60.5	30.59	24.90	30.27	25.24	24.23	25.35
12/02/1941	107.0	149.88	115.36	110.98	115.07	108.97	102.08
06/11/1941	67.7	51.32	27.11	17.29	21.18	22.13	20.51
06/10/1942	56.0	3.99	4.01	3.60	3.49	3.61	3.53
09/02/1944	43.8	1.70	1.66	1.64	1.63	1.60	1.59
11/11/1944	38.2	1.40	1.38	1.37	1.37	1.33	1.34
13/12/1945	59.1	3.56	3.34	3.18	3.59	3.95	5.64
24/01/1947	51.0	2.33	2.24	2.30	2.30	2.31	2.49
23/02/1948	41.0	1.69	2.01	1.98	1.93	1.95	2.29
23/11/1948	30.2	1.15	1.15	1.15	1.16	1.13	1.12
03/11/1949	66.8	5.67	5.17	4.79	4.65	4.77	4.68
02/06/1951	27.5	1.21	1.19	1.17	1.16	1.18	1.17
31/03/1952	48.4	2.08	2.01	1.96	1.94	1.92	1.91
19/11/1952	111.9	925.74	396.82	212.21	183.34	156.62	146.11
09/10/1953	115.6	261.26	295.10	216.87	190.06	196.30	182.85
02/01/1955	27.3	1.10	1.31	1.51	1.48	1.46	1.44
12/01/1956	97.6	54.85	42.59	52.27	60.28	75.45	70.45
04/11/1956	131.2	1202.83	677.64	406.69	356.49	966.31	876.21
09/12/1957	38.0	1.40	1.38	1.63	2.15	2.40	2.33
24/01/1959	52.6	21.23	44.79	31.98	26.33	25.03	22.73
21/03/1960	47.4	2.08	3.22	2.83	2.72	2.81	2.74
22/10/1960	20.4	1.03	1.03	1.03	1.05	1.07	1.07
22/09/1962	49.1	3.03	2.92	3.00	2.90	3.01	2.93
31/01/1963	62.7	4.65	6.33	12.42	17.11	17.22	35.79
21/06/1964	57.8	3.33	3.13	2.99	2.96	3.00	2.95
01/06/1965	44.3	2.30	2.08	1.97	1.94	1.94	1.91
26/10/1965	54.1	2.95	3.19	3.04	2.96	3.02	2.98
31/10/1966	68.7	342.23	165.25	87.38	68.96	56.53	139.65
21/11/1967	64.9	44.43	613.62	277.02	200.92	164.47	189.87
04/01/1969	84.4	29.13	23.32	56.34	64.62	72.84	66.51
26/03/1970	45.8	2.17	2.02	1.99	2.67	2.76	4.18
29/12/1970	52.3	2.48	2.37	2.59	2.54	3.90	3.78
21/09/1972	72.6	32.39	19.64	103.30	336.56	190.73	165.95
23/10/1972	38.0	1.70	1.97	3.52	3.28	3.48	3.34
27/05/1974	71.4	7.66	6.85	6.23	6.03	6.22	6.08
27/02/1975	47.0	2.21	2.13	2.05	2.02	2.01	1.99
15/12/1975	37.6	1.37	1.36	1.35	1.34	1.31	1.31
27/12/1976	84.9	20.12	773.38	675.99	1320.85	520.34	445.62
20/12/1977	55.7	20.55	13.08	9.12	8.21	8.67	8.18
06/11/1978	76.6	12.02	10.31	9.04	8.66	9.00	9.17
14/04/1980	34.6	1.27	1.25	1.25	1.25	1.22	1.22
04/10/1980	26.6	1.89	1.72	1.59	1.55	1.54	1.52
16/09/1982	42.1	1.96	2.50	2.24	2.17	2.21	2.16
06/03/1983	19.9	1.03	1.03	1.03	1.03	1.01	1.01
22/09/1984	73.2	36.53	21.65	15.32	14.02	15.73	14.95
06/01/1985	55.5	3.43	3.13	3.14	3.06	3.12	3.06
23/10/1985	47.5	2.15	2.04	1.99	1.96	1.95	1.93
23/01/1987	90.2	99.96	599.21	940.32	1355.37	758.34	729.78
25/10/1987	91.7	65.29	43.69	34.76	31.85	46.39	44.78
27/09/1989	97.7	253.57	203.80	139.16	181.58	185.85	169.38
26/10/1989	82.8	17.19	14.57	12.57	11.98	12.46	12.09
01/12/1990	71.6	51.21	110.51	69.10	57.21	48.96	44.40
23/10/1991	56.1	3.02	2.93	2.80	2.75	2.77	3.40
09/05/1993	42.4	5.02	9.30	6.75	6.04	6.49	6.21
29/10/1993	88.9	94.05	919.06	331.78	253.14	195.51	174.53
08/10/1994	53.0	2.57	4.00	5.61	5.20	6.07	5.78
16/11/1995	94.7	48.27	37.22	29.51	27.53	28.31	27.20
01/02/1997	39.8	1.47	1.45	1.44	1.43	1.40	1.39
21/12/1997	68.1	6.70	5.98	5.45	5.27	5.44	5.32
12/01/1999	53.1	3.42	4.16	3.62	3.47	3.61	3.51
26/10/1999	50.6	11.85	44.54	25.96	21.49	20.98	19.13
05/03/2001	53.1	8.51	6.37	5.00	4.68	4.96	4.76
20/11/2001	86.1	37.43	26.92	20.96	19.53	20.14	19.32
25/11/2002	78.2	12.28	10.65	10.36	9.87	10.28	9.98
04/10/2003	36.0	1.31	1.53	1.62	1.59	1.57	1.55
18/10/2004	61.7	4.66	7.88	6.34	5.98	6.29	6.05
09/02/2006	44.2	10.81	8.74	6.37	5.74	6.16	6.81
08/04/2007	62.9	4.45	4.12	6.85	6.44	6.78	6.52
08/04/2008	110.9	1950.33	1153.94	463.75	391.90	272.59	249.13
27/02/2009	82.3	17.82	15.07	18.22	22.38	22.91	21.74
02/02/2010	111.0	5054.30	1392.77	795.57	619.40	375.96	439.00
26/11/2010	155.1	14426.33	6350.46	38743.12	109478.20	14894.71	12843.47
24/10/2011	30.0	1.15	1.17	1.18	1.17	1.14	1.14
25/11/2012	67.3	7.07	9.77	7.99	7.53	7.94	7.65
16/09/2014	33.1	1.22	1.21	1.21	1.21	1.18	1.18
29/11/2014	37.8	1.38	1.36	1.36	1.35	1.32	1.31
22/04/2016	85.5	21.06	17.59	14.97	14.21	14.78	14.32
26/04/2017	62.8	16.17	11.61	12.16	10.93	11.39	10.74

Conditional (cumulative given the maximum) return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day after**	**2 days after**	**3 days after**	**4 days after**	**5 days after**	**6 days after**
19/10/1937	61.2	5.42	5.51	5.51	5.53	5.53	5.53
23/09/1939	28.2	1.12	1.13	1.43	2.21	2.29	2.23
23/12/1939	60.5	13.76	12.29	12.65	11.67	11.41	11.68
12/02/1941	107.0	257.24	262.26	244.29	252.13	246.22	243.96
06/11/1941	67.7	23.82	17.22	13.23	14.60	14.80	14.37
06/10/1942	56.0	4.22	4.31	4.17	4.16	4.19	4.17
09/02/1944	43.8	1.89	1.90	1.92	1.92	1.91	1.91
11/11/1944	38.2	1.48	1.48	1.50	1.50	1.49	1.49
13/12/1945	59.1	4.68	4.75	4.77	4.93	5.04	5.70
24/01/1947	51.0	2.79	2.82	2.87	2.89	2.89	2.95
23/02/1948	41.0	1.72	1.87	1.87	1.85	1.86	1.99
23/11/1948	30.2	1.16	1.16	1.17	1.18	1.17	1.16
03/11/1949	66.8	8.14	8.30	8.27	8.28	8.29	8.28
02/06/1951	27.5	1.16	1.14	1.14	1.14	1.14	1.14
31/03/1952	48.4	2.40	2.42	2.45	2.45	2.44	2.44
19/11/1952	111.9	765.80	553.45	399.54	394.29	374.82	371.23
09/10/1953	115.6	521.60	615.99	513.96	510.79	508.98	504.29
02/01/1955	27.3	1.10	1.20	1.29	1.27	1.26	1.25
12/01/1956	97.6	103.24	105.97	107.92	114.07	120.29	118.66
04/11/1956	131.2	2289.17	2166.41	1751.64	1752.23	2150.22	2113.80
09/12/1957	38.0	1.47	1.48	1.59	1.80	1.89	1.87
24/01/1959	52.6	8.59	12.35	9.90	9.02	8.78	8.38
21/03/1960	47.4	2.30	2.83	2.66	2.63	2.66	2.63
22/10/1960	20.4	1.02	1.02	1.02	1.03	1.05	1.04
22/09/1962	49.1	2.89	2.86	2.90	2.88	2.91	2.88
31/01/1963	62.7	6.10	7.06	9.17	10.66	10.65	14.98
21/06/1964	57.8	4.29	4.35	4.37	4.38	4.38	4.38
01/06/1965	44.3	2.19	2.09	2.07	2.07	2.06	2.05
26/10/1965	54.1	3.44	3.62	3.61	3.60	3.62	3.61
31/10/1966	68.7	64.13	43.80	28.98	26.09	23.67	36.53
21/11/1967	64.9	19.75	72.12	44.08	37.70	34.11	36.65
04/01/1969	84.4	38.32	37.71	49.59	53.31	55.45	53.75
26/03/1970	45.8	2.22	2.18	2.20	2.47	2.50	3.01
29/12/1970	52.3	3.01	3.05	3.16	3.16	3.66	3.62
21/09/1972	72.6	23.31	18.52	36.89	65.64	49.69	46.56
23/10/1972	38.0	1.61	1.73	2.27	2.20	2.26	2.22
27/05/1974	71.4	11.57	11.82	11.71	11.73	11.75	11.73
27/02/1975	47.0	2.32	2.32	2.33	2.33	2.32	2.31
15/12/1975	37.6	1.45	1.45	1.47	1.47	1.46	1.45
27/12/1976	84.9	34.62	192.66	153.73	214.14	136.49	127.30
20/12/1977	55.7	9.43	7.45	6.01	5.77	5.90	5.76
06/11/1978	76.6	17.88	18.20	17.76	17.79	17.84	17.95
14/04/1980	34.6	1.31	1.31	1.32	1.32	1.31	1.31
04/10/1980	26.6	1.44	1.37	1.31	1.30	1.29	1.28
16/09/1982	42.1	1.91	2.15	2.03	2.01	2.02	2.01
06/03/1983	19.9	1.02	1.02	1.02	1.02	1.02	1.02
22/09/1984	73.2	25.41	19.91	16.67	16.40	16.96	16.73
06/01/1985	55.5	3.87	3.85	3.90	3.90	3.91	3.90
23/10/1985	47.5	2.34	2.34	2.36	2.36	2.35	2.35
23/01/1987	90.2	90.77	217.87	227.81	274.14	207.30	204.41
25/10/1987	91.7	79.65	72.78	65.78	65.55	71.81	71.48
27/09/1989	97.7	204.86	190.56	146.02	164.99	164.65	160.08
26/10/1989	82.8	29.04	29.82	28.98	29.04	29.09	29.03
01/12/1990	71.6	28.06	40.59	29.26	27.09	25.11	24.11
23/10/1991	56.1	3.83	3.90	3.92	3.92	3.92	4.15
09/05/1993	42.4	3.07	4.16	3.45	3.28	3.39	3.32
29/10/1993	88.9	82.85	252.66	132.23	119.13	105.57	101.09
08/10/1994	53.0	3.15	3.81	4.37	4.25	4.54	4.45
16/11/1995	94.7	82.85	84.04	78.58	78.70	78.60	78.39
01/02/1997	39.8	1.58	1.58	1.60	1.60	1.59	1.59
21/12/1997	68.1	9.16	9.30	9.20	9.21	9.24	9.22
12/01/1999	53.1	3.52	3.89	3.66	3.63	3.67	3.64
26/10/1999	50.6	6.00	11.53	8.40	7.66	7.57	7.24
05/03/2001	53.1	5.53	4.77	4.17	4.09	4.17	4.11
20/11/2001	86.1	46.66	43.87	40.14	40.09	40.11	39.90
25/11/2002	78.2	19.89	20.39	20.31	20.33	20.39	20.34
04/10/2003	36.0	1.37	1.47	1.51	1.50	1.49	1.49
18/10/2004	61.7	5.79	7.41	6.69	6.62	6.71	6.64
09/02/2006	44.2	4.72	4.22	3.51	3.35	3.46	3.63
08/04/2007	62.9	6.12	6.22	7.30	7.22	7.32	7.24
08/04/2008	110.9	1055.62	834.73	482.29	467.90	409.66	401.57
27/02/2009	82.3	28.39	29.06	30.20	32.50	32.47	32.12
02/02/2010	111.0	1705.00	914.98	594.18	555.37	457.97	487.32
26/11/2010	155.1	23445.22	19868.80	29220.32	46087.65	21279.83	20527.98
24/10/2011	30.0	1.16	1.17	1.18	1.18	1.17	1.16
25/11/2012	67.3	8.93	10.55	9.69	9.62	9.74	9.65
16/09/2014	33.1	1.25	1.25	1.26	1.26	1.25	1.25
29/11/2014	37.8	1.46	1.46	1.48	1.48	1.47	1.47
22/04/2016	85.5	36.41	37.41	36.16	36.23	36.29	36.21
26/04/2017	62.8	10.95	9.29	9.12	8.82	8.93	8.73

Return periods of annual maximum daily rainfalls and cumulative daily rainfalls in days before and after the annual maximum.

Univariate return periods in years								
Date of maximum	**Daily AMS (mm)**	**On AMS**	**1 day before&after**	**2 days before&after**	**3 days before&after**	**4 days before&after**	**5 days before&after**	**6 days before&after**
19/10/1937	61.2	2.31	1.59	1.67	1.67	3.29	3.16	6.54
23/09/1939	28.2	1.05	1.03	1.03	1.52	2.08	2.03	2.16
23/12/1939	60.5	2.26	5.83	5.08	4.97	4.00	3.81	3.43
12/02/1941	107.0	14.43	5.43	4.71	4.20	3.74	3.68	3.14
06/11/1941	67.7	2.93	14.71	12.90	13.89	11.87	11.31	9.49
06/10/1942	56.0	1.94	1.67	1.58	1.40	3.06	2.96	6.36
09/02/1944	43.8	1.37	1.25	1.18	1.13	1.11	1.11	1.08
11/11/1944	38.2	1.21	1.14	1.11	1.21	1.19	1.18	1.16
13/12/1945	59.1	2.15	1.53	1.44	1.53	1.71	1.74	1.92
24/01/1947	51.0	1.66	1.31	2.61	2.18	1.98	1.93	1.86
23/02/1948	41.0	1.28	1.21	1.28	1.22	1.31	1.30	1.41
23/11/1948	30.2	1.07	1.03	1.02	1.03	1.03	1.03	1.02
03/11/1949	66.8	2.83	2.32	1.92	1.62	1.51	1.49	1.51
02/06/1951	27.5	1.05	1.06	1.04	1.04	1.04	1.05	1.04
31/03/1952	48.4	1.54	1.47	1.78	2.57	2.66	2.57	2.63
19/11/1952	111.9	17.74	11.46	7.26	5.44	4.34	4.13	3.57
09/10/1953	115.6	20.74	9.03	7.74	6.39	5.01	5.33	4.39
02/01/1955	27.3	1.04	1.04	1.18	1.23	1.18	1.18	1.26
12/01/1956	97.6	9.72	4.66	3.40	3.37	3.78	4.28	3.84
04/11/1956	131.2	39.94	25.98	15.88	12.77	9.24	21.75	15.96
09/12/1957	38.0	1.21	1.17	1.13	1.24	1.37	1.40	2.77
24/01/1959	52.6	1.74	3.90	4.68	3.72	3.32	3.19	5.15
21/03/1960	47.4	1.50	1.31	1.55	1.37	1.31	1.29	1.24
22/10/1960	20.4	1.01	1.01	1.01	1.01	1.02	1.04	1.03
22/09/1962	49.1	1.57	1.52	1.46	1.38	1.31	1.30	1.24
31/01/1963	62.7	2.44	1.73	1.89	2.35	3.70	3.54	6.66
21/06/1964	57.8	2.06	1.59	1.42	1.29	1.24	1.23	1.19
01/06/1965	44.3	1.39	1.36	1.26	1.18	1.15	1.14	1.12
26/10/1965	54.1	1.83	1.45	1.64	1.65	1.99	1.94	1.85
31/10/1966	68.7	3.04	38.25	86.16	141.74	97.03	84.08	101.88
21/11/1967	64.9	2.64	4.21	9.64	7.63	7.51	7.94	14.66
04/01/1969	84.4	5.63	3.70	4.04	57.99	77.34	80.54	53.75
26/03/1970	45.8	1.44	1.33	1.23	1.18	1.30	1.29	1.40
29/12/1970	52.3	1.73	3.91	3.09	4.64	4.57	5.99	5.88
21/09/1972	72.6	3.52	3.74	2.84	5.03	6.81	6.40	5.19
23/10/1972	38.0	1.21	1.28	1.61	1.90	1.76	1.73	1.88
27/05/1974	71.4	3.36	2.04	1.75	1.49	1.40	1.38	1.32
27/02/1975	47.0	1.49	1.32	1.25	1.18	1.14	1.14	1.11
15/12/1975	37.6	1.20	1.15	1.16	1.19	1.19	1.18	1.17
27/12/1976	84.9	5.75	2.79	9.64	10.17	11.00	10.28	8.00
20/12/1977	55.7	1.92	3.70	2.98	3.14	2.68	2.60	3.58
06/11/1978	76.6	4.12	2.35	1.94	1.61	1.50	1.47	1.42
14/04/1980	34.6	1.14	1.37	1.27	1.31	1.26	1.25	1.21
04/10/1980	26.6	1.04	1.49	1.35	1.32	1.82	1.79	1.80
16/09/1982	42.1	1.32	1.28	1.38	1.26	1.21	1.20	1.16
06/03/1983	19.9	1.01	1.03	1.02	1.02	1.02	1.02	1.01
22/09/1984	73.2	3.61	3.81	2.89	2.22	1.97	2.00	1.82
06/01/1985	55.5	1.91	2.32	3.06	2.69	2.33	2.27	2.03
23/10/1985	47.5	1.51	1.91	1.89	1.58	1.47	1.45	1.37
23/01/1987	90.2	7.14	5.93	9.66	12.88	12.24	13.76	11.17
25/10/1987	91.7	7.60	4.61	3.37	3.22	2.73	3.27	2.92
27/09/1989	97.7	9.76	7.35	6.02	4.97	5.05	5.68	4.67
26/10/1989	82.8	5.28	14.75	10.99	8.35	6.33	5.95	4.86
01/12/1990	71.6	3.39	5.77	7.85	6.38	5.03	4.77	3.97
23/10/1991	56.1	1.95	1.43	1.33	1.23	1.18	1.18	1.24
09/05/1993	42.4	1.32	2.10	3.25	2.46	2.18	2.12	1.95
29/10/1993	88.9	6.77	5.11	9.91	7.44	5.71	5.89	4.82
08/10/1994	53.0	1.77	1.44	1.72	1.80	1.65	1.67	1.55
16/11/1995	94.7	8.61	3.72	2.83	2.18	1.94	1.90	1.95
01/02/1997	39.8	1.25	1.19	1.17	1.15	1.12	1.12	1.10
21/12/1997	68.1	2.97	1.92	1.69	1.98	1.90	1.86	2.17
12/01/1999	53.1	1.77	1.92	1.95	1.62	1.50	1.48	2.00
26/10/1999	50.6	1.64	2.69	4.58	3.37	3.95	3.78	3.21
05/03/2001	53.1	1.77	2.88	2.50	2.66	2.77	2.68	2.38
20/11/2001	86.1	6.04	21.22	15.41	12.32	8.94	8.32	6.60
25/11/2002	78.2	4.39	2.35	1.94	1.70	1.57	1.55	1.52
04/10/2003	36.0	1.16	1.29	1.44	1.37	1.45	1.43	1.36
18/10/2004	61.7	2.35	1.71	2.05	1.68	1.57	1.55	1.48
09/02/2006	44.2	1.38	4.67	3.70	2.76	2.38	2.32	2.19
08/04/2007	62.9	2.46	1.63	1.48	1.75	1.61	1.58	1.48
08/04/2008	110.9	17.01	47.74	32.12	31.33	21.04	19.07	14.14
27/02/2009	82.3	5.17	3.15	2.48	2.41	2.44	2.38	2.12
02/02/2010	111.0	17.08	23.10	16.56	16.40	11.54	10.66	10.54
26/11/2010	155.1	107.07	20.70	12.42	41.03	122.04	105.04	69.17
24/10/2011	30.0	1.07	1.04	1.04	1.04	1.04	1.03	1.03
25/11/2012	67.3	2.88	2.57	2.68	2.10	3.09	2.98	2.60
16/09/2014	33.1	1.11	1.05	1.06	1.07	1.07	1.07	1.08
29/11/2014	37.8	1.20	1.24	1.17	1.13	1.10	1.10	1.41
22/04/2016	85.5	5.89	2.80	2.31	1.92	2.55	2.47	2.28
26/04/2017	62.8	2.45	3.07	2.51	2.29	2.03	1.98	1.80

		Joint "or" return periods in years					
Date of maximum	**Daily AMS (mm)**	**1 day before&after**	**2 days before&after**	**3 days before&after**	**4 days before&after**	**5 days before&after**	**6 days before&after**
19/10/1937	61.2	1.57	1.59	1.56	2.02	2.05	2.18
23/09/1939	28.2	1.03	1.03	1.05	1.05	1.05	1.05
23/12/1939	60.5	2.09	2.07	2.13	2.06	2.10	1.96
12/02/1941	107.0	5.19	4.45	3.94	3.54	3.59	3.00
06/11/1941	67.7	2.78	2.76	2.85	2.81	2.87	2.73
06/10/1942	56.0	1.57	1.48	1.35	1.78	1.80	1.87
09/02/1944	43.8	1.22	1.16	1.12	1.10	1.09	1.07
11/11/1944	38.2	1.12	1.10	1.14	1.13	1.11	1.11
13/12/1945	59.1	1.51	1.41	1.45	1.54	1.57	1.60
24/01/1947	51.0	1.30	1.53	1.54	1.49	1.49	1.44
23/02/1948	41.0	1.18	1.18	1.16	1.19	1.17	1.19
23/11/1948	30.2	1.03	1.02	1.02	1.02	1.02	1.02
03/11/1949	66.8	2.08	1.81	1.55	1.46	1.46	1.45
02/06/1951	27.5	1.03	1.03	1.03	1.02	1.02	1.02
31/03/1952	48.4	1.36	1.39	1.49	1.48	1.49	1.46
19/11/1952	111.9	9.14	6.45	5.00	4.09	4.03	3.40
09/10/1953	115.6	8.17	6.95	5.82	4.69	5.14	4.13
02/01/1955	27.3	1.03	1.03	1.04	1.04	1.04	1.04
12/01/1956	97.6	4.37	3.26	3.16	3.43	3.95	3.41
04/11/1956	131.2	19.37	13.46	11.14	8.44	17.61	12.79
09/12/1957	38.0	1.14	1.11	1.14	1.16	1.16	1.20
24/01/1959	52.6	1.64	1.66	1.69	1.66	1.68	1.69
21/03/1960	47.4	1.28	1.34	1.27	1.24	1.22	1.19
22/10/1960	20.4	1.01	1.01	1.01	1.01	1.01	1.01
22/09/1962	49.1	1.39	1.34	1.29	1.25	1.23	1.19
31/01/1963	62.7	1.69	1.73	1.89	2.14	2.18	2.28
21/06/1964	57.8	1.55	1.39	1.26	1.22	1.22	1.17
01/06/1965	44.3	1.26	1.21	1.15	1.13	1.12	1.10
26/10/1965	54.1	1.42	1.48	1.47	1.56	1.56	1.50
31/10/1966	68.7	2.97	3.01	3.03	3.03	3.04	3.02
21/11/1967	64.9	2.30	2.48	2.52	2.50	2.57	2.56
04/01/1969	84.4	3.32	3.34	5.52	5.54	5.61	5.45
26/03/1970	45.8	1.28	1.21	1.16	1.22	1.21	1.25
29/12/1970	52.3	1.63	1.60	1.69	1.68	1.72	1.69
21/09/1972	72.6	2.72	2.38	2.93	3.08	3.18	2.83
23/10/1972	38.0	1.15	1.16	1.20	1.19	1.19	1.18
27/05/1974	71.4	2.00	1.71	1.47	1.38	1.37	1.30
27/02/1975	47.0	1.29	1.22	1.16	1.13	1.12	1.10
15/12/1975	37.6	1.13	1.12	1.13	1.12	1.10	1.11
27/12/1976	84.9	2.72	4.59	4.75	4.77	4.98	4.26
20/12/1977	55.7	1.77	1.73	1.79	1.73	1.74	1.78
06/11/1978	76.6	2.28	1.90	1.58	1.47	1.46	1.39
14/04/1980	34.6	1.11	1.10	1.12	1.11	1.10	1.10
04/10/1980	26.6	1.03	1.03	1.04	1.04	1.04	1.04
16/09/1982	42.1	1.21	1.22	1.18	1.16	1.14	1.12
06/03/1983	19.9	1.01	1.01	1.01	1.01	1.00	1.01
22/09/1984	73.2	2.78	2.42	2.03	1.84	1.90	1.71
06/01/1985	55.5	1.68	1.73	1.74	1.67	1.68	1.57
23/10/1985	47.5	1.39	1.38	1.35	1.31	1.29	1.25
23/01/1987	90.2	4.59	5.29	5.82	5.66	6.21	5.37
25/10/1987	91.7	4.12	3.16	2.96	2.57	3.08	2.67
27/09/1989	97.7	5.79	4.95	4.26	4.26	4.88	3.94
26/10/1989	82.8	4.66	4.43	4.28	3.87	4.01	3.37
01/12/1990	71.6	2.89	3.00	3.00	2.82	2.90	2.56
23/10/1991	56.1	1.41	1.31	1.21	1.17	1.17	1.21
09/05/1993	42.4	1.26	1.29	1.31	1.30	1.30	1.27
29/10/1993	88.9	4.20	5.16	4.74	4.13	4.46	3.66
08/10/1994	53.0	1.41	1.49	1.51	1.44	1.45	1.38
16/11/1995	94.7	3.60	2.75	2.14	1.91	1.89	1.90
01/02/1997	39.8	1.16	1.14	1.12	1.10	1.09	1.08
21/12/1997	68.1	1.88	1.65	1.82	1.75	1.75	1.86
12/01/1999	53.1	1.55	1.54	1.45	1.38	1.37	1.51
26/10/1999	50.6	1.52	1.57	1.59	1.60	1.61	1.56
05/03/2001	53.1	1.62	1.60	1.65	1.65	1.66	1.58
20/11/2001	86.1	5.43	5.19	5.13	4.67	4.87	4.08
25/11/2002	78.2	2.30	1.90	1.67	1.54	1.53	1.49
04/10/2003	36.0	1.12	1.13	1.14	1.14	1.13	1.13
18/10/2004	61.7	1.67	1.78	1.57	1.49	1.48	1.40
09/02/2006	44.2	1.35	1.34	1.36	1.35	1.35	1.33
08/04/2007	62.9	1.61	1.45	1.62	1.52	1.51	1.41
08/04/2008	110.9	14.22	12.94	13.05	11.26	11.79	9.13
27/02/2009	82.3	2.94	2.37	2.26	2.26	2.27	1.99
02/02/2010	111.0	12.06	10.36	10.29	8.40	8.63	7.74
26/11/2010	155.1	19.85	12.09	32.90	62.28	63.94	45.29
24/10/2011	30.0	1.04	1.03	1.03	1.03	1.02	1.02
25/11/2012	67.3	2.18	2.15	1.87	2.23	2.27	2.02
16/09/2014	33.1	1.05	1.06	1.06	1.05	1.04	1.06
29/11/2014	37.8	1.15	1.13	1.10	1.08	1.07	1.16
22/04/2016	85.5	2.73	2.25	1.87	2.37	2.37	2.13
26/04/2017	62.8	2.07	1.95	1.88	1.75	1.75	1.60

Joint "and" return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day before&after**	**2 days before&after**	**3 days before&after**	**4 days before&after**	**5 days before&after**	**6 days before&after**
19/10/1937	61.2	2.36	2.49	2.58	4.14	3.83	7.92
23/09/1939	28.2	1.05	1.06	1.53	2.08	2.03	2.16
23/12/1939	60.5	7.31	6.42	5.70	4.81	4.39	4.44
12/02/1941	107.0	16.39	17.58	18.68	18.55	16.06	18.57
06/11/1941	67.7	19.82	17.44	15.95	14.18	12.23	12.30
06/10/1942	56.0	2.10	2.11	2.06	3.57	3.36	7.21
09/02/1944	43.8	1.41	1.39	1.39	1.39	1.39	1.38
11/11/1944	38.2	1.23	1.22	1.29	1.29	1.30	1.28
13/12/1945	59.1	2.19	2.22	2.33	2.49	2.49	2.76
24/01/1947	51.0	1.68	3.03	2.45	2.29	2.24	2.25
23/02/1948	41.0	1.32	1.40	1.36	1.43	1.44	1.53
23/11/1948	30.2	1.07	1.07	1.08	1.08	1.08	1.08
03/11/1949	66.8	3.29	3.12	3.04	3.01	2.95	3.08
02/06/1951	27.5	1.08	1.06	1.06	1.06	1.07	1.06
31/03/1952	48.4	1.69	2.03	2.74	2.86	2.74	2.91
19/11/1952	111.9	29.26	25.59	24.91	23.68	19.85	23.67
09/10/1953	115.6	27.38	29.78	30.59	28.87	24.33	29.86
02/01/1955	27.3	1.06	1.20	1.23	1.19	1.19	1.27
12/01/1956	97.6	11.30	11.08	12.09	13.15	12.00	14.34
04/11/1956	131.2	83.95	72.91	73.57	67.20	70.34	104.84
09/12/1957	38.0	1.25	1.23	1.31	1.43	1.47	2.83
24/01/1959	52.6	4.55	5.46	4.01	3.66	3.44	5.69
21/03/1960	47.4	1.54	1.78	1.63	1.61	1.62	1.59
22/10/1960	20.4	1.01	1.01	1.02	1.02	1.04	1.03
22/09/1962	49.1	1.75	1.74	1.70	1.67	1.68	1.66
31/01/1963	62.7	2.53	2.76	3.25	4.68	4.27	8.23
21/06/1964	57.8	2.14	2.12	2.12	2.11	2.10	2.11
01/06/1965	44.3	1.51	1.45	1.43	1.42	1.43	1.41
26/10/1965	54.1	1.87	2.07	2.12	2.43	2.37	2.38
31/10/1966	68.7	52.06	117.00	151.57	106.76	84.84	117.83
21/11/1967	64.9	5.54	12.67	8.89	8.98	8.67	17.62
04/01/1969	84.4	6.82	7.98	73.35	100.26	85.05	78.95
26/03/1970	45.8	1.51	1.48	1.47	1.55	1.56	1.65
29/12/1970	52.3	4.55	3.61	4.93	4.92	6.15	6.44
21/09/1972	72.6	5.44	4.62	7.09	9.38	7.96	8.10
23/10/1972	38.0	1.35	1.70	1.93	1.80	1.77	1.94
27/05/1974	71.4	3.50	3.50	3.50	3.48	3.43	3.48
27/02/1975	47.0	1.53	1.52	1.52	1.51	1.52	1.51
15/12/1975	37.6	1.23	1.24	1.27	1.27	1.29	1.27
27/12/1976	84.9	6.07	16.64	16.13	18.03	14.15	15.52
20/12/1977	55.7	4.44	3.61	3.56	3.18	3.01	4.23
06/11/1978	76.6	4.34	4.33	4.32	4.29	4.20	4.31
14/04/1980	34.6	1.42	1.31	1.34	1.29	1.30	1.26
04/10/1980	26.6	1.51	1.37	1.33	1.83	1.79	1.81
16/09/1982	42.1	1.39	1.51	1.41	1.39	1.40	1.37
06/03/1983	19.9	1.03	1.02	1.02	1.02	1.02	1.02
22/09/1984	73.2	5.58	4.74	4.27	4.14	4.00	4.16
06/01/1985	55.5	2.79	3.70	3.12	2.83	2.71	2.63
23/10/1985	47.5	2.14	2.14	1.80	1.73	1.73	1.68
23/01/1987	90.2	10.99	18.33	21.87	22.21	19.40	23.13
25/10/1987	91.7	9.46	8.98	9.55	9.20	8.90	10.08
27/09/1989	97.7	15.23	14.97	14.45	15.26	13.55	16.02
26/10/1989	82.8	23.50	18.20	13.18	11.20	9.25	10.13
01/12/1990	71.6	8.13	11.23	8.42	7.19	6.26	6.41
23/10/1991	56.1	1.97	1.98	1.98	1.98	1.98	2.02
09/05/1993	42.4	2.27	3.51	2.53	2.26	2.20	2.07
29/10/1993	88.9	9.51	18.31	14.10	12.39	10.70	12.16
08/10/1994	53.0	1.82	2.11	2.18	2.09	2.11	2.06
16/11/1995	94.7	9.38	9.38	9.40	9.29	8.82	9.62
01/02/1997	39.8	1.29	1.29	1.29	1.28	1.29	1.28
21/12/1997	68.1	3.09	3.10	3.44	3.44	3.31	3.84
12/01/1999	53.1	2.27	2.35	2.05	1.98	1.97	2.48
26/10/1999	50.6	3.09	5.26	3.59	4.23	3.94	3.58
05/03/2001	53.1	3.38	2.96	2.98	3.14	2.98	2.85
20/11/2001	86.1	35.07	26.38	19.28	15.77	12.45	13.88
25/11/2002	78.2	4.58	4.59	4.65	4.61	4.49	4.68
04/10/2003	36.0	1.35	1.50	1.40	1.48	1.48	1.41
18/10/2004	61.7	2.45	2.85	2.62	2.58	2.54	2.58
09/02/2006	44.2	5.11	4.04	2.85	2.50	2.41	2.35
08/04/2007	62.9	2.50	2.52	2.77	2.71	2.65	2.68
08/04/2008	110.9	106.43	79.20	71.03	57.19	37.89	50.15
27/02/2009	82.3	5.87	5.74	6.05	6.23	5.77	6.16
02/02/2010	111.0	52.93	44.67	44.84	38.30	27.40	41.32
26/11/2010	155.1	137.52	140.30	301.43	677.17	310.45	581.90
24/10/2011	30.0	1.07	1.08	1.08	1.08	1.09	1.08
25/11/2012	67.3	3.59	3.92	3.45	4.50	4.15	4.21
16/09/2014	33.1	1.11	1.12	1.13	1.13	1.15	1.14
29/11/2014	37.8	1.31	1.26	1.24	1.23	1.24	1.48
22/04/2016	85.5	6.21	6.28	6.34	7.13	6.54	7.15
26/04/2017	62.8	3.97	3.41	3.20	3.03	2.92	2.94

Conditional (maximum given the cumulative) return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day before&after**	**2 days before&after**	**3 days before&after**	**4 days before&after**	**5 days before&after**	**6 days before&after**
19/10/1937	61.2	3.75	4.17	4.31	13.63	12.11	51.82
23/09/1939	28.2	1.08	1.09	2.33	4.32	4.11	4.67
23/12/1939	60.5	42.63	32.63	28.30	19.23	16.75	15.23
12/02/1941	107.0	88.96	82.76	78.39	69.42	59.16	58.34
06/11/1941	67.7	291.64	224.99	221.43	168.33	138.39	116.78
06/10/1942	56.0	3.51	3.33	2.88	10.93	9.92	45.82
09/02/1944	43.8	1.77	1.64	1.58	1.54	1.54	1.50
11/11/1944	38.2	1.39	1.35	1.56	1.53	1.54	1.49
13/12/1945	59.1	3.36	3.19	3.58	4.25	4.33	5.30
24/01/1947	51.0	2.19	7.91	5.35	4.52	4.32	4.20
23/02/1948	41.0	1.60	1.79	1.66	1.87	1.87	2.15
23/11/1948	30.2	1.11	1.10	1.11	1.11	1.11	1.10
03/11/1949	66.8	7.64	6.00	4.92	4.54	4.39	4.67
02/06/1951	27.5	1.14	1.11	1.10	1.09	1.13	1.10
31/03/1952	48.4	2.48	3.61	7.05	7.61	7.05	7.66
19/11/1952	111.9	335.37	185.87	135.40	102.72	81.98	84.56
09/10/1953	115.6	247.16	230.52	195.58	144.58	129.73	131.24
02/01/1955	27.3	1.11	1.41	1.50	1.41	1.40	1.61
12/01/1956	97.6	52.61	37.74	40.79	49.72	51.36	55.02
04/11/1956	131.2	2180.83	1157.91	939.48	620.63	1530.05	1672.94
09/12/1957	38.0	1.47	1.39	1.63	1.97	2.06	7.83
24/01/1959	52.6	17.73	25.52	14.94	12.16	10.97	29.30
21/03/1960	47.4	2.02	2.76	2.23	2.10	2.09	1.97
22/10/1960	20.4	1.02	1.02	1.03	1.04	1.09	1.07
22/09/1962	49.1	2.67	2.53	2.34	2.19	2.18	2.06
31/01/1963	62.7	4.37	5.21	7.62	17.29	15.12	54.82
21/06/1964	57.8	3.41	3.02	2.72	2.61	2.59	2.50
01/06/1965	44.3	2.05	1.82	1.69	1.63	1.63	1.58
26/10/1965	54.1	2.72	3.40	3.50	4.83	4.60	4.40
31/10/1966	68.7	1991.23	10080.04	21483.55	10359.80	7133.13	12004.87
21/11/1967	64.9	23.32	122.08	67.84	67.41	68.82	258.22
04/01/1969	84.4	25.26	32.23	4253.42	7754.04	6849.78	4243.64
26/03/1970	45.8	2.00	1.82	1.74	2.01	2.01	2.32
29/12/1970	52.3	17.78	11.17	22.89	22.49	36.88	37.89
21/09/1972	72.6	20.36	13.14	35.65	63.86	50.99	42.06
23/10/1972	38.0	1.72	2.73	3.66	3.17	3.06	3.63
27/05/1974	71.4	7.16	6.13	5.22	4.87	4.74	4.60
27/02/1975	47.0	2.03	1.90	1.78	1.73	1.73	1.68
15/12/1975	37.6	1.41	1.44	1.51	1.51	1.52	1.48
27/12/1976	84.9	16.92	160.39	164.02	198.39	145.38	124.22
20/12/1977	55.7	16.46	10.73	11.19	8.53	7.83	15.15
06/11/1978	76.6	10.20	8.40	6.97	6.42	6.19	6.11
14/04/1980	34.6	1.94	1.67	1.76	1.63	1.62	1.52
04/10/1980	26.6	2.26	1.85	1.76	3.33	3.20	3.26
16/09/1982	42.1	1.78	2.08	1.77	1.68	1.68	1.60
06/03/1983	19.9	1.06	1.04	1.05	1.04	1.04	1.03
22/09/1984	73.2	21.29	13.69	9.50	8.18	8.01	7.59
06/01/1985	55.5	6.48	11.34	8.39	6.60	6.15	5.35
23/10/1985	47.5	4.10	4.04	2.84	2.54	2.51	2.30
23/01/1987	90.2	65.14	177.08	281.64	271.92	266.80	258.40
25/10/1987	91.7	43.59	30.30	30.71	25.08	29.11	29.43
27/09/1989	97.7	111.99	90.10	71.77	77.10	76.90	74.86
26/10/1989	82.8	346.67	200.11	110.01	70.87	55.04	49.23
01/12/1990	71.6	46.89	88.14	53.71	36.15	29.83	25.45
23/10/1991	56.1	2.81	2.63	2.43	2.34	2.33	2.50
09/05/1993	42.4	4.76	11.39	6.21	4.93	4.67	4.05
29/10/1993	88.9	48.59	181.56	104.86	70.77	62.97	58.61
08/10/1994	53.0	2.61	3.62	3.93	3.43	3.53	3.20
16/11/1995	94.7	34.92	26.53	20.52	18.06	16.77	18.74
01/02/1997	39.8	1.53	1.51	1.48	1.44	1.45	1.40
21/12/1997	68.1	5.95	5.23	6.83	6.54	6.16	8.32
12/01/1999	53.1	4.35	4.58	3.32	2.99	2.93	4.97
26/10/1999	50.6	8.30	24.06	12.09	16.72	14.89	11.51
05/03/2001	53.1	9.73	7.39	7.93	8.71	7.99	6.79
20/11/2001	86.1	744.25	406.41	237.56	141.06	103.68	91.60
25/11/2002	78.2	10.77	8.90	7.93	7.24	6.94	7.11
04/10/2003	36.0	1.74	2.16	1.91	2.15	2.12	1.91
18/10/2004	61.7	4.20	5.85	4.42	4.06	3.93	3.80
09/02/2006	44.2	23.87	14.93	7.86	5.95	5.59	5.16
08/04/2007	62.9	4.09	3.71	4.86	4.35	4.20	3.96
08/04/2008	110.9	5081.18	2543.82	2225.26	1203.07	722.64	708.98
27/02/2009	82.3	18.51	14.24	14.57	15.19	13.73	13.04
02/02/2010	111.0	1222.76	739.78	735.62	442.14	292.08	435.39
26/11/2010	155.1	2847.19	1742.87	12367.21	82639.41	32610.08	40249.32
24/10/2011	30.0	1.12	1.12	1.13	1.12	1.12	1.11
25/11/2012	67.3	9.23	10.51	7.24	13.89	12.38	10.95
16/09/2014	33.1	1.17	1.19	1.21	1.22	1.23	1.24
29/11/2014	37.8	1.63	1.48	1.40	1.36	1.37	2.09
22/04/2016	85.5	17.40	14.51	12.16	18.15	16.14	16.29
26/04/2017	62.8	12.19	8.56	7.34	6.15	5.78	5.29

Conditional (cumulative given the maximum) return periods in years							
Date of maximum	**Daily AMS (mm)**	**1 day before&after**	**2 days before&after**	**3 days before&after**	**4 days before&after**	**5 days before&after**	**6 days before&after**
19/10/1937	61.2	5.46	5.76	5.96	9.58	8.86	18.33
23/09/1939	28.2	1.11	1.11	1.61	2.19	2.13	2.28
23/12/1939	60.5	16.51	14.49	12.86	10.87	9.91	10.02
12/02/1941	107.0	236.55	253.69	269.61	267.73	231.78	268.01
06/11/1941	67.7	57.99	51.03	46.65	41.47	35.79	35.98
06/10/1942	56.0	4.08	4.10	3.99	6.93	6.51	13.99
09/02/1944	43.8	1.93	1.91	1.90	1.90	1.91	1.90
11/11/1944	38.2	1.49	1.48	1.57	1.56	1.58	1.55
13/12/1945	59.1	4.72	4.77	5.02	5.35	5.35	5.94
24/01/1947	51.0	2.79	5.03	4.07	3.81	3.72	3.74
23/02/1948	41.0	1.69	1.80	1.75	1.84	1.85	1.97
23/11/1948	30.2	1.15	1.15	1.16	1.16	1.16	1.16
03/11/1949	66.8	9.31	8.84	8.60	8.51	8.36	8.72
02/06/1951	27.5	1.13	1.11	1.11	1.11	1.12	1.11
31/03/1952	48.4	2.60	3.14	4.23	4.42	4.23	4.49
19/11/1952	111.9	519.11	454.05	441.93	420.23	352.24	420.04
09/10/1953	115.6	567.82	617.67	634.36	598.84	504.58	619.36
02/01/1955	27.3	1.11	1.25	1.28	1.24	1.24	1.33
12/01/1956	97.6	109.81	107.76	117.50	127.81	116.64	139.36
04/11/1956	131.2	3353.02	2912.19	2938.37	2684.16	2809.66	4187.56
09/12/1957	38.0	1.51	1.49	1.59	1.73	1.78	3.41
24/01/1959	52.6	7.94	9.52	7.00	6.39	6.00	9.93
21/03/1960	47.4	2.31	2.67	2.45	2.41	2.43	2.39
22/10/1960	20.4	1.02	1.02	1.02	1.03	1.05	1.04
22/09/1962	49.1	2.76	2.73	2.68	2.64	2.65	2.61
31/01/1963	62.7	6.17	6.74	7.92	11.41	10.42	20.08
21/06/1964	57.8	4.41	4.37	4.36	4.34	4.33	4.34
01/06/1965	44.3	2.09	2.01	1.98	1.96	1.98	1.96
26/10/1965	54.1	3.43	3.79	3.87	4.44	4.33	4.36
31/10/1966	68.7	158.10	355.28	460.26	324.20	257.62	357.80
21/11/1967	64.9	14.61	33.43	23.45	23.70	22.88	46.49
04/01/1969	84.4	38.39	44.91	413.00	564.53	478.92	444.55
26/03/1970	45.8	2.17	2.13	2.12	2.23	2.24	2.38
29/12/1970	52.3	7.87	6.25	8.52	8.51	10.64	11.13
21/09/1972	72.6	19.15	16.29	24.98	33.05	28.05	28.53
23/10/1972	38.0	1.63	2.05	2.33	2.17	2.14	2.34
27/05/1974	71.4	11.77	11.79	11.77	11.70	11.53	11.72
27/02/1975	47.0	2.28	2.26	2.25	2.24	2.25	2.24
15/12/1975	37.6	1.47	1.49	1.52	1.53	1.54	1.52
27/12/1976	84.9	34.91	95.64	92.68	103.63	81.31	89.19
20/12/1977	55.7	8.55	6.93	6.85	6.11	5.80	8.14
06/11/1978	76.6	17.87	17.83	17.80	17.67	17.29	17.76
14/04/1980	34.6	1.62	1.50	1.53	1.47	1.48	1.44
04/10/1980	26.6	1.57	1.42	1.38	1.90	1.86	1.88
16/09/1982	42.1	1.83	1.98	1.85	1.82	1.84	1.80
06/03/1983	19.9	1.04	1.03	1.03	1.03	1.03	1.02
22/09/1984	73.2	20.12	17.10	15.41	14.94	14.43	14.99
06/01/1985	55.5	5.33	7.07	5.96	5.40	5.18	5.03
23/10/1985	47.5	3.23	3.21	2.71	2.60	2.60	2.53
23/01/1987	90.2	78.52	130.97	156.26	158.70	138.57	165.26
25/10/1987	91.7	71.93	68.28	72.60	69.95	67.65	76.62
27/09/1989	97.7	148.70	146.17	141.06	148.97	132.24	156.44
26/10/1989	82.8	124.00	96.04	69.55	59.11	48.79	53.47
01/12/1990	71.6	27.57	38.06	28.54	24.36	21.21	21.74
23/10/1991	56.1	3.84	3.86	3.86	3.85	3.85	3.93
09/05/1993	42.4	3.00	4.65	3.34	3.00	2.92	2.75
29/10/1993	88.9	64.38	124.01	95.45	83.88	72.45	82.37
08/10/1994	53.0	3.21	3.72	3.86	3.69	3.72	3.65
16/11/1995	94.7	80.75	80.79	80.93	79.98	75.98	82.82
01/02/1997	39.8	1.61	1.62	1.61	1.60	1.62	1.60
21/12/1997	68.1	9.17	9.20	10.22	10.21	9.83	11.41
12/01/1999	53.1	4.02	4.16	3.63	3.51	3.50	4.39
26/10/1999	50.6	5.07	8.64	5.90	6.95	6.48	5.89
05/03/2001	53.1	5.99	5.24	5.28	5.56	5.28	5.05
20/11/2001	86.1	211.67	159.21	116.39	95.20	75.17	83.77
25/11/2002	78.2	20.10	20.13	20.41	20.24	19.71	20.51
04/10/2003	36.0	1.57	1.75	1.63	1.73	1.72	1.64
18/10/2004	61.7	5.77	6.71	6.18	6.08	5.98	6.06
09/02/2006	44.2	7.06	5.59	3.94	3.45	3.33	3.25
08/04/2007	62.9	6.15	6.18	6.81	6.65	6.52	6.58
08/04/2008	110.9	1810.60	1347.35	1208.26	972.92	644.51	853.16
27/02/2009	82.3	30.35	29.66	31.29	32.23	29.86	31.84
02/02/2010	111.0	904.22	763.11	766.09	654.25	468.03	705.91
26/11/2010	155.1	14723.76	15021.12	32273.28	72503.18	33239.21	62302.51
24/10/2011	30.0	1.15	1.15	1.16	1.16	1.16	1.15
25/11/2012	67.3	10.35	11.31	9.95	12.97	11.95	12.15
16/09/2014	33.1	1.24	1.25	1.26	1.26	1.28	1.27
29/11/2014	37.8	1.58	1.51	1.49	1.48	1.49	1.78
22/04/2016	85.5	36.59	37.01	37.34	41.96	38.51	42.11
26/04/2017	62.8	9.71	8.35	7.84	7.43	7.15	7.20