



Northland Storm rainfall

Prepared for:

Northland Regional Council

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Scope of Work

In broad terms, this report deals with examining the temporal storm rainfall event properties in the Northland region and a review of the design storm rainfall hyetographs currently used in the Northland region. This report also examines the differences in the results obtained using different versions of High Intensity Rainfall Design System (HIRDS) when applied to the Northland region. HIRDS was developed by the National Institute of Water and Atmospheric Research (NIWA). The HIRDS versions considered in this study are versions 3 and 2.

This report is divided into two parts. The first part of the report deals the temporal storm rainfall event properties in the Northland region. The second part deals with the comparison between the results of HIRDS version 3 and HIRDS version 2 when used in the Northland region.

1. Storm Rainfall Properties in Northland

1.1 Introduction

The main purpose of this part of the report is to examine the temporal storm rainfall properties in the Northland region. This part of the report also provides a literature review about the different methods which can be used to identify a storm rainfall event from a continuous record of rainfall time series. Section 1.6 of the report discusses the different design rainfall hyetographs used in the Northland region.

1.2 Storm Rainfall Identification

The study of the temporal properties of storm rainfall events requires the identification of these events from a continuous rainfall record. The identification of a rainfall event from continuous rainfall records is dependent on the inter-event time definition (IETD). The IETD can be formally defined as the minimum time without rainfall between two successive rainfall periods. Two successive rainfall periods separated by a time interval greater than the chosen IETD value are regarded as two separate storm rainfall events. Conversely, if the separation time is less than or equal to the chosen IETD value then the two successive rainfall periods are considered as single storm rainfall event. Figure 1-1 shows a schematic diagram illustrating how the IETD can be used for Identification of storm rainfall events from a continuous rainfall record.

The choice of the appropriate IETD value is both application and location dependent (Guo and Adams, 1998, 2009). However, it should be selected *“to ensure stochastic independence between consecutive storms and also be long enough, as compared to the time of concentration of the watershed, so that runoff events resulting from consecutive rainfall events do not overlap”* (Guo and Adams, 2009). Driscoll et al. (1989) found that IETD of 6 hours produced the most consistent results in the USA. Guo and Adams (1998) considered IETD of 6 hours to be appropriate for urban catchments in the Toronto region of Canada. In Seoul, Korea, IETD of 10 hours is found to be appropriate (Park, 1995; Kwon, 2003). In broad terms, IETD value between 6 to 12 hours is regarded as adequate for most locations (cf. Restrepo-Posada and Eagleson, 1982; Guo and Baetz, 2007). In the author's present knowledge there is no agreed value for IETD in New Zealand.

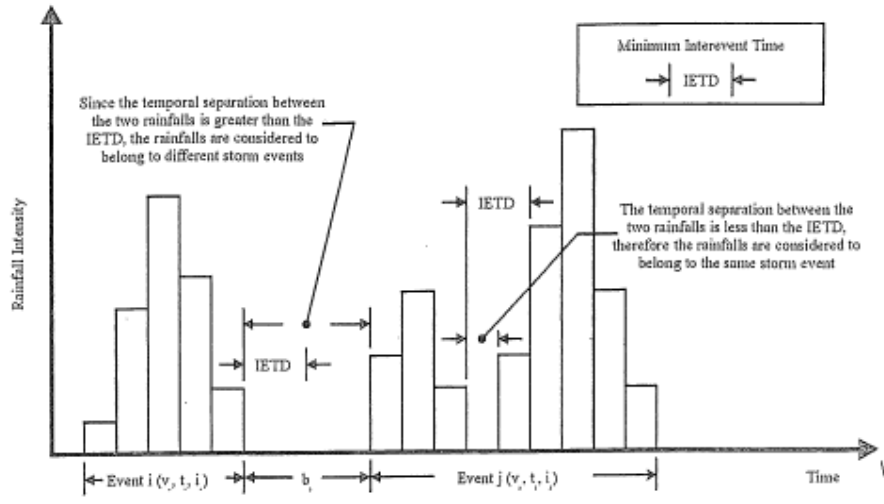


Figure 1-1: Identification of discrete rainfall events for a continuous rainfall record based on IETD (Source Adams and Papa, 2000).

There are three approaches which can be used for determining the appropriate IETD value (cf. Adams and Papa, 2000):

1. The Auto-Correlation Analysis Approach: This type of analysis provides a convenient way for representing the degree of time dependence between successive values of a time series separated by a chosen time period known as the lag. The degree of this dependence is measured by calculating the autocorrelation coefficient. The sample lag-k autocorrelation coefficient r_k of a time series X_t is given by:

$$r_k = \frac{\sum_{t=1}^{N-k} (X_t - \bar{X})(X_{t+k} - \bar{X})}{\sum_{t=1}^N (X_t - \bar{X})^2}$$

where N is the total number of data points and $\bar{X}$ is the mean value of the time series. The autocorrelation coefficient r_k measures the amount of the linear relationship between observations separated by k data intervals. Theoretically, it has a numerical

value which is bounded between (+1) and (-1). A value of (+1) would indicate that the observations separated by a lag of k have a strong tendency to follow each other in time in a linear fashion with a positive slope. On the other hand, a value of (-1) would indicate that the observations separated by a lag of k have a strong tendency to follow each other in a linear fashion with a negative slope. A value of r_k not significantly different from zero would suggest that the successive values of the time separated by k time steps can be regarded as statistically independent. The determination of the IETD value on the basis of the autocorrelation analysis involves developing a correlogram (a plot of r_k against the lag k). The appropriate IETD value is equal to the lag time beyond which the autocorrelation coefficient values are not significantly different from zero.

2. The Number of Rainfall Events Approach: This is the simplest approach. The determination of the appropriate IETD value based on this approach involves the examination of the functional relationship between IETD and the number of rainfall events (cf. Nix, 1994). The appropriate IETD value is defined as that beyond which an increase in the IETD values does not result in a substantial change in the number of events.
3. The Coefficient of Variation of Inter-event-time Approach: This approach assumes that the probability density function of the inter-event times can be described by a one-parameter exponential distribution, as illustrated in many studies (Restrepo-Posada and Eagleson 1982; Nix, 1994). The coefficient of variation of the one-parameter exponential distribution is one, because its mean and its standard deviation are equal. Similar to the number of rainfall events approach for determining the appropriate IETD value, the determination of the appropriate IETD value using the coefficient of variation approach involves the development of the functional relationship between IETD and the coefficient of variation of the inter-event times, based on the observed data. Once this relationship is developed, the IETD value is the one which results in the value of the coefficient of variation of the inter-event times being not significantly different from unity.

1.3 Inter-Event Time Definition (IETD) in Northland

The purpose of this part of the report is to determine an appropriate value for the IETD in Northland. For this purpose, the rainfall data from 11 rainfall stations in Northland is selected. A summary description of these catchment is shown in Table 1-1. These rainfall stations are selected from the available 37 automatic stations in the region taking into consideration the geographical spread and the available record length.

In this part of the report, three storm rainfall event properties are considered for determining the appropriate IETD value in Northland. These three properties are:

- 1) Number of rainfall events.
- 2) Average rainfall event depth.
- 3) Median rainfall event depth.

Figures 1-2 to 1-12 show the variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the 11 selected stations. Examination of the figures shows that both the average and the median event depth values increase with the increase in the IETD value. However, the number of rainfall events generally decreases with the increase the IETD value. Further examination of these figures reveals that when the IETD value is greater than 6 hours the rate the number of events does not change substantially. Thus, an IETD value of 6 hours is used in this report in identifying the rainfall events from the continuous rainfall records in Northland.

Table 1-1: A summary Description of the 11 selected rainfall stations including the start and the end dates for the data used in identification of IETD.

Station No	Station Name	Start date	End date
641010	Awaroa at Wallace Road	19-Sep-2007 13:10:00	21-Aug-2012 13:30:00
643118	Kaipara Harbour at Pouto Point	23-Nov-2006 11:20:00	13-Jul-2012 11:20:00
536816	Mangakahia at Twin Bridges	22-Apr-1999 12:30:00	16-Aug-2012 13:50:00
546416	Ngunguru at Polerain	28-Oct-1987 09:30:00	15-Oct-2012 12:05:00
546216	Okarika at Rowland Road	1-May-1977 00:00:00	27-Mar-2012 11:55:00
534403	Opononi Omapere Hokianga Harbour	25-Sep-2006 12:55:00	12-Jul-2012 13:25:00
536812	Opouteke at Brookvale	2-Nov-1987 13:02:00	15-Aug-2012 13:20:00
533302	Rotokakahii at Kohe Road	19-Nov-1998 14:00:00	31-Aug-2012 10:00:00
531313	Takahue at Te Rore	1-Dec-2011 10:45:00	31-Aug-2012 13:05:00
640436	Waihoihoi at Brynderwyn	16-Feb-1981 10:30:00	13-Aug-2013 10:10:00
543010	Waitangi at McDonald Road	30-Apr-1986 12:09:00	26-Jun-2013 14:55:00

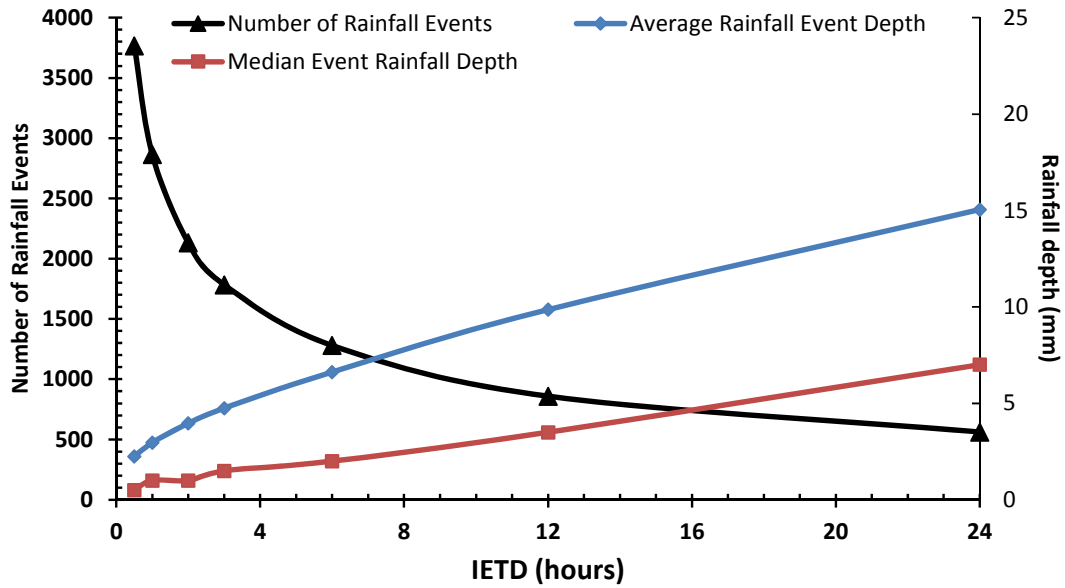


Figure 1-2: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Awaroa station.

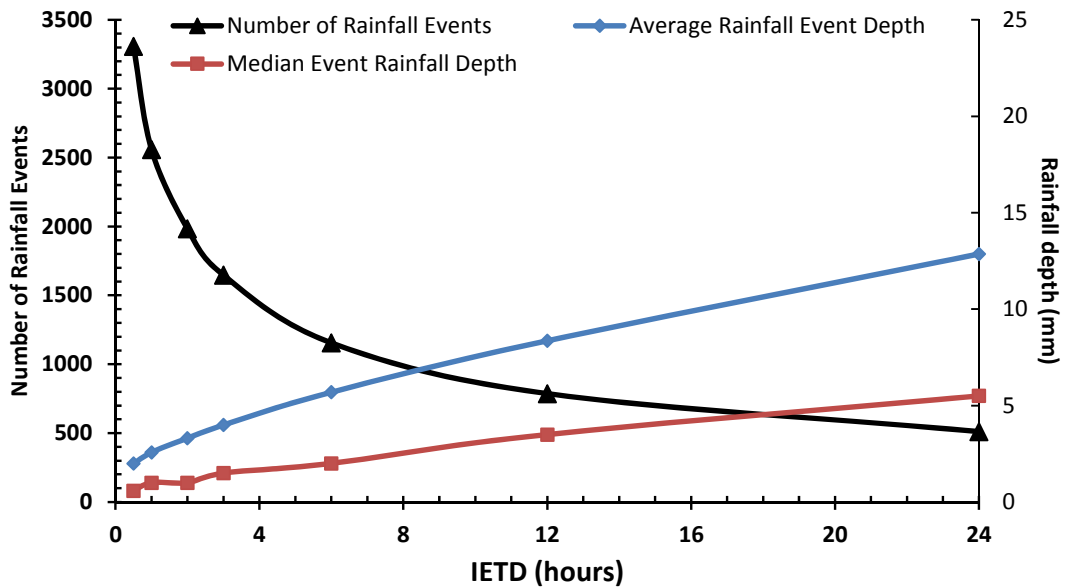


Figure 1-3: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Kaipara Harbour station.

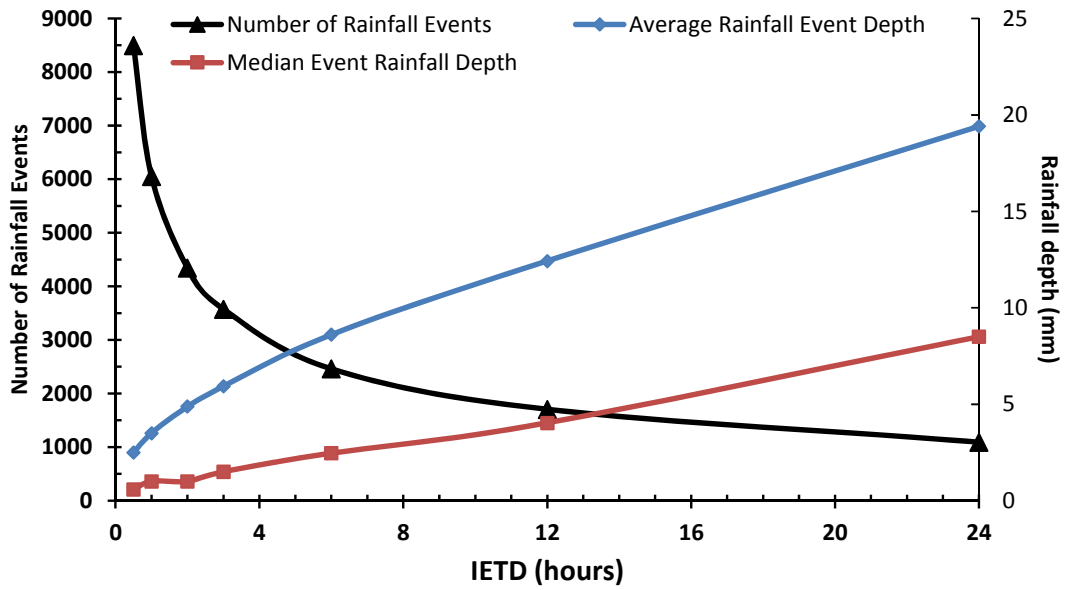


Figure 1-4: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Mangakahia station.

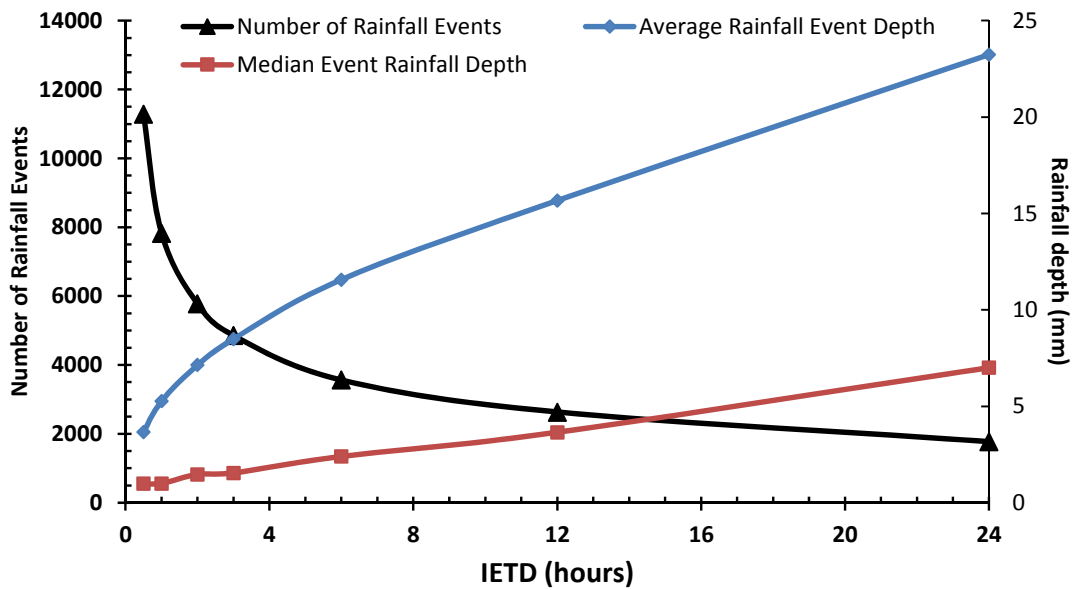


Figure 1-5: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Ngunguru station.

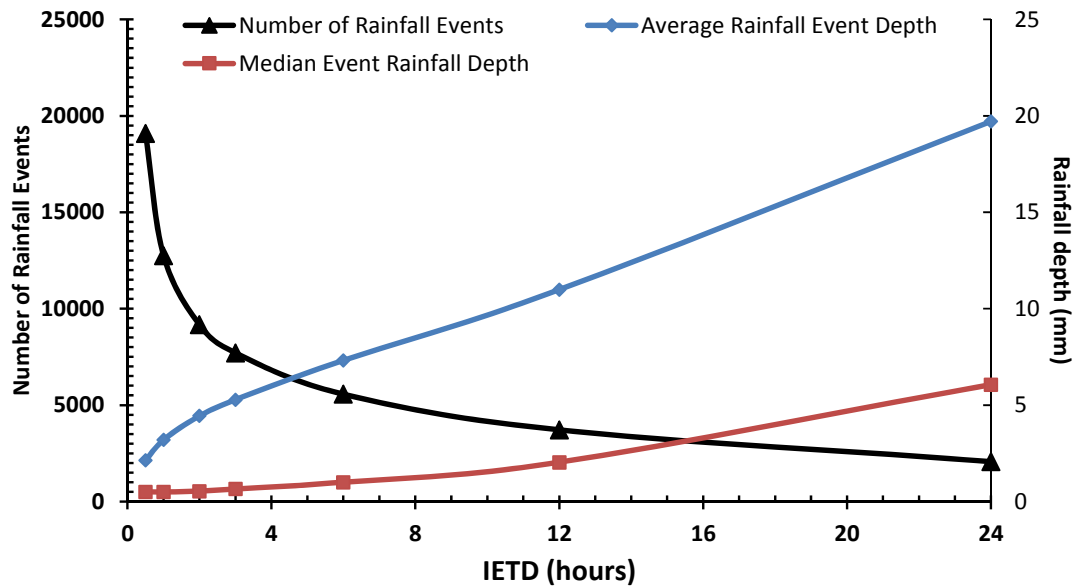


Figure 1-6: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Okarika station.

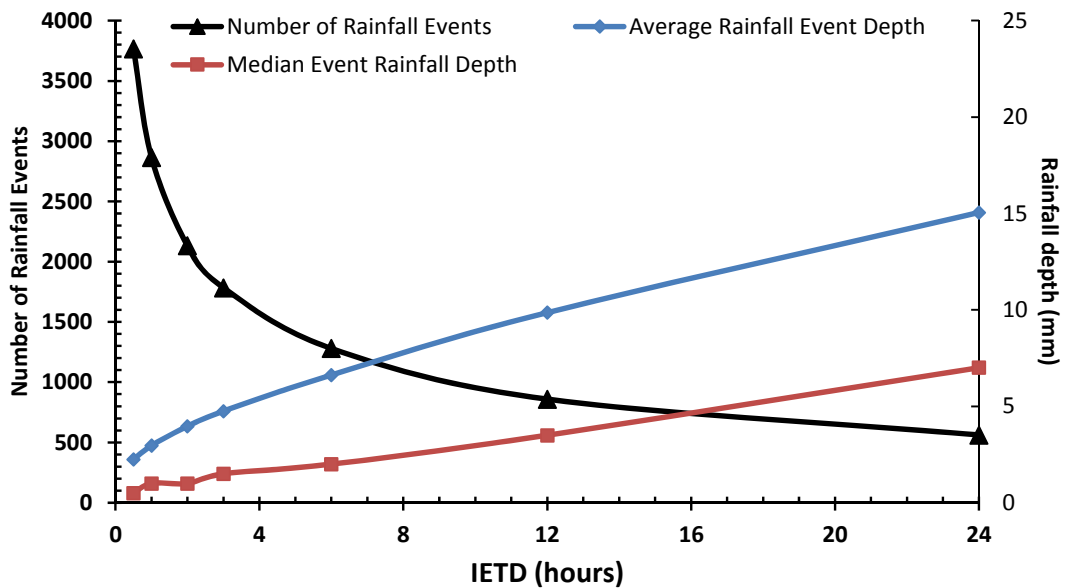


Figure 1-7: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Opononi station.

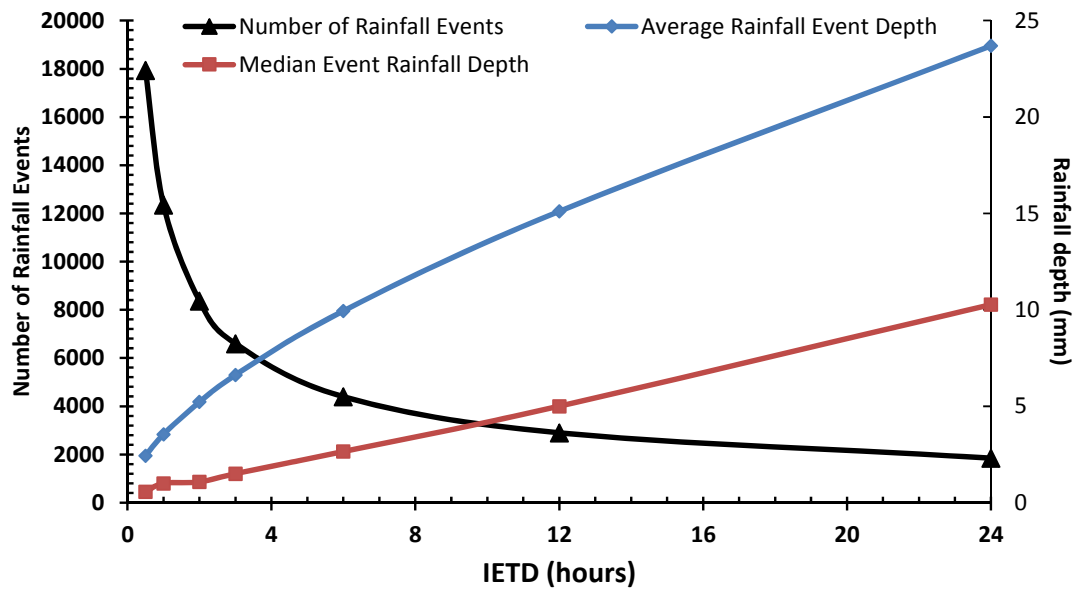


Figure 1-8: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Opouteke station.

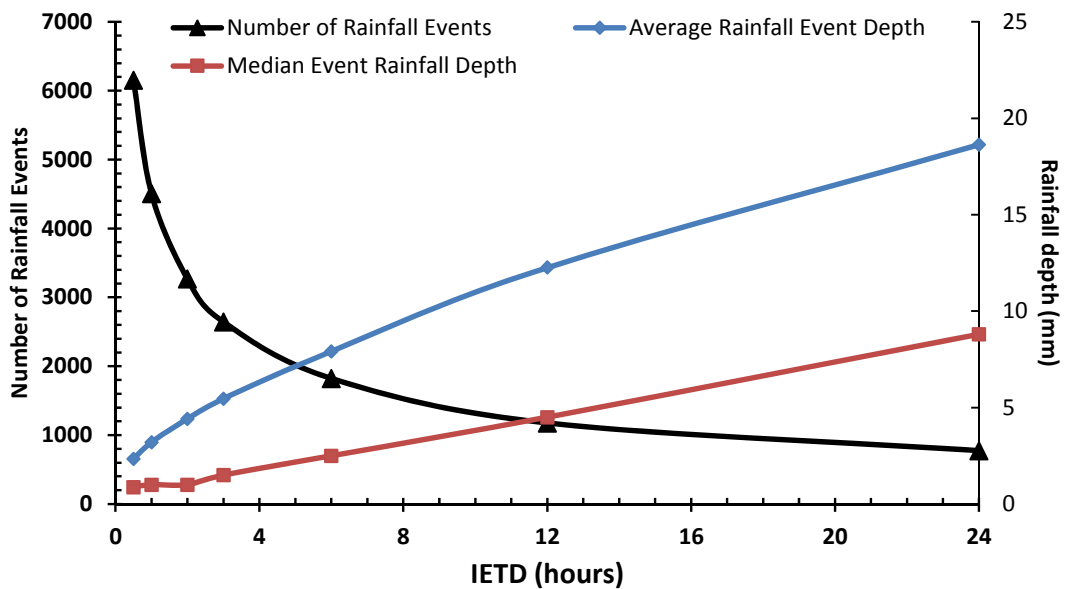


Figure 1-9: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Rotokakahii station.

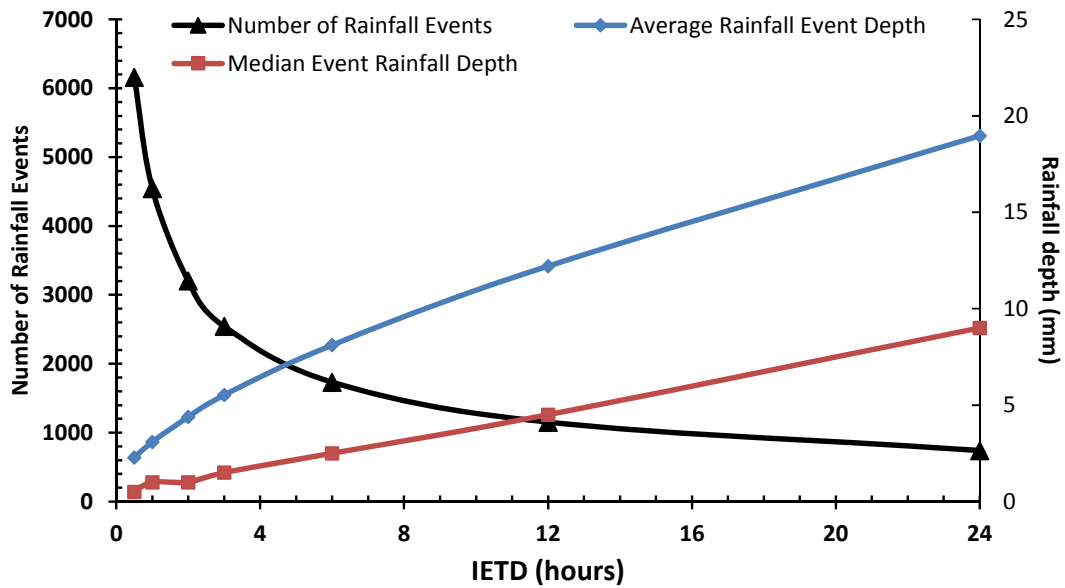


Figure 1-10: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Takahue station.

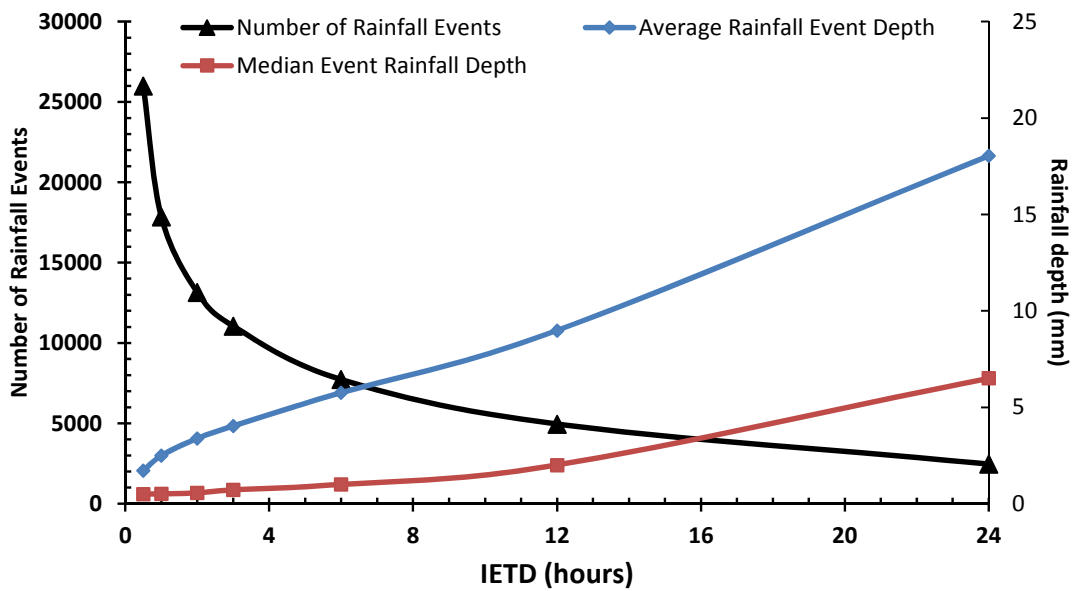


Figure 1-11: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Waihoihoi station.

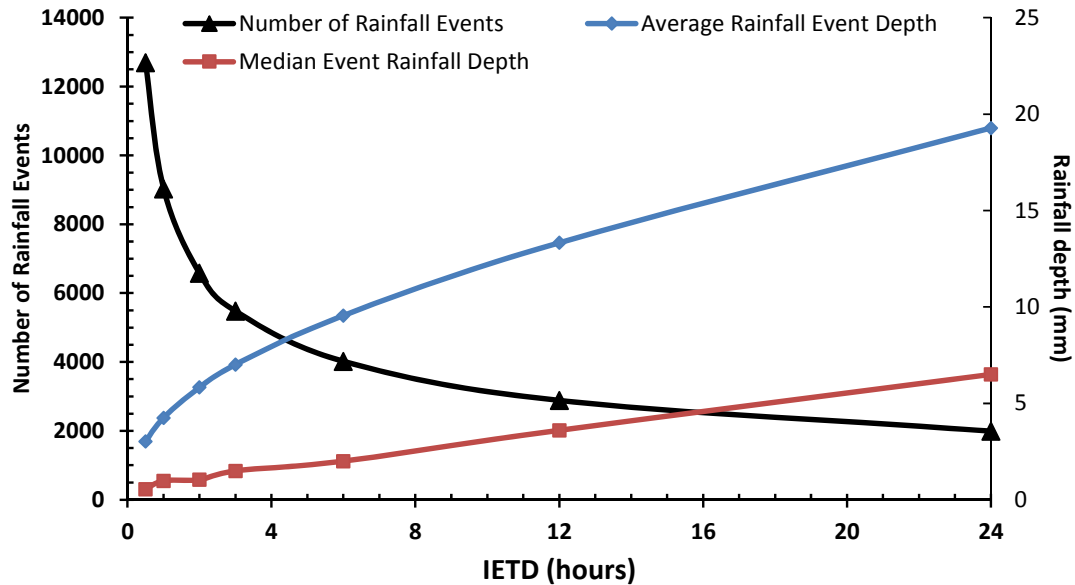


Figure 1-12: Variation of the number of rainfall events, the average rainfall event depth and the median event depth with the IETD value for the Waitangi station.

1.4 Design Storm Rainfall profiles

In the estimation of the design flood hydrograph using event-based rainfall-runoff modelling procedures, the specification of the design storm profiles/hyetographs is paramount. These profiles are used to determine the temporal distribution of the storm rainfall event.

In the estimation of the design flood hydrographs using the event-based rainfall-runoff modelling procedures, numerous methods have been developed to determine the design storm profiles. However, these methods can be grouped into two categories depending the method used in their determination. The first category is exclusively developed using the actual observed storm profiles. The second category is developed based on depth-duration frequency curves and some observed properties of the observed storm rainfall event hyetographs such as the location of peak intensity. A review of these methods is given in the coming section of the report.

1.1 Design Storm Hyetographs

1.4.1 Constant Intensity Design storm Hyetograph

In this design storm the rainfall intensity is assumed to be constant during the duration of the storm. Thus, its shape is rectangular. This type of design storm hyetograph is commonly used in conjunction with the rational method which assumes that “the rainfall intensity is constant over the time of concentration”. For a given return period the intensity is determined from the IDF curves with the storm duration equal to the time of concentration. Although, the constant intensity design storm hyetograph is widely used it may underestimate the flow peaks (Alfieri et al., 2008).

1.4.2 Alternating Block Design Hyetograph

This design hyetograph is constructed from the Intensity-Duration-Frequency (IDF) curves (Chow et al., 1988). For a particular return period, the total duration of the storm D is divided into n successive sub-durations. These sub-durations have the same discretization time interval Δt . The intensity for each of the different sub-durations $\Delta t, 2\Delta t, \dots, n\Delta t$ is determined from the IDF curves and the corresponding rainfall depth is calculated. Rainfall depth increment blocks are found by finding the differences in rainfall depth of the successive sub-durations. The rainfall block with the maximum depth is placed at the centre and the remaining blocks are arranged in a descending order alternately to the right and left of the central block.

1.4.3 USA Soil Conservation Service (SCS) Design storm Hyetographs

The SCS design storm hyetographs are developed for durations up to 24 hours. On the basis of the characteristics of the DDF curves, the USA is divided into four major regions. Each region has its own design hyetograph. Accordingly, there are four cumulative hyetographs accounting for the regional variations. These four design hyetographs are known as type I, IA, II and III. Figure 1-13 shows the dimensionless cumulative plots of the SCS design storm hyetographs for the 24-hour storm duration. These design storm types are developed from the DDF/IDF curves using a similar procedure to that of the alternating block design hyetograph. However, the main difference between the SCS design hyetographs and the alternating block design hyetograph is that the location of the rainfall block with maximum

depth increment block is not necessarily central in the case of the SCS design hyetographs (McCuen, 2005). The position of this maximum rainfall block (peak) is found by analysing the data of actual observed rainfall hyetographs. For type I and type IA the position of the peak occurs at around 8 hours (i.e. around one third of the total storm duration). However, for type II and III the position of the peak is central. Studies carried out by SCS indicated that the positioning of the peak varies geographically. Figure 1-14 shows the US regions to which these types are applicable. As shown in Figure 1-13, type I and type IA are applicable to maritime climate with wet winters and dry summers (Chow et al. 1988). Likewise, type III is applicable to the Gulf of Mexico while type II is applicable to the rest of the country.

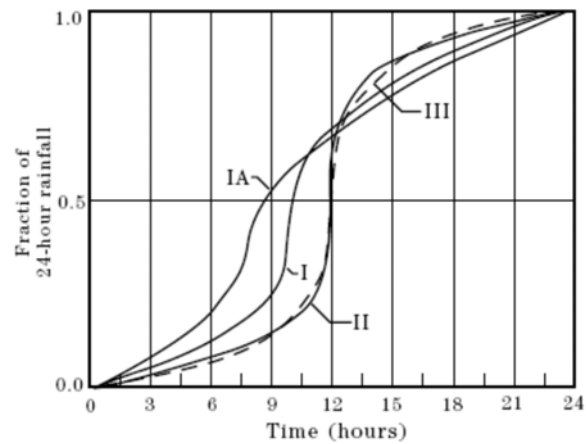


Figure 1-13: Dimensionless cumulative plots of the SCS design storm Hyetographs for 24-hour storm duration (Source: USDA, 1986).

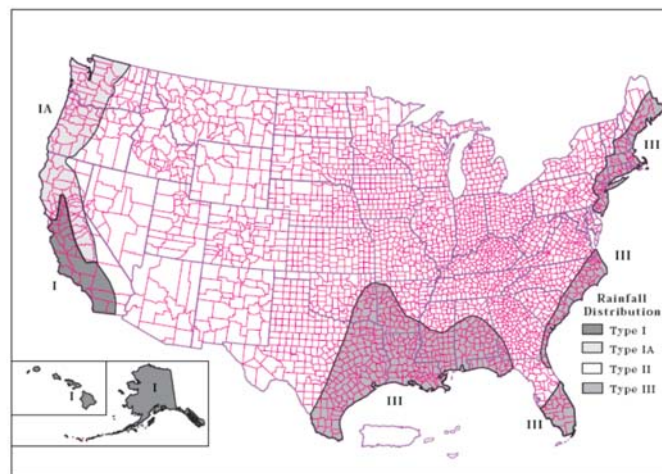


Figure 1-14: Geographic regions of the SCC design hyetographs within the USA (Source: USDA, 1986).

1.4.4 Huff Design Storm Hyetographs

Huff (1967, 1990) developed a family of dimensionless cumulative rainfall hyetographs to characterize the inter-storm variability for the Chicago urban area in the USA. The development of these hyetographs was based on the analysis of measured point rainfall values and the areal rainfall values. Huff (1967) subjectively defined storm rainfall as *“a rain period separated from preceding and succeeding rainfall by 6 hours or more”*. The storm rainfall data was obtained from *“a 400-square-mile network of 49 recording”*. Huff (1990) noted the rainfall network is located in *“extremely flat prairie land; therefore no significant topographic or urban influences on local precipitation occur”*. Storm rainfalls included in the analysis were those in which *“the mean rainfall exceeded 0.50 inch (12.7 mm) and/or one or more gages recorded more than 25.4 mm”*. In this way, a database of 261 storms having durations ranging from 1 to 48 hours were developed and subsequently used in the analysis. The derived dimensionless cumulative rainfall hyetographs are classified as *“first-, second-, third-, or fourth-quartile storms depending on whether the greatest percentage of total storm rainfall occurred in the first, second, third, or fourth quarter of the storm period”*.

Huff (1967) noted that *“fourth-quartile storms occurred most often with durations greater than 24 hours; first-quartile and second-quartile storms occurred most frequently with durations less than or equal to 12 hours; and third-quartile storms most often had durations of 12.1 to 24 hours”*. Example of fourth quartile dimensionless cumulative rainfall hyetographs of point rainfall for different probability of occurrence is shown in Figure 1-15.

Huff (1990) noted that for most purposes, the median curves are probably most applicable to design” and that extreme curves at 10% and 90% probability levels are useful in estimating runoff for extreme conditions. Figure 1-16 shows the point rainfall median cumulative hyetographs for the different quartiles which was developed by William et al. (2005) using the data presented in Huff (1990). Comparison of these hyetographs with those of the SCS design hyetographs (Figure 1-13) indicates that the Huff design storm hyetographs are more flat than those of the SCS.

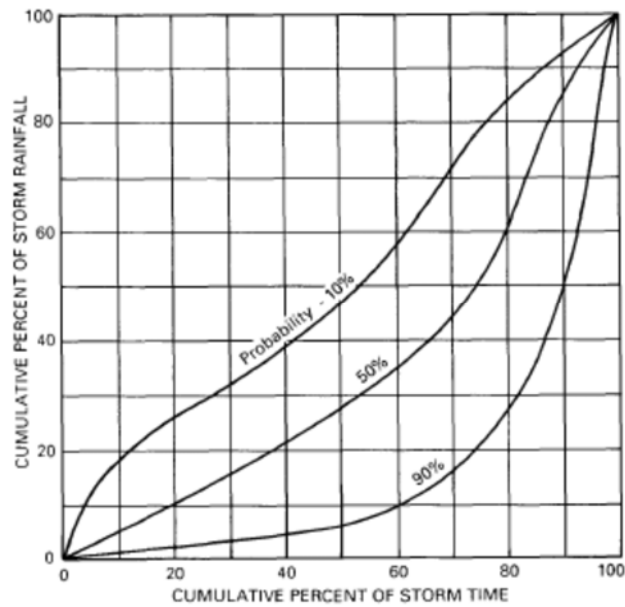


Figure 1-15: Cumulative Hyetographs point rainfall in the fourth quartile for different probability levels (Source: Huff, 1990).

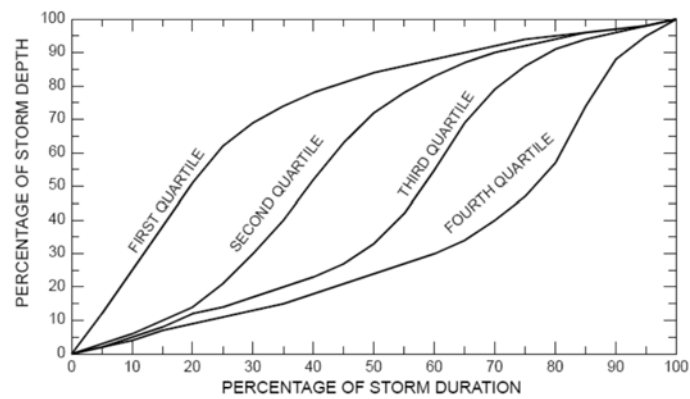


Figure 1-16: Average dimensionless cumulative hyetographs at a point for different quartiles (Source: William et al. (2005)).

1.5 Dimensionless hyetographs for selected Rainfall events in Northland

This part of the report focuses on examining the dimensionless hyetographs for a number of selected extreme storm rainfall events obtained from the 11 selected rainfall gauging stations. One rainfall event per station is selected. The selected event from each

station is the one having the maximum storm rainfall depth. The properties of these selected rainfall events are shown in Table 1-2.

Examination on Table 1-2 shows that these storm rainfall events have long storm durations. Likewise, most of these events occurred during the summer/autumn months. Five of these eleven events occurred in 2007 in which there was a La Niña episode (https://en.wikipedia.org/wiki/La_Ni%C3%B1a). Two of the eleven events occurred in 1988. However, the remaining four events occurred 1997, 2002, 2010 and 2011. The years 1988, 2010 and 2011 are associated with a La Niña episodes (http://www.stormfax.com/el_nino.htm). However, the years 1997 and 2002 are associated El Niño episodes (http://www.stormfax.com/el_nino.htm). The results shown in the table suggest that extreme storm rainfall events may be linked to El Niño and La Niña events.

Table 1-2: Properties of storm rainfall events having the maximum depth for the 11 selected rainfall stations

Station No	Station Name	Start date and time	Storm Duration (hours)	Total rainfall Depth (mm)
641010	Awaroa at Wallace Road	17/12/2010 12:25	8.58	126.0
643118	Kaipara Harbour at Pouto Point	6/02/2007 17:45	14.17	88.0
536816	Mangakahia at Twin Bridges	18/06/2002 12:00	74.00	208.67
546416	Ngunguru at Polerain	28/03/2007 7:45	41.00	438.5
546216	Okarika at Rowland Road	5/03/1988 6:07	154.68	340.27
534403	Opononi Omapere Hokianga Harbour	22/01/2011 13:50	31.67	153.0
536812	Opouteke at Brookvale	6/03/1988 1:32	115.7	404.78
533302	Rotokakahii at Kohe Road	5/02/2007 16:45	52.00	161.5
531313	Takahue at Te Rore	5/02/2007 16:40	51.50	219.0
640436	Waihoihoi at Brynderwyn	29/06/1997 16:26	30.39	296.3
543010	Waitangi at McDonald Road	27/03/2007 12:25	62.08	350.0

1.5.1 The Awaroa station hyetograph

Figure 1-17 shows the dimensionless cumulative hyetograph for the Awaroa storm rainfall event with maximum depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Awaroa storm rainfall event with the maximum

rainfall depth occurred on 17/12/2010. It has a total depth of 126 mm and a duration of 8.58 hours. Examination of the figure shows that the Awaroa station dimensionless hyetograph lies between the Huff first quartile and second quartile dimensionless hyetographs. However, it is much closer to the second quartile dimensionless hyetograph. For the Awaroa station dimensionless hyetograph, a significant amount of the total rainfall depth occurred between 20% and 50% of the storm duration.

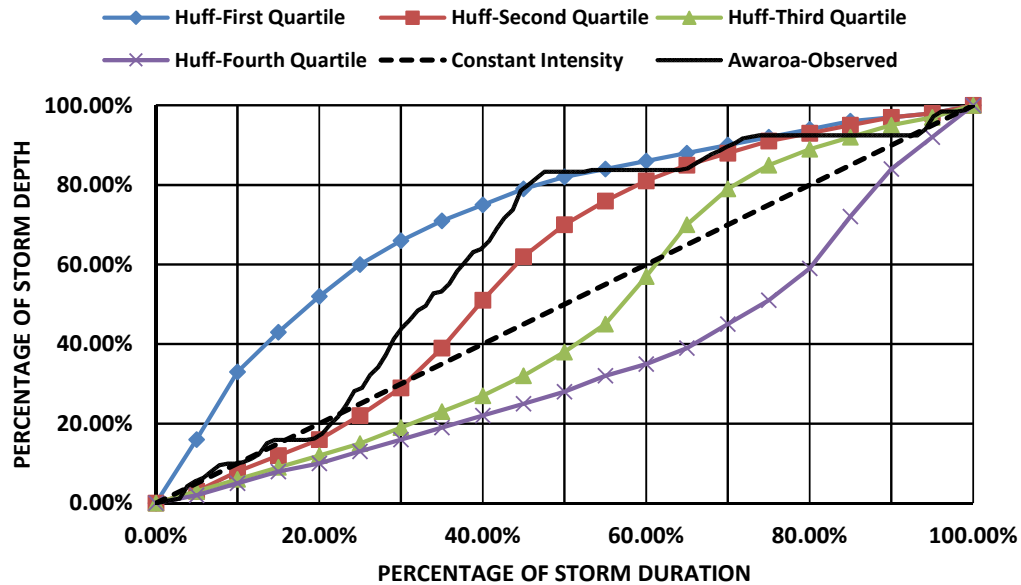


Figure 1-17: Dimensionless cumulative hyetograph for the Awaroa storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.2 The Kaipara Harbour station hyetograph

Figure 1-18 shows the dimensionless cumulative hyetograph for the Kaipara Harbour storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Kaipara Harbour storm rainfall event with the maximum rainfall depth occurred on 6/02/2007. It has a total rainfall depth of 88 mm and a duration of 14.17 hours. Examination of the figure shows that the Kaipara Harbour dimensionless hyetograph lies outside the Huff dimensionless hyetographs. For the Awaroa station dimensionless hyetograph, a significant amount of the total rainfall depth occurred between 70% and 90% of the storm duration.

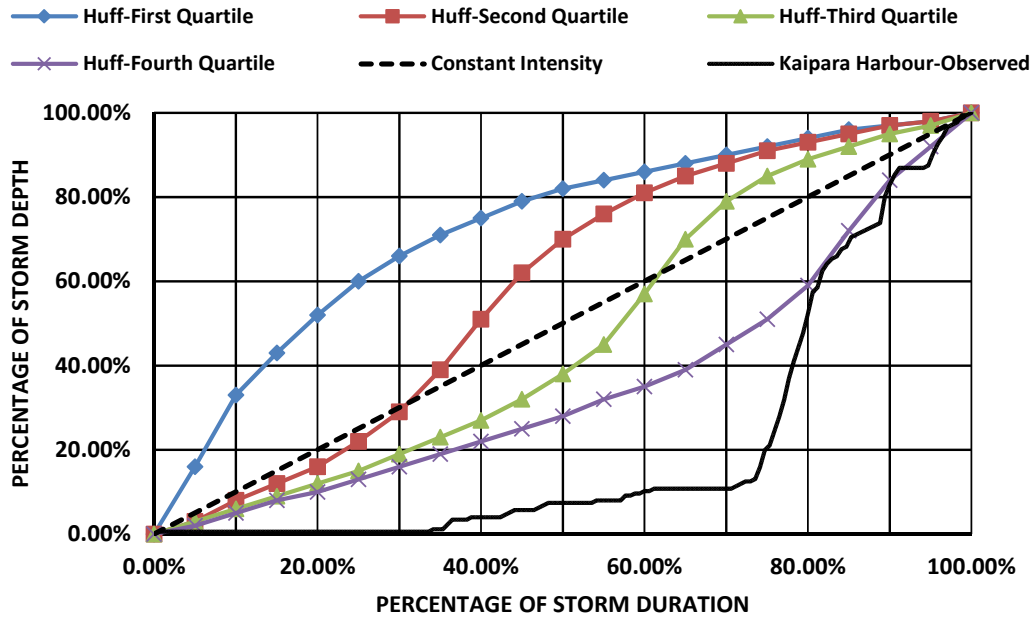


Figure 1-18: Dimensionless cumulative hyetograph for the Kaipara Harbour storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.3 The Mangakahia station hyetograph

Figure 1-19 shows the dimensionless cumulative hyetograph for the Mangakahia storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Mangakahia storm rainfall event with the maximum rainfall depth occurred on 18/06/2002. It has a total rainfall depth of 208.67 mm and a duration of 74.0 hours. Examination of the figure shows that the Mangakahia dimensionless hyetograph generally lies between the first quartile and the third quartile of Huff dimensionless hyetographs. For the Mangakahia station dimensionless hyetograph, around 40% of the total rainfall depth occurred in the first 35% of the storm duration. Overall, the constant dimensionless cumulative hyetograph can be regarded as providing a good approximation to the Mangakahia dimensionless hyetograph.

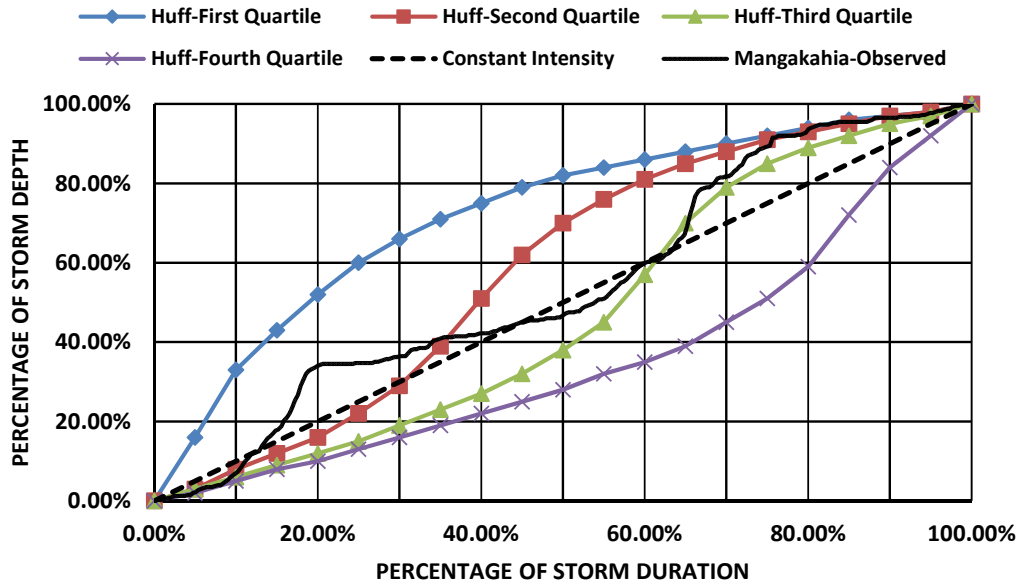


Figure 1-19: Dimensionless cumulative hyetograph for the Mangakahia storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.4 The Ngunguru station hyetograph

Figure 1-20 shows the dimensionless cumulative hyetograph for the Ngunguru storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Ngunguru storm rainfall event with the maximum rainfall depth occurred on 28/03/2007. It has a total rainfall depth of 438.5 mm and a duration of 41.0 hours. Examination of the figure shows that most of the Ngunguru dimensionless hyetograph lies between the third quartile and the fourth quartile of Huff dimensionless hyetographs. However, it is much closer to the Huff third quartile dimensionless hyetographs. For the Ngunguru station dimensionless hyetograph, around 40% of the total rainfall depth occurred in the first 55% of the storm duration.

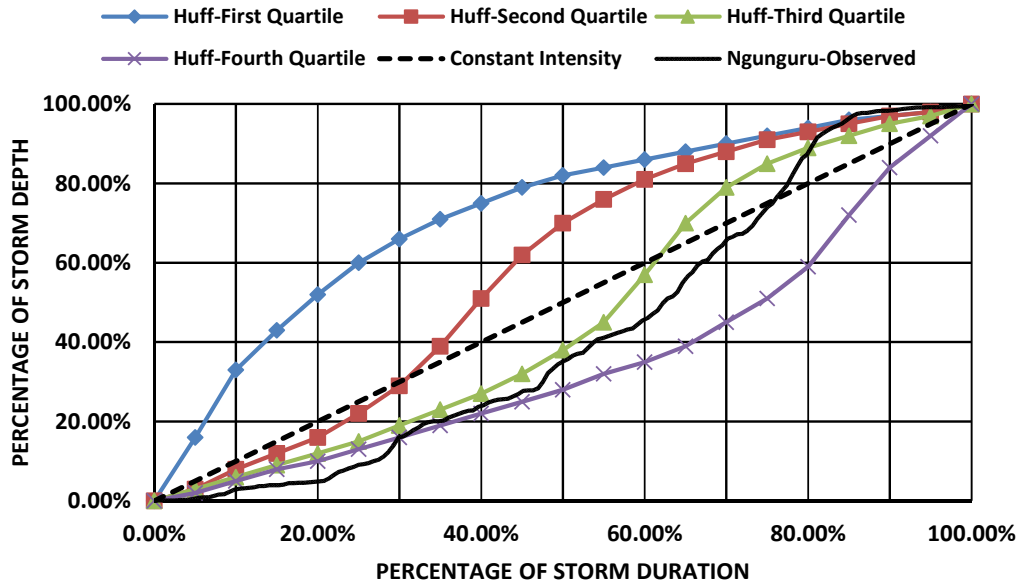


Figure 1-20: Dimensionless cumulative hyetograph for the Ngunguru storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.5 The Okarika station hyetograph

Figure 1-21 shows the dimensionless cumulative hyetograph for the Okarika storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Okarika storm rainfall event with the maximum rainfall depth occurred on 5/03/1988. It has a total rainfall depth of 340.27 mm and a duration of 154.68 hours. Examination of the figure shows that the Huff second quartile dimensionless cumulative hyetograph can be regarded as providing a good approximation to the Okarika dimensionless hyetograph. For the Okarika storm rainfall event, around 60% of the total rainfall depth occurred the first 40% of the storm duration.

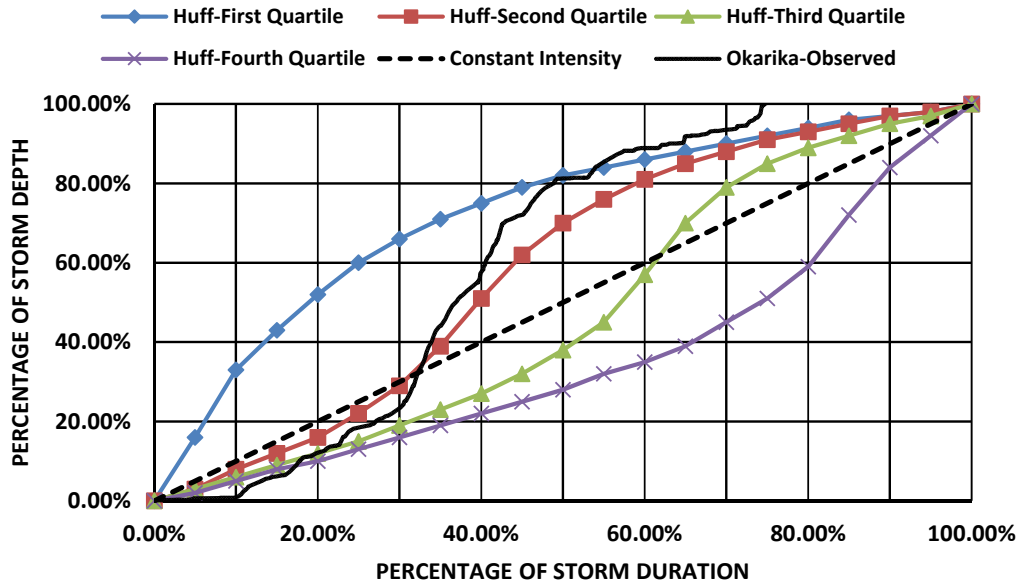


Figure 1-21: Dimensionless cumulative hyetograph for the Okarika storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.6 The Opononi station hyetograph

Figure 1-22 shows the dimensionless cumulative hyetograph for the Opononi storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Opononi rainfall storm event with the maximum rainfall depth occurred on 22/01/2011. It has a total rainfall depth of 153.0 mm and a duration of 31.67 hours. Examination of the figure shows that a significant part of the Opononi dimensionless hyetograph lies between the third quartile and the fourth quartile of Huff dimensionless hyetographs. For the Opononi rainfall storm event, around 40% of the total rainfall depth occurred in the third quartile of the storm duration.

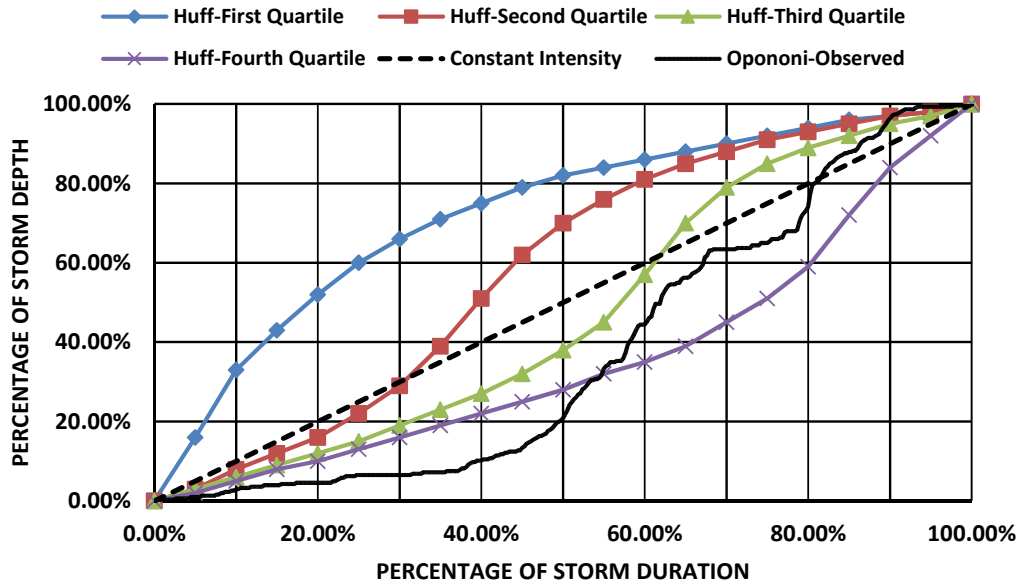


Figure 1-22: Dimensionless cumulative hyetograph for the Opononi storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.7 The Opouteke station hyetograph

Figure 1-23 shows the dimensionless cumulative hyetograph for the Opouteke storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Opouteke rainfall storm event with the maximum rainfall depth occurred on 22/01/2011. It has a total rainfall depth of 404.78 mm and a duration of 115.70 hours. Examination of the figure shows that the Opouteke dimensionless hyetograph lies between the first quartile and the fourth quartile of Huff dimensionless hyetographs. Overall, the constant dimensionless cumulative hyetograph can be regarded as providing a good approximation to the Opouteke dimensionless hyetograph. However, there are periods of intense rainfall around 30% of the storm duration.

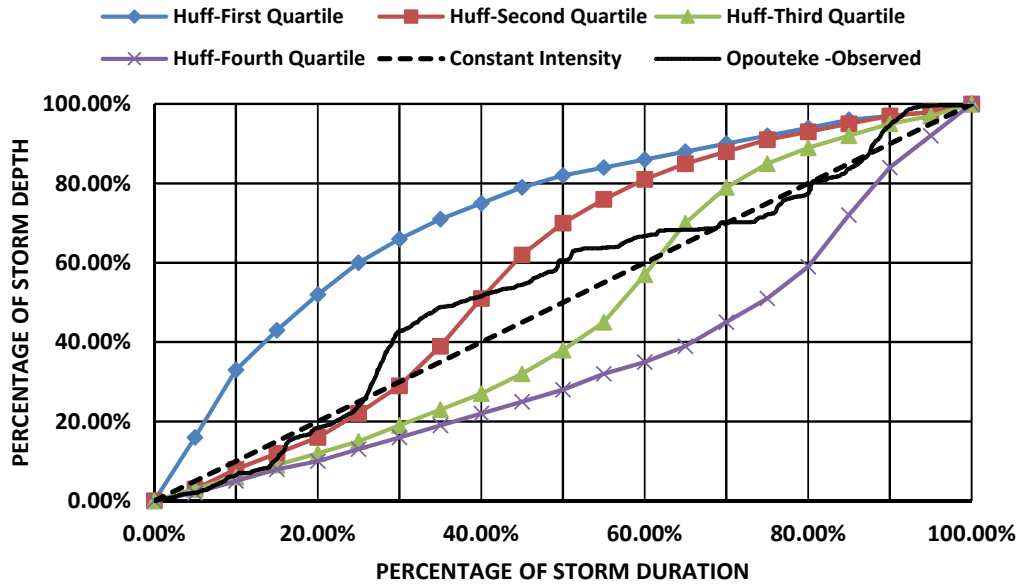


Figure 1-23: Dimensionless cumulative hyetograph for the Opouteke storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.8 The Rotokakahi station hyetograph

Figure 1-24 shows the dimensionless cumulative hyetograph for the Rotokakahi storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Rotokakahi rainfall storm event with the maximum rainfall depth occurred on 5/02/2007. It has a total rainfall depth of 161.5 mm and a duration of 52.00 hours. Examination of the figure shows that the Rotokakahi dimensionless hyetograph lies between the second quartile and the fourth quartile of Huff dimensionless hyetographs. Overall, the Huff third quartile dimensionless cumulative hyetograph can be regarded as providing a good approximation to the Rotokakahi dimensionless hyetograph. However, there are periods of intense rainfall around 30% and 50 % of the storm duration.

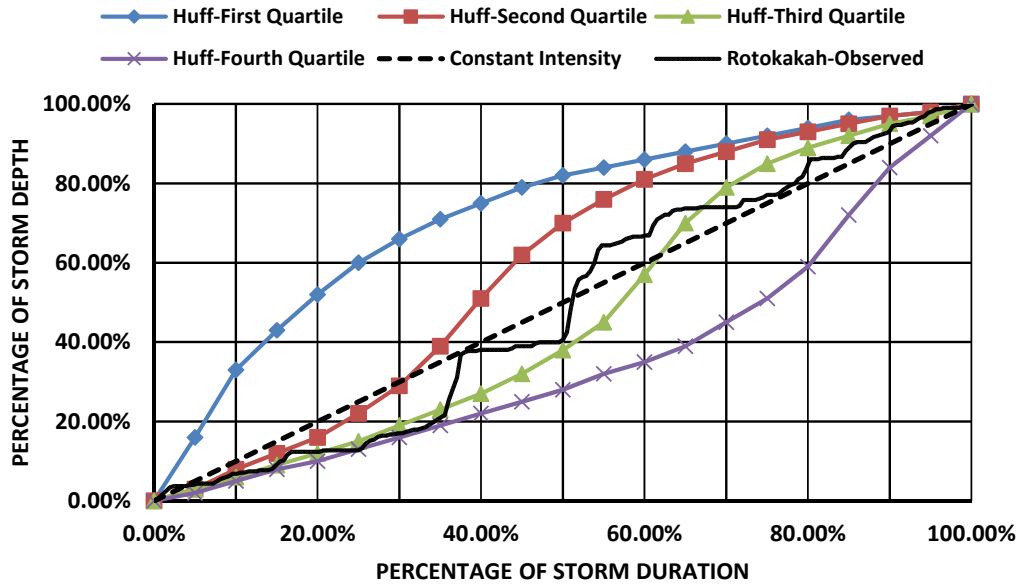


Figure 1-24: Dimensionless cumulative hyetograph for the Rotokakahi storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.9 The Takahue station hyetograph

Figure 1-25 shows the dimensionless cumulative hyetograph for the Takahue storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Takahue rainfall storm event with the maximum rainfall depth occurred on 5/02/2007. It has a total rainfall depth of 219 mm and a duration of 51.5 hours. Examination of the figure shows that most of the Takahue dimensionless hyetograph lies between the second quartile and the fourth quartile of Huff dimensionless hyetographs. In overall, the Huff third quartile dimensionless cumulative hyetograph can be regarded as providing a good approximation to the Takahue dimensionless hyetograph. However, there are periods of intense rainfall around 30% and 50 % of the storm duration.

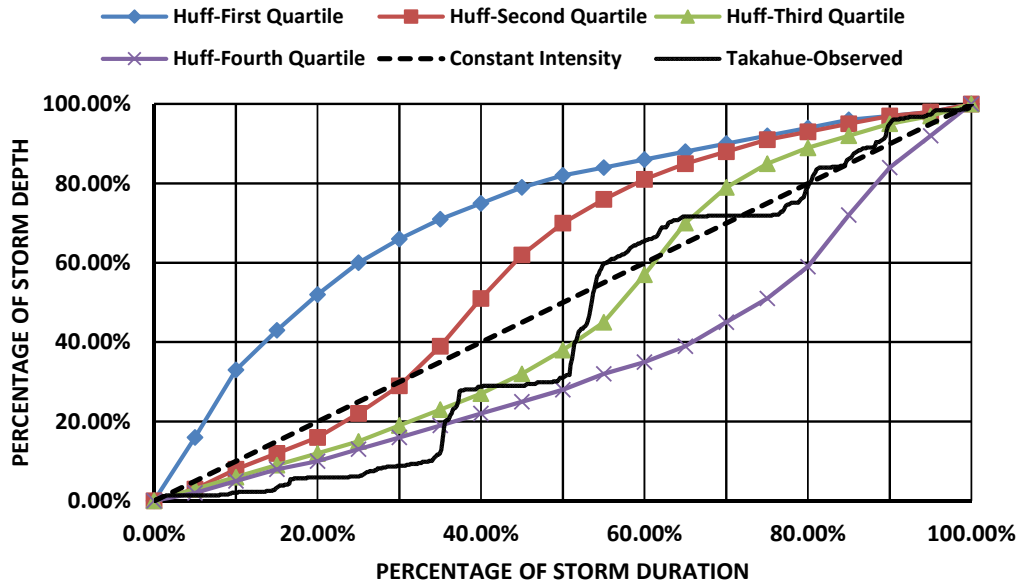


Figure 1-25: Dimensionless cumulative hyetograph for the Takahue storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.10 The Waihoihoi station hyetograph

Figure 1-26 shows the dimensionless cumulative hyetograph for the Waihoihoi storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Waihoihoi rainfall storm event with the maximum rainfall depth occurred on 29/06/1997. It has a total rainfall depth of 296.3 mm and a duration of 30.39 hours. Examination of the figure shows that most of the Waihoihoi dimensionless hyetograph lies to the left of the Huff fourth quartile dimensionless hyetographs. However, around 60% of the total rainfall depth occurred in the last 10% of the storm duration which would suggest a very intense rainfall occurring in the last 10% of the storm duration.

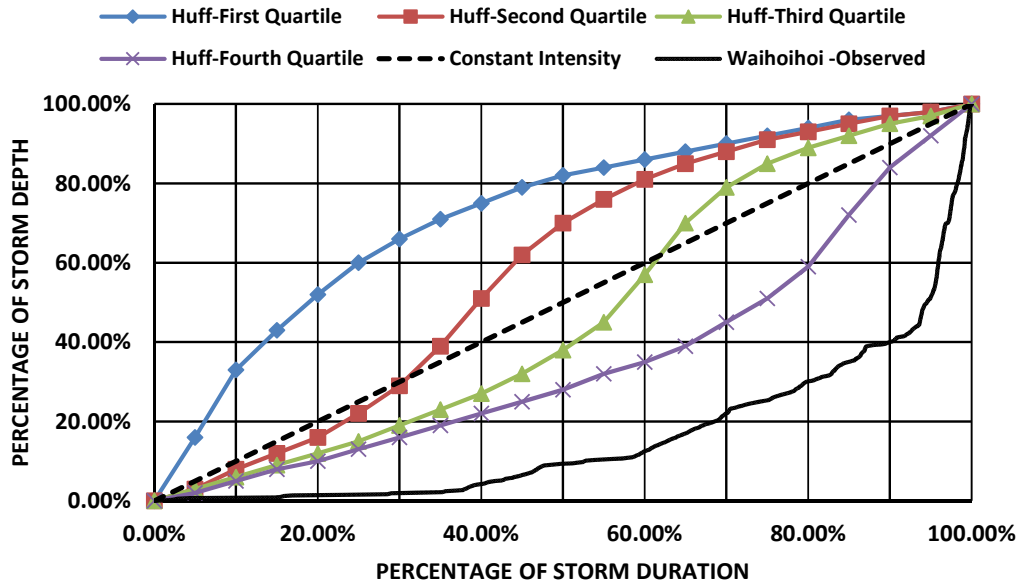


Figure 1-26: Dimensionless cumulative hyetograph for the Rotokakahi storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.5.11 The Waitangi station hyetograph

Figure 1-27 shows the dimensionless cumulative hyetograph for the Waitangi storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetograph. The Waitangi rainfall storm event with the maximum rainfall depth occurred on 27/03/2007. It has a total rainfall depth of 350.0 mm and a duration of 62.08 hours. For the Waitangi rainfall storm event examination of the figure reveals that around 80% the total rainfall depth occurred in the second half of the storm duration. The figure also shows that a significant portion of the total rainfall depth occurred in the third quartile.

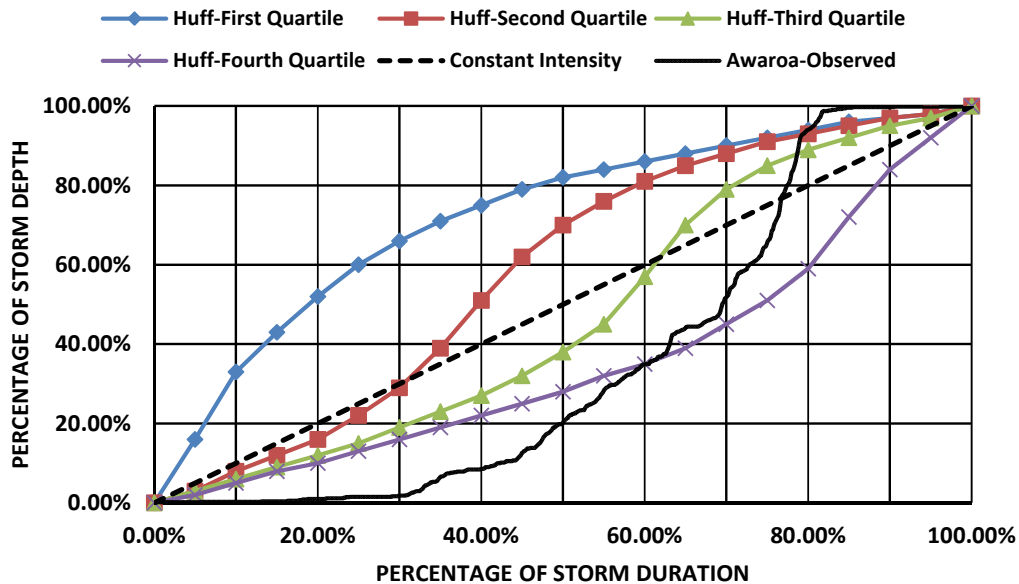


Figure 1-27: Dimensionless cumulative hyetograph for the Waitangi storm rainfall event with the maximum rainfall depth together with the average Huff and the constant intensity dimensionless cumulative hyetographs.

1.6 Summary of Design Storm profiles used Northland

This part of the report provides an overview of the design storm hyetographs used in the Northland region.

1.6.1 The MWH Design Storm Hyetograph

MWH (2010) conducted a rainfall assessment study in the Northland region to provide design rainfall estimates for all of the priority catchments to be used as input to rainfall-runoff models. As a part of the MWH study, a standard temporal profile for the design storm was developed. MWH (2010) noted that the “*standard temporal rainfall pattern was developed for the region based on the largest storms recorded at four intensity raingauges. The storms were extracted from the record at each gauge and normalised so that the peak rainfall depth and time to peak both equal 1.0*”. The standard temporal profile (i.e. the cumulative hyetograph) was obtained by averaging the normalized storm cumulative hyetographs. The MWH design storm is predominately used in rural catchments and Northland Regional Council (NRC) has applied different design storm durations based on catchment size. Figure 1-28 shows the MWH standard cumulative hyetograph together with other dimensionless

cumulative hyetographs. Examination of the figure shows the second half of the duration of the MWH standard cumulative hyetograph lies between the Huff third quartile and the fourth quartile dimensionless hyetographs.

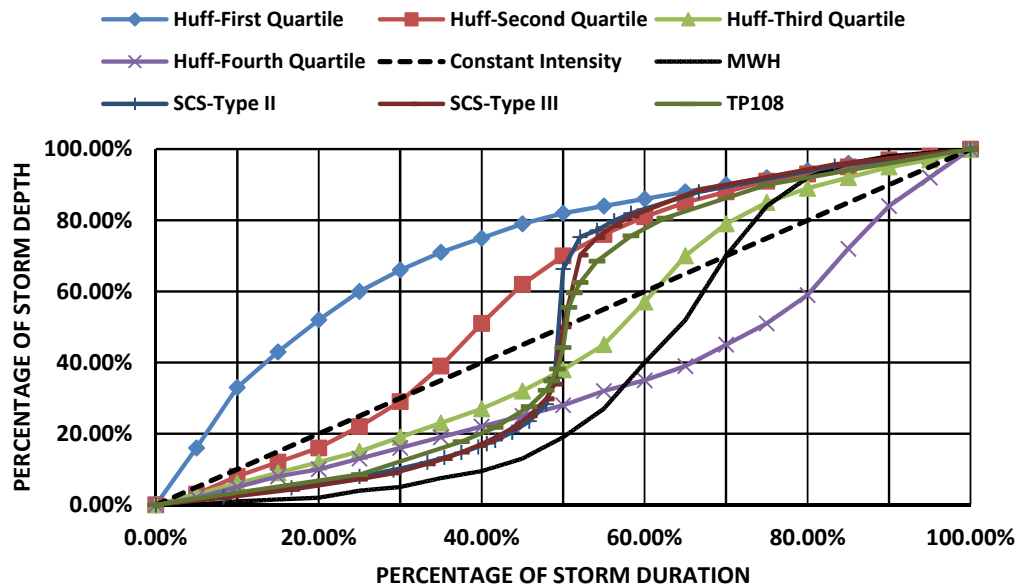


Figure 1-28 The MWH dimensionless cumulative hyetograph together with the average Huff, the constant intensity dimensionless, the SCS-Type II, the SCS-Type III and the TP108 dimensionless cumulative hyetographs.

1.1.1 The Northland Regional Council (NRC) Design Storm Hyetograph for small Urban Catchments

The Northland Regional Council modified the MWH design storm hyetograph so that it can be used in small urban catchments with storm water pipe networks. The main aim of the modification was to achieve higher peak rainfall intensity to align more closely with HIRDS data for short durations.

Figure 1-29 shows the NRC standard cumulative hyetograph together with the average Huff and the constant intensity dimensionless cumulative hyetograph. Examination of the figure shows around 80% of the total rainfall depth occurs in the second half of the storm duration. The figure also shows that the NRC standard cumulative hyetograph peaks around 70% of the storm duration. Similar to the MWH standard cumulative hyetograph, the NRC standard cumulative hyetograph lies between the Huff third quartile and the fourth quartile dimensionless hyetographs.

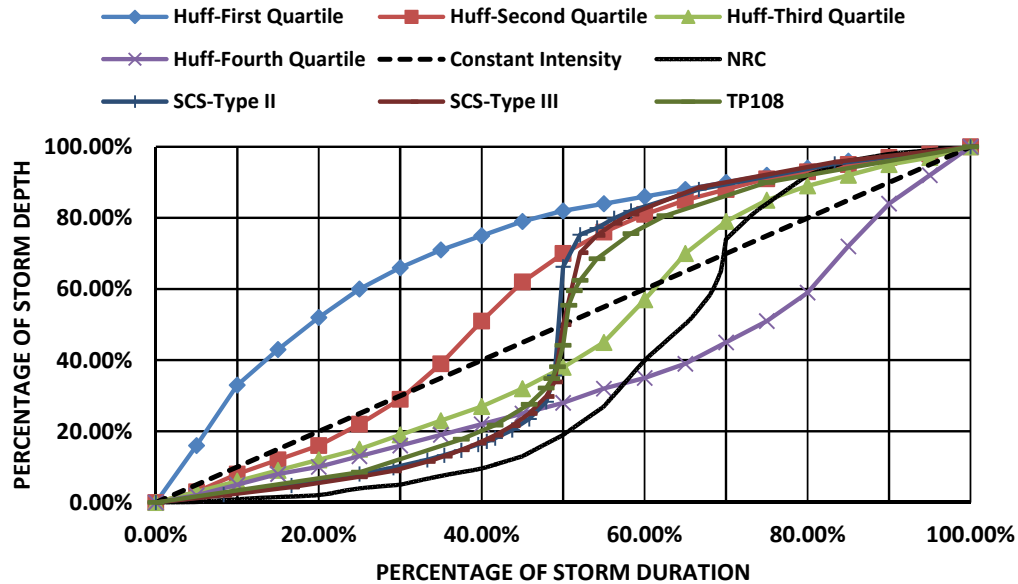


Figure 1-29 The NRC dimensionless cumulative hyetograph together with the average Huff, the constant intensity dimensionless, the SCS-Type II, the SCS-Type III and the TP108 dimensionless cumulative hyetographs.

1.6.2 The GHD Design Storm Hyetograph

The GHD design storm hyetograph is based on *“the assumption that 50% of the rainfall event will coincide with half of the storm duration”*. It was noted that *“this approach has been adopted to give the best available estimate of rainfall in the catchments rather than use the regional design rainfalls in the Council’s Engineering Standards & Guidelines”* (GHD, 2010). The storm duration adopted by GHD is 24 hours. This is line with the (SCS) and design storm hyetographs. It is also in line with the TP108 design hyetograph used in the Auckland region (ARC, 1999). GHD (2010) noted that *“the use of 24-hour storm duration is an accepted convention that allows the effects of all intensities and durations to be incorporated into an assessment of catchments that have varying times of concentration”*.

Figure 1-30 shows the GHD design storm hyetograph together with other the dimensionless cumulative hyetographs. Examination of the figure shows that the GHD design storm hyetograph is similar to the TP108 design storm. It is also close to the SCS-Type II and the SCS-Type III design storm hyetographs. The GHD design storm hyetograph lies between the Huff second quartile and the Huff fourth quartile dimensionless hyetographs.

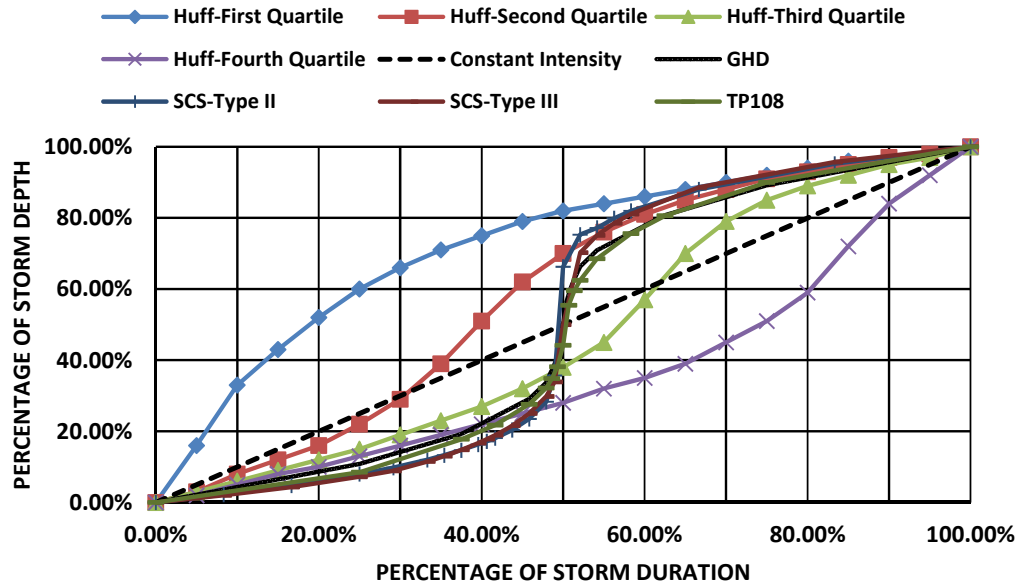


Figure 1-30 The GHD dimensionless cumulative hyetograph together with the average Huff, the constant intensity dimensionless, the SCS-Type II, the SCS-Type III and the TP108 dimensionless cumulative hyetographs.

1.6.3 The SCS-Type-1A Design Storm Hyetograph

The Whangarei District Council (WDC) recommended the use of the SCS Type-1A design storm hyetograph (WDC, 2010). WDC (2010) noted the use SCS Type 1A design storm hyetograph is acceptable in determining peak flow and run-off volumes. It has also noted that the TP108 design storm profile *“for estimation of pre-development peak run-off in Whangarei District is not considered appropriate”*. Furthermore, WDC (2010) noted that for the computation related to the estimation of treatment volumes, the TP108 type design storm hyetograph shall be used. Figure 1-31 shows The SCS Type-1A dimensionless cumulative hyetograph together with other the dimensionless cumulative hyetographs. Examination of the figure shows that SCS Type-1A hyetograph lies between the Huff second quartile and the Huff fourth quartile dimensionless hyetographs.

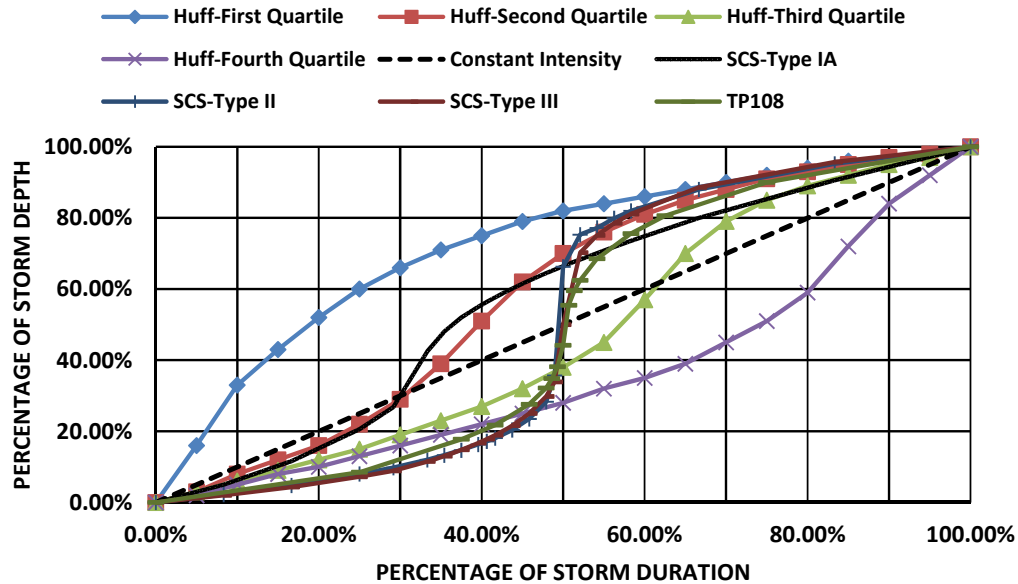


Figure 1-31: The SCS-Type-1A dimensionless cumulative hyetograph together with the average Huff and the constant intensity dimensionless, the SCS-Type II, the SCS-Type III and the TP108 dimensionless cumulative hyetographs.

1.7 Discussion about Design Storm profiles used Northland

In this part of the report, a review of the design storm Hyetographs used in the Northland region is given. It has been found there are four design storm hyetographs which are mainly used in the Northland region. These four hyetographs are:

- 1) The MWH design storm hyetograph.
- 2) The NRC design storm hyetograph for small urban Catchments- a modified form of the MWH design storm hyetograph.
- 3) The GHD design storm hyetograph.
- 4) The SCS-Type-1A design storm hyetograph.

A plot of these four design storm hyetographs is shown in Figure 1-32. Examination of the figure shows these four design storm hyetographs have different temporal profiles. In the case of the SCS-Type-1A design storm hyetograph, around 65% of the total rainfall storm depth coincides with the first half of the storm duration. In the case of the GHD design storm hyetograph, around 50% of the total rainfall storm depth coincides with half of the storm

duration. While in the case of the MWH and the NRC design storm hyetographs around 20% of the total rainfall storm depth coincides with half of the storm duration.

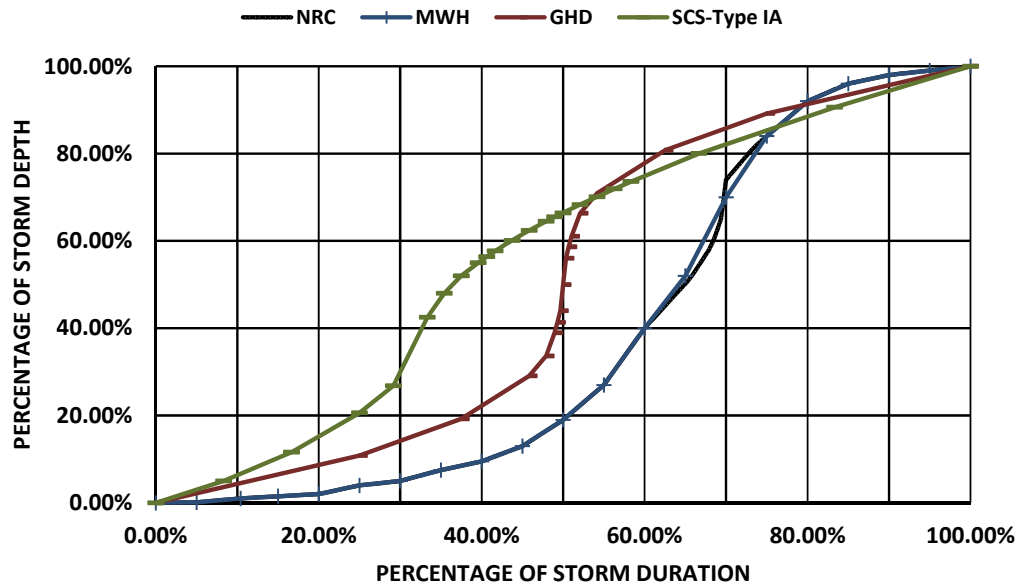


Figure 1-32: Dimensionless cumulative hyetographs used in the Northland region.

In terms of peak intensity, the GHD and the NRC design storm hyetographs have higher peak intensities than the SCS-Type-1A and the MWH design storm hyetographs. The peak intensity the SCS-Type-1A design storm hyetograph coincides with around 30% of storm duration. The peak intensity the GHD design storm hyetograph coincides with around 50% of storm duration. However, in the case of the MWH and the NRC design storm hyetograph the peak intensity coincides with around 70 % of storm duration.

The question which would arise in the context of the Northland is which design storm design storm hyetograph should be used in practice in conjunction with an event-based rainfall-runoff flood estimation. In broad terms, a typical event-based rainfall-runoff flood estimation procedure would normally have a number of design hyetographs to be used depending on the catchment type and the engineering application to be undertaken. The hyetograph may not necessarily resemble the actual observed temporal storm patterns. In the development of the flood estimation procedure, the rainfall-runoff model is calibrated to produce a flood hydrograph with a given return period (T) using the design hyetograph. Thus,

there is no guarantee that the use of other hyetographs in conjunction with the rainfall-runoff model would yield the T-year flood hydrograph (Faulkner, 1999).

In the context of the Northland region, the four design storm hyetographs have different temporal profiles, their use in conjunction with an event rainfall-runoff model with fixed parameters values would yield different design flood hydrographs. However, it is theoretically possible that these design storm hyetographs may yield comparable flood estimates if individual calibration of the rainfall-runoff model is conducted for each of these four design storm hyetographs.

The use of the MWH and the NRC design storm hyetographs in flood estimation in the Northland region is theoretically sound. The MWH design storm hyetograph is used in flood estimation in rural catchments. However, the NRC design storm hyetograph-(a modified form of the MWH design storm hyetograph) with higher peak intensity than the MWH design storm hyetograph is used for small urban catchments. The GHD design storm hyetograph is very peaky and hence it would be most suitable for estimation of runoff peak from small urban catchments. The SCS-Type-1A design storm hyetograph used by WDC is the least intense among the SCS design storms. In the context of the Northland region, the SCS-Type-1A design storm hyetograph would be suitable for winter flooding conditions caused by low intensity rainfall storm events with long duration.

The adoption of different design storm hyetographs for rural and urban catchments in the Northland region is in line with the UK flood estimation practice. In the UK, two design storm profiles are recommended, namely, the 75 % winter design hyetograph and the 50 % summer design hyetograph (see Figure 1-33). The 75 % winter design hyetograph is more peaked than the 75 % of the winter storm hyetographs while the 50 % summer design hyetograph is more peaked than 50 % of the summer storm hyetographs. The 75 % winter storm hyetographs is used for flood estimation in rural catchments. However, the peakier 50 % summer storm hyetograph, due to convective storms, is used in urban catchments. These profiles are recommended for use for durations up to several days (Faulkner, 1999).

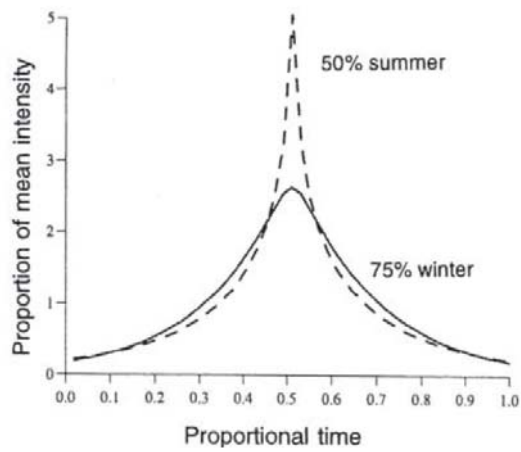


Figure 4.4 Design rainfall profiles for summer and winter, drawn as normalised hyetographs

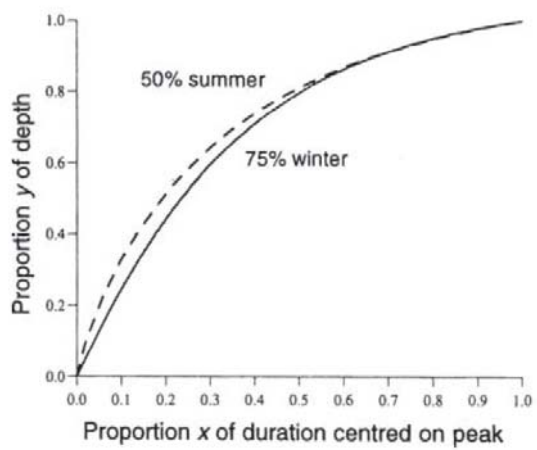


Figure 4.5 Design rainfall profiles, drawn as cumulative proportions of depth, centred on peak

Figure 1-33: The UK FEH design hyetographs (Faulkner, 1999).

2. HIRDS: Comparison between Version 2 and Version 3

2.1 Introduction

This part of the report provides an overview of the High Intensity Rainfall Design System (HIRDS) and its development. HIRDS was developed by the National Institute of Water and Atmospheric Research (NIWA). This part will provide a comparison between the results of HIRDS version 3 and HIRDS version 2 when used in the Northland region.

2.2 NIWA High Intensity Rainfall Design System (HIRDS) Version 3

HIRDS is a computer based system which enables the estimation of both the intensity-duration-frequency (IDF) curves and the depth-duration-frequency (DDF) curves at any location in New Zealand. The latest version 3 of HIRDS can be operated via a user friendly web interface accessible through the following website: <http://hirds.niwa.co.nz/> (Figure 2-1). However, HIRDS version 2 can be operated by running a software package installed on a PC. In principal, HIRSDS version 2 and version 3 have the same underlying theoretical background. In order to estimate the DDF and IDF curves, the user needs to supply information about the coordinates of the location. Once the coordinates are entered in the appropriate input entry boxes in the website by the user, HIRDS will automatically generate a table of DDF and IDF curves together with other supplementary information for the desired location. HIRDS can also provide adjusted DDF and IDF curves to take into account the envisaged impacts of climate change. HIRDS v3 provides DDF and IDF curves at 10 different rainfall durations (10, 20, 30 and 60 minutes and 2, 6, 12, 24, 72 and 48 hours) and 11 different design return periods/average recurrence intervals (1.58, 2, 5, 10, 20, 30, 40, 50, 60, 80 and 100 year). The HIRDS computer engine was developed using a very comprehensive rainfall data set covering the time period up to the end of 2005. The rainfall data used in developing HIRDS has been obtained from NIWA national significant databases and from the regional council archives. Thomson (2010) noted that a total of 3213 sites were available for HIRDS development. However, around 68% of these sites were manual rainfall gauges where the rainfall is measured from 9 am to 9 am in the subsequent day. Thomson (2010) also noted

that data from close stations located within 500 m from each other were merged to form a composite series which reduced the total number of sites available for the development of HIRDS by around 14% and hence 2697 sites were used in the HIRDS development. However, the specific details of how this composite series is derived were not discussed in great details in Thomson (2010). Furthermore, the restricted daily rainfall from manually read rainfall gauging stations were converted to unrestricted 24, 48 and 72-hours rainfall values using adjustment factors of 1.14, 1.07 and 1.04, respectively. These adjustment factors values are very similar with those endorsed by WMO (1983).

The development of HIRDS version 3 and version 2 is based on the regional frequency index approach which uses the Annual Maximum (AM) model. In the development of HIRDS, no censoring of rainfall outliers was undertaken. Based on the work of Cunnane (1989), Thomson (2010) noted that outliers will only have small effects on the overall results if efficient parameter estimation methods such as the maximum likelihood and L-moments are used to fit extreme value distribution to the data. The AM values were extracted from the site archived records where there were at least 6 annual maximum values and from years having at least 10 months of data. However, the definition of what constitutes a year is not provided in Thomson (2010).

HIRDS use the regional frequency index approach for deriving the DDF curves, and uses the median of the AM value as the index factor. The median AM value has an annual non-exceedance probability of 0.5 corresponding to a 2-year return period. When the record length of the site is greater than 20 years the median AM was taken as the 50th percentile of the AM ranked values. However, when the record length of the site is between 6 to 20 years the median AM was taken as the 50th percentile in the ranked annual exceedance series. This series has on average one extreme event per year and it is regarded a special limiting case of the more general peak-over-threshold (POT) series. For each of the 10 rainfall durations used by HIRDS, a thin-plate spline was fitted to the corresponding median AM surface. The fitted surface was mapped into a 2 km by 2 km digital elevation model. The mapped surface is subsequently used by HIRDS to provide an estimate for median AM value (index factor) at any given location in New Zealand.

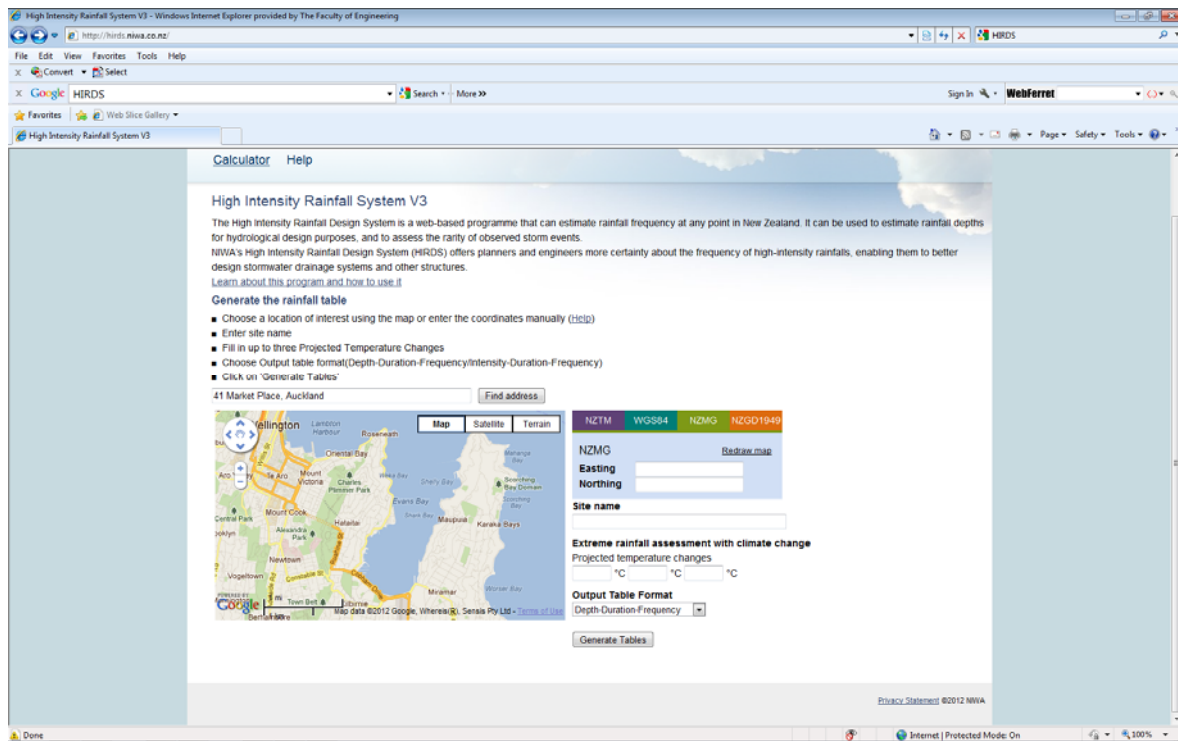


Figure 2-1: Snap shot of HIRDS website.

In HIRDS regionalization approach, the pooling group/region is tailor made for the site. The pooling group for a gauged site is determined using the region of the influence approach. In principle, the region of influence approach uses a similarity index to determine the members of the pooling group. Further details on the region of the influence approach can be found in Burn (1997), Robson and Reed (1999) and Thomson (2010). Additional criteria were also used in forming the pooling group. For sub-daily durations where there are few automatic rainfall gauging stations, the pooling group is required to have at least 15 sites with an equivalent station year equal to 4 times the target return period. For other non-sub-daily durations, the pooling group is required to have at least 15 sites with an equivalent station year equal to 5 times the target return period station. Once pooling group is formed for a chosen gauged site, the regional weighted L-moments are calculated where the weights reflect both the record of the pooling group members and their similarity to the chosen gauged site. Similar to the median AM values thin-plate splines were fitted to the corresponding L-moment surfaces and the fitted surfaces were consequently mapped into a 2 km by 2 km digital elevation model. The L-moment mapped surfaces are subsequently used by HIRDS to provide an estimate for the L-moments at any given location in New Zealand.

HIRDS uses the GEV distribution as a default for describing the AM values for the different durations. Thomson (2010) noted that the GEV distribution was selected for use in HIRDS as it has provided the best fit in most of the sites in a comparative study which considered two other rival distributions, namely, the Generalized Logistic (GL) distribution and the Gumbel (Extreme Value type I (EVI)) distribution. For a given location, the GEV distribution parameters are estimated by the methods of L-moments utilizing the information obtained from the thin-plate mapped surfaces of the mapped index factors and L-moments.

Thomson (2010) noted that the derived DDF curves can be internally inconsistent and possible contradictions can arise when durations are treated separately. HIRDS uses an eight coefficient multi-threshold non-linear model for smoothing the DDF curves. Further details on this smoothing procedure can be found in Faulkner (1999) and Thomson (2010).

2.3 Comparison between HIRDS Version 3 and Version 2

In order to compare the results of HIRDS version 3 (HIRDSV3) and HIRDS version 2 (HIRDSV2) in the Northland region, a grid of 5km x 5 km in ArcMap using ET Geo Wizards is mapped over the Northland region. Then this grid is clipped on the project boundary area and a total of 535 points were obtained in the project area as shown in Figure 2-2.

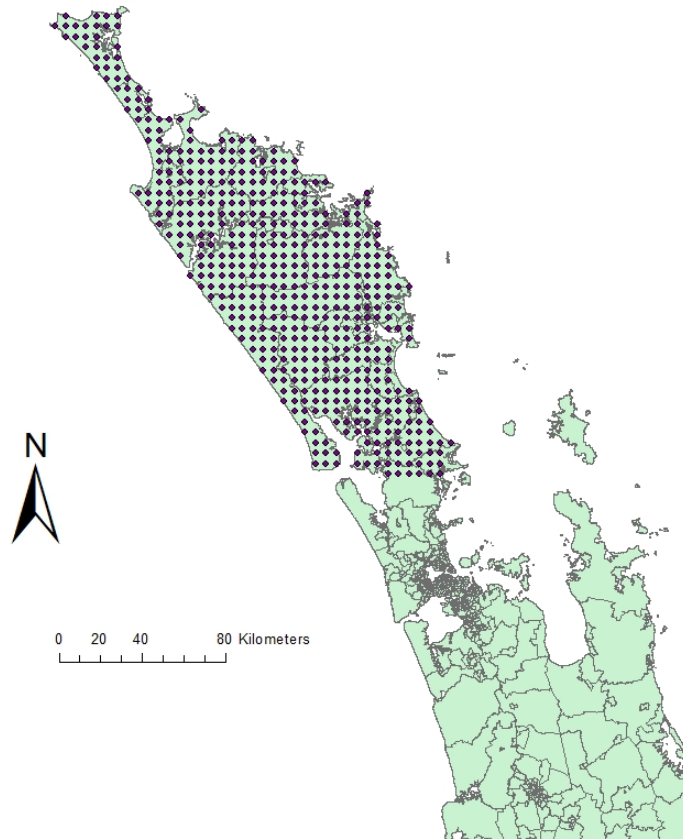


Figure 2-2: Location of Grid points on the Map

The location of these points in terms of longitude and latitude were determined next and the data is retrieved using HIRDS V2 and HIRDS V3 for all these 535 selected points. The data retrieved includes the rainfall depths (mm) for different duration (10 min, 20 min, 30 min, 1hr, 2hr, 6hr, 12hr, 24hr, 48hr and 72hr) with different annual recurrence intervals (ARI). The ARI for HIRDSV2 includes 2, 10, 20, 30, 40, 50, 60, 70, 80, 100, 125 and 150 years while ARI for HIRDSV3 includes 1.58, 2, 5, 10, 20, 30, 40, 50, 60, 70, 80 and 100 years. Based on the available data, the followings are considered for comparing the results of HIRDSV2 and HIRDSV3:

- 30 min duration with ARI of 10 years
- 30 min duration with ARI of 100 years
- 2hr duration with ARI of 10 years
- 2hr duration with ARI of 100 years

- 24hr duration with ARI of 10 years
- 24hr duration with ARI of 100 years

In order to compare the results, first of all Kriging Interpolation method was used to interpolate the rainfall depth values for all durations and the ARI values used in this study. The percentage difference between HIRDSV3 and HIRDSV2 is subsequently calculated and the results are shown in Figures 2-3 to 2-5.

In the case of the 30 min 10-year ARI, Figure 2-3 shows the percentage difference values vary between +14.9% (overestimation – HIRDS v3 higher than v2) to -11.6% (underestimation – HIRDS v3 lower than v2). However, in the case of the 30min 100 year ARI, the percentage difference values vary between +18.3% to -18.9%. Furthermore, in most of the study area HIRDSV3 rainfall values are greater than those obtained by HIRDSV2.

In the case of the 2hr 10year ARI, inspection of Figure 2-4 indicates that the percentage difference values vary between +36.3% (Overestimation) to -7.02%. However, in the case of the of the 2hr 100year ARI the percentage difference values vary between +26% to -5.94%. Interestingly, there is a localised area of high positive values immediately South of the Hokianga harbour. The reasons for this have not been investigated as part of this study.

In the case of the 24hr 10year ARI, examination of Figure 2-5 reveals that the percentage difference values vary between +57.9% to -4.93%. However, in the case of the 24hr 100 year ARI the percentage difference values vary between +48.5% to -15.1%. In the upper north part of Northland, HIRDSV3 rainfall values are generally less than those obtained by HIRDSV2.

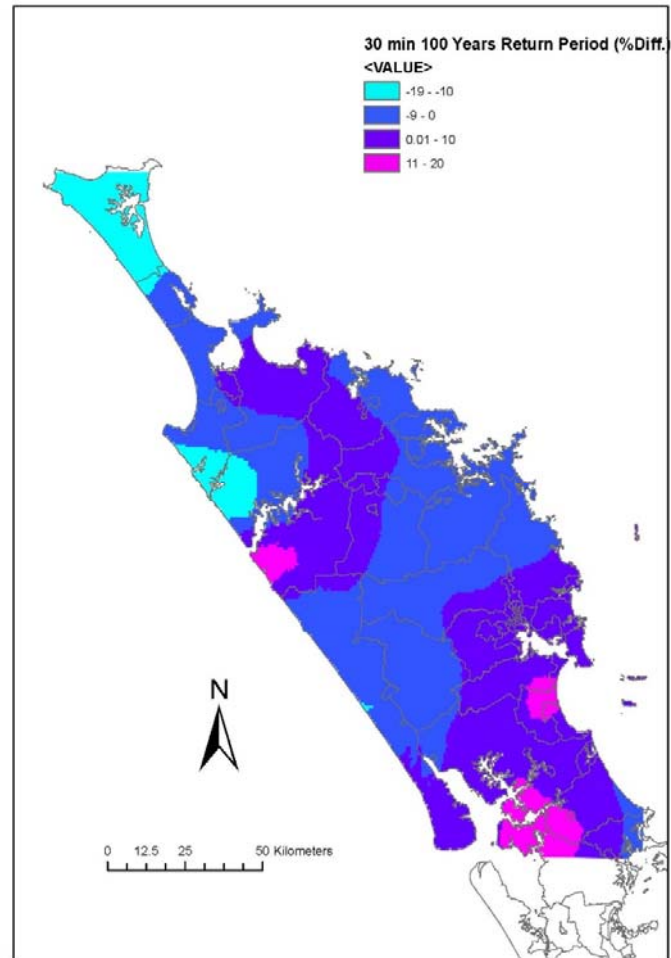
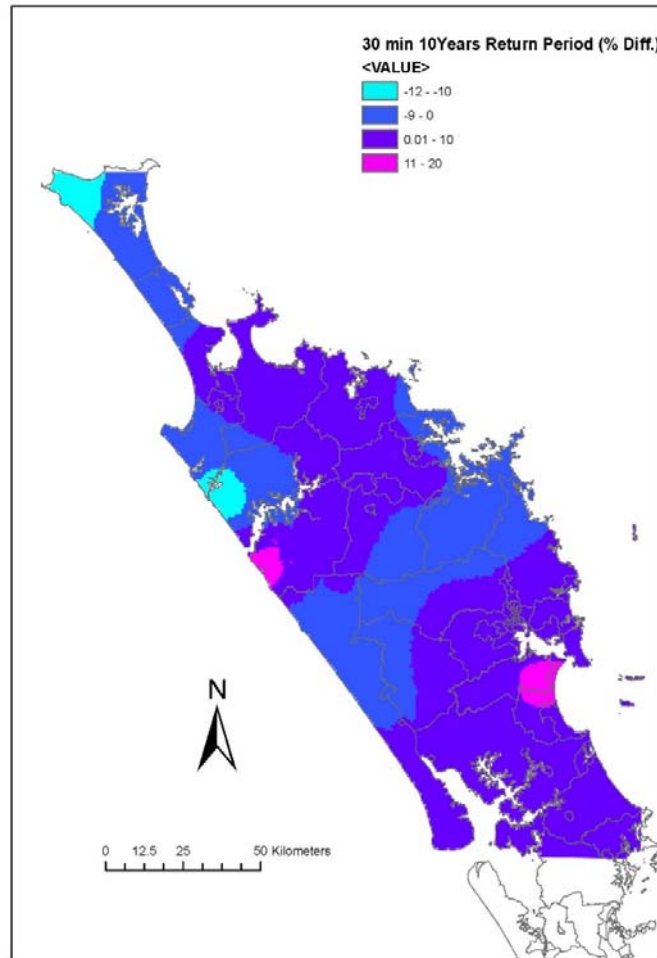


Figure 2-3: Percentage differences between HIRDSV3 and HIRDSV2 (a) 30 min 10 year ARI (b) 30 min 100 year ARI.

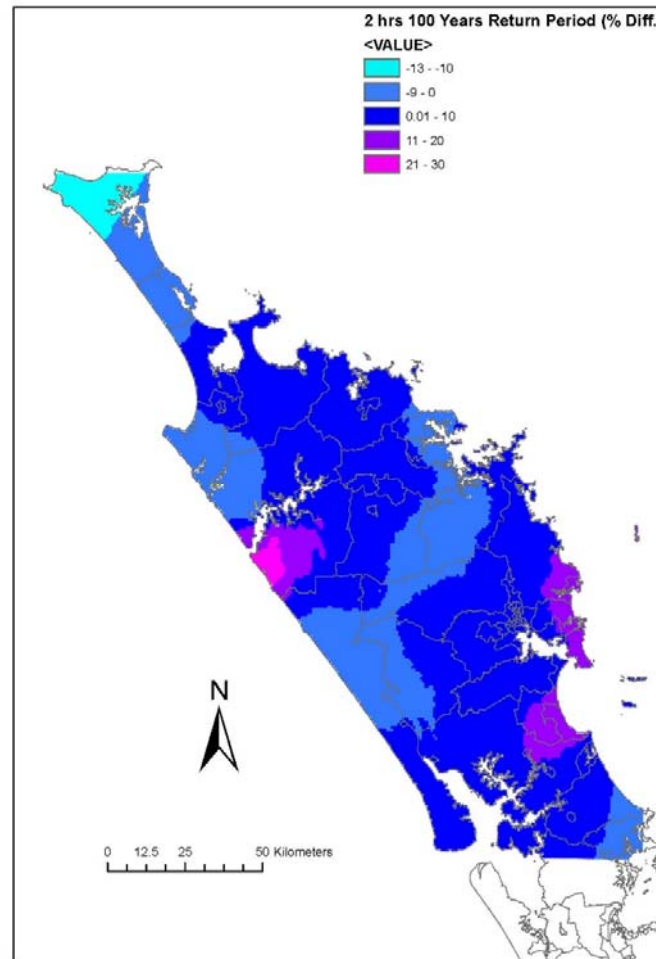
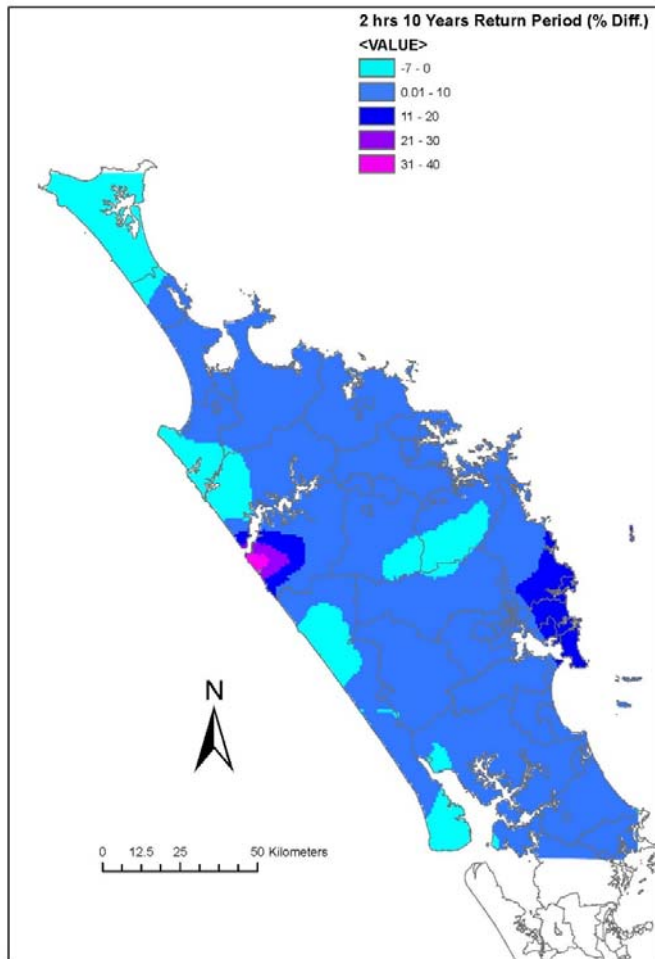


Figure 2-4: Percentages difference between HIRDSV3 and HIRDSV2 (a) 2hr 10 year ARI (b) 2hr 100 year ARI

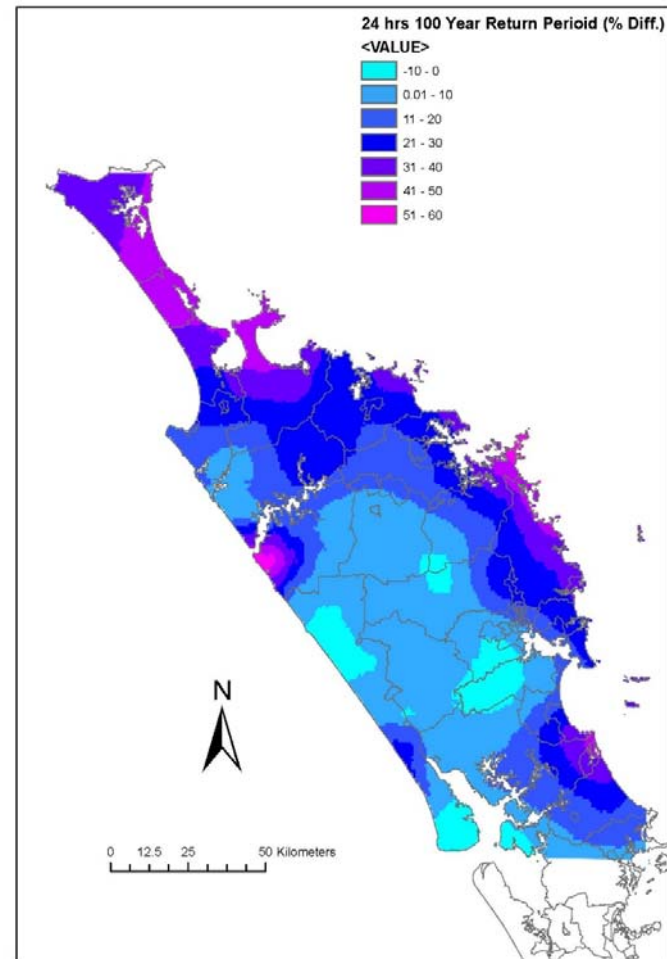
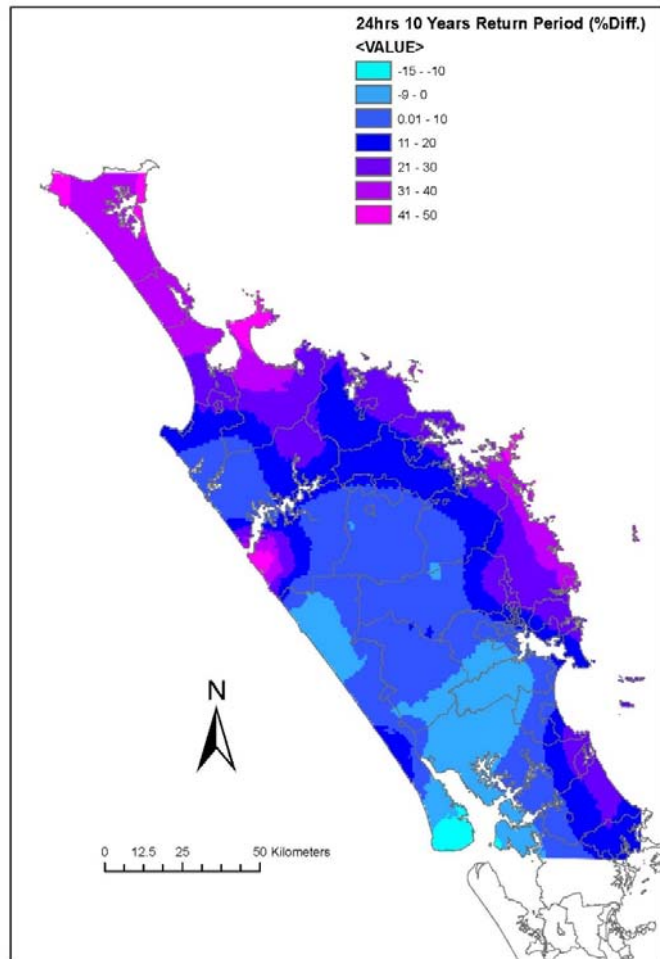


Figure 2-5: Percentages difference between HIRDSV3 and HIRDSV2 (a) 24hr 10 year ARI b) 24hr 100 year ARI

Summary and Conclusions

In this report, the temporal rainfall storm event properties in the Northland region are examined. The study of the temporal properties of rainfall storm events requires the identification of these events from a continuous rainfall record. The identification of a rainfall event from continuous rainfall records is dependent on the inter-event time definition (IETD). The IETD can be formally defined as the minimum time without rainfall between two successive rainfall periods.

The study found an appropriate IETD value for the Northland region is 6 hours. The present study examined the dimensionless hyetographs for a number of selected extreme rainfall storm events obtained from the 11 selected rainfall gauging stations. One rainfall event per station is selected. The selected event from each station is that having the maximum rainfall storm depth. The study also found that the occurrence of these extreme maximum rainfall storm events may be linked to El Niño and La Niña events. These rainfall storm events are generally found to have long durations. The dimensionless hyetographs of these extreme events are found to be quite variable with no common structure. The dimensionless hyetographs compare very well with those obtained by Huff (1967, 1990) in the Chicago urban area in the USA. In future studies, consideration should be given to the study of the dimensionless hyetographs of rainfall storm events of shorter durations as well as their implication in the design and the operation of storm-water infrastructure.

In this report, a review of the design storm Hyetographs used in the Northland region is given. It has been found there are four design storm hyetographs which are mainly used in the Northland region. These four hyetographs are:

- 1) The MWH design storm hyetograph.
- 2) The NRC design storm hyetograph for small urban Catchments- a modified form of the MWH design storm hyetograph.
- 3) The GHD design storm hyetograph.
- 4) The SCS-Type-1A design storm hyetograph.

These four design storm hyetographs have different temporal profiles. They also have different peak intensity and time to peak. In terms of peak intensity, the GHD and the NRC

design storm hyetographs have higher peak intensities than the SCS-Type-1A and the MWH design storm hyetographs.

In flood estimation practice, the use of a design storm hyetograph with an event based rainfall-runoff requires calibration. Once the flood estimation procedure is calibrated it is a complete package. This implies that the use of design storm hyetographs other than those used in the calibration of the flood estimation procedure may produce unreliable results. In the Northland region, it is a normal practice that the flood estimation procedures are regularly calibrated (Kay, pers. comm. 2016).

The approach used by NRC involving the use of the MWH and the NRC design storm hyetographs in flood estimation in the Northland region is theoretically sound. The MWH design storm hyetograph is used in flood estimation in rural catchments. However, the NRC design storm hyetograph-(a modified form of the MWH design storm hyetograph) with higher peak intensity than the MWH design storm hyetograph is used for small urban catchments. The adoption of different design storm hyetographs for rural and urban catchments in the Northland region is in line with the UK flood estimation practice. In the author's opinion, the use of the MWH and the NRC design storm hyetographs in the Northland region should be also supported. The GHD design storm hyetograph is very peaky and hence it would be most suitable for estimation of runoff peak from small urban catchments. The SCS-Type-1A design storm hyetograph used by WDC is the least intense among the SCS design storms. In the context of the Northland region, the SCS-Type-1A design storm hyetograph would be suitable for winter flooding conditions caused by low intensity rainfall storm events with long duration.

This report has explored a number of issues related to rainfall storm events in the Northland region. A comparative study between the results of HIRDS version 3 and HIRDS version 2 is conducted in the present study. It has been found that there are significant differences between the results of HIRDS version 3 and HIRDS version 2. Significant differences are found in the case of higher return periods, especially the 100yr ARI, with significantly higher rainfall depths in HIRDS v3.

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