EXTREME RAINFALL EVENTS: TOO SMALL AND TOO FEW?

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ABSTRACT

As a local authority North Shore City Council needs to know how frequently extreme events are likely to occur within the city.

Extreme events described by Average Recurrence Interval are useful for specific locations within a city but not for the management of a city, region or country.

This paper contains an assessment of NSCC's rain gauge network and details the number and severity of recorded rainfall events across the city.

Current extreme event methodology underestimates the frequency/depth of extreme rainfall events of less than 5 years Average Recurrence Interval. In many instances the period of recorded data is sufficient to determine the magnitude of extreme events without resorting to extreme value theory.

Rainfall depths for frequent extreme events are underestimated by up to 20% using standard methods.

Coupled with underestimation of event size is the misunderstanding that Average Recurrence Interval can be applied to a large geographic area. From North Shore records it is apparent 2 year ARI storms occur within North Shore at least twice a year – four times more frequently than most people expect. Areal extents of an extreme event can vary from <1% up to 60% of the city area.

This paper details how often North Shore City Council and cities in general should expect extreme storm events to occur.

KEYWORDS

Average Recurrence Interval, Extreme Events, Flood Frequency, North Shore City Council, Rainfall, Areal Extents, Annual Maxima, Partial Series.

1 INTRODUCTION

1.1 STUDY OVERVIEW

As a local authority North Shore City Council needs to know how frequently extreme events are likely to occur. Using different calculation methods gives different results. This paper is an attempt to document the differences between approaches, recommend the best approach, and determine the number of extreme events North Shore City is likely to have per annum.

1.2 STUDY OBJECTIVE

There is a perception that extreme events described by annual recurrence interval apply to whole cities and regions. The objective of this study was to calculate the number of extreme events North Shore City experiences per annum to change this perception.

A secondary objective was to compare the usefulness of Annual Maxima Series and Partial Series for calculation of extreme events.

1.3 STUDY SCOPE

The study uses rainfall data from within North Shore City and rainfall data from long term rainfall sites close to North Shore City to meet the study objectives.

The data from the rain gauges was assessed using

- Annual Maxima and extreme value theory to determine ARI's for each event.
- Partial Series analysis to determine ARI's for each event

1.4 ASSUMPTIONS AND LIMITATIONS

The major assumption in the work undertaken is the ARI of the rainfall event is the same as the ARI of the resultant runoff event.

The EV1 distribution was used when calculating the ARI of the Annual Maxima series.

To calculate ARI from the partial series the Australian Rainfall and Runoff equation was used. The equation for ARI calculation is a simple relationship between the length of record and the rank of the event.

$$ARI = \frac{n+1-2b}{m-b}$$

where

$n =$ Length of record in years

$m =$ rank of the record being assessed

$b =$ fitting parameter – in this study a value of 0.4 was used. 0.4 is the value used in Australian Rainfall and Runoff. 0.44 is the value used by Gringorten which fits the closest with the EV1 distribution (Chow, 1988)

There are eight rain gauge locations within North Shore City. The assessment in this study was based on these eight gauges. It is likely Extreme rainfall events (greater than or equal to a two year ARI) occur within North Shore City which are not recorded by any of the existing gauges. The analysis undertaken probably underestimates the number of extreme events likely to occur in North Shore City per annum due to the existing number of rain gauges.

Just because an extreme event occurs does not mean there will necessarily be any issues requiring council response. Events smaller than a 2 year ARI are not considered to cause issues for residents.

1.5 BACKGROUND

1.5.1 NSCC CATCHMENT DESCRIPTION

North Shore City covers an area of 130km^2; the city has 46 Stormwater catchments. The largest catchment in the city is 1300 Ha. The catchments are mainly drained by streams and are predominantly residential in land use. North Shore City Council has eight permanent rain gauge sites the site with the longest record has over 35 years of data. All 8 rain gauges have records longer than 10 years.

This paper is an attempt to quantify how often North Shore City Council is likely to have an extreme rainfall event occur somewhere within the councils' jurisdiction. The paper also provides some detail on the use of partial series analysis compared to Annual Maxima analysis for understanding of storm events. Some insight is given as to the areal extents of extreme events for different duration storms.

Unlike other urban areas in New Zealand North Shore does not have a major watercourse running through the city. Flooding which occurs in North Shore City is not due to a river level breaking its banks due to rainfall which has occurred outside of the city. Any flooding in North Shore is due to rain which has fallen over North Shore City.

Flooding which affects residents in North Shore can be caused by short intense rainfall events or longer less intense events. Short intense events cause flooding from overland flow, longer duration events cause flooding from backwater.

NSCC has a Level of Service (LOS) for pipes of nominally 10 years and a LOS for flooding of habitable floors of nominally 100 years. Events smaller than 10 or 100 year events do cause flooding issues for NSCC residents. Any extreme event (heavy rainfall) can cause resident issues. Flooding can be caused by blockage/partial blockage of the pipe network, under design of the stormwater reticulation, non compliant buildings, lack of private or public maintenance of pipes and overland flow paths.

North Shore floods are not dominated by large river flows; North Shore is made up of many catchments. If North Shore did have a large river which dominated the frequency of flooding for the city, the flow record would be the best source of data with regard to recurrence interval. Because of the topology of North Shore the best source of data is rainfall data. As NSSC consists of relatively small catchments, it is assumed the ARI of rainfall events will be similar to the ARI of flood events.

1.5.2 ARI'S AND WHAT THEY MEAN AT A CITY LEVEL

The use of Average Recurrence Intervals (ARI's) to describe extreme events has become widespread. Often in the media a 100 year event is reported to have occurred somewhere in the country. Engineers and Planners should be clear on what a 100yr ARI event means.

There is a common misconception introduced by media and reinforced by some engineers that a 100yr event is an event which occurs to a city once every 100 years. The number of 100 year events a city receives every 100 years is a function of the size of the city, the topology, and the type of rainfall events the city receives.

Another misconception is that when a 100year ARI event occurs it causes the same amount of damage regardless of where it falls. Each location in a catchment has a critical duration rainfall event which will cause the most significant impact.

Any individual geospatial location has a 1% chance of a 100yr ARI event occurring per annum. The probability of experiencing the event holds for the property, perhaps the neighborhood, maybe the catchment but probably not the entire city.

A city typically covers a wide geographic area with a range of topography. Within the city it is likely a number of unique areas exist independently of each other with regard to rainfall.

Rainfall is highly spatial and temporal, each storm is unique with regard to the area it covers, the speed at which it moves and the amount of rain which falls.

Councils should not expect to receive 1*100yr event every hundred years, or 1*10 yr event every 10 years, nor even 1*2yr event every 2 years. The number of extreme events a city should expect to occur within the city boundaries can only be determined by assessing rainfall data recorded within the city and through assessing reported flooding events.

North Shore City Council's network of 8 rain gauges has been assessed to determine the frequency at which residents in the city are affected by extreme rainfall events.

1.5.3 WHAT CAUSES FLOODING

Flooding is typically caused by large rainfall events. Small to medium sized rainfall events do not generally cause issues to North Shore City residents. Rainfall events with an ARI of 2 years and greater are recorded as having caused flooding of residential buildings.

The Level of Service for stormwater reticulation in residential areas is nominally a 10 Year ARI.

A level of service up to the 10 year ARI Assumes:

- catchpits are not blocked,
- roads have sufficient capacity,
- vehicle crossings are compliant,
- private and public stormwater reticulation is maintained,
- all reticulation was designed to the current LOS,
- impermeable areas when added are correctly catered for by the LOS,
- a reticulated system exists,
- overland flow paths are unobstructed and correctly sized

If all the above were true residents should not get flooded in events less that the 10 Year ARI. Unfortunately the above is not true and residents do experience flooding in events smaller than the 10 year ARI event.

2 STUDY METHODOLOGY – EXTREME RAIN EVENT IDENTIFICATION

2.1 OVERVIEW

2.2 AVAILABLE RAINFALL DATA

Eight rain gauges were used from within North Shore City. The rain gauges used are NSCC01, NSCC02, NSCC03, NSCC04, NSCC05, NSCC06, NSCC07, NSCC08. The rain gauge with the shortest record is NSCC06 with 10.5 years data, the rain gauge with the longest record is gauge NSCC07 with 37 years of data.

Two rain gauges were used from outside of North Shore City. The rain gauges used were Whenuapai and Albert Park. The Whenuapai gauge has the longest period of record, 64 years. The Albert park gauge has 45 years of data. Daily data is available for the Albert Park gauge for a much longer period.

2.3 EXTREME RAIN EVENT DEFINITION

In this paper an extreme event has been defined as any event greater than or equal to a two year ARI event. The actual size of the two year event varies for every duration and for every gauge. The size of the two year event also changes depending on whether Annual Maxima data is being used with extreme value theory or whether a Partial Series analysis has been undertaken.

2.4 RAIN EVENT INDEPENDENCE DEFINITION

A rain event was considered to be independent if no other events occurred at any of the other gauge locations that were greater than or equal to a 2 year ARI event. If a coincident event did occur at another gauge but was smaller than an extreme event the event was considered to be independent.

2.5 PARTIAL SERIES – RAIN EVENT ARI DEVELOPMENT

Five minute rainfall data was used from the ten rain gauges discussed above. The data was extracted based on a twelve hour dry inter event period. Events were extracted for nine durations, 10 minute, 20 minute, 30 minute, 60 minute, 120 minute, 180 minute, 360 minute, 720 minute, 1440 minute.

Each rain gauge had a different number of events extracted. Whenuapai, the gauge with the longest record had 4107 events identified from 1945 to present. NSCC06, the gauge with the shortest record had 676 events extracted from 1999 to present. On average 60 events per annum per gauge were identified. In total 14460 events were identified from all 10 gauges.

The ARI per event was calculated using the equation given in Section 1.4. The ARI was calculated for every event and for every duration.

All events with a 2 year ARI and greater were compared to check the degree of independence of the rain gauges in each event.

Gauge independence was checked for all eight NSCC gauges (all North Shore City Council gauges). Regional independence was also checked by comparing the long term gauges, Whenuapai, Albert Park, NSCC07 against each other.

2.6 ANNUAL MAXIMA – RAIN EVENT ARI DEVELOPMENT

Describe reasons for application of Annual Maxima approach.

Five minute rainfall data was used from the ten rain gauges discussed above. The data was extracted based on a twelve hour dry inter event period. Events were extracted for nine durations, 10 minute, 20 minute, 30 minute, 60 minute, 120 minute, 180 minute, 360 minute, 720 minute, 1440 minute.

During the partial series analysis, each rain gauge had a different number of events extracted as described above in section 2.3. From the Partial Series events the largest event per annum per duration was selected to create the annual maxima series.

The annual maxima data was then processed using an extreme value distribution, EV1, to create the ARI for each annual maxima event. Following application of the EV1 distribution all events with a 2 year ARI and greater were compared to check the degree of independence of the rain gauges in each event.

Gauge independence was checked for all eight NSCC gauges (all North Shore City Council gauges). Regional independence was also checked by comparing the long term gauges, Whenuapai, Albert Park, NSCC07 against each other.

3 STUDY RESULTS AND DISCUSSION

3.1 COMPARISON OF ANNUAL MAXIMA VS PARTIAL SERIES COMPUTED RETURN INTERVALS

3.1.1 GENERAL

Figures 1 to 6, compare Partial Series and Annual Maxima rain event depths and the computed ARI for a given duration. It can be seen that all these figures follow the same trend, regardless of duration or gauge location. For ARIs less than 5 years the partial series record's events larger then those predicted when using the annual maxima series and extreme value theory.

For the 5 year ARI event the Partial Series event depth exceeds the Annual Maxima series value by:

- 8% for Whenuapai 1440 min, across all durations 0% (average)
- 0% for Albert Park 1440 min, across all durations 5% (average)
- 9% for NSCC07 1440 min, across all durations 7% (average)

For the 2 year ARI event the Partial Series event depth exceeds the predicted Annual Maxima series value by:

- 15% for Whenuapai 1440 min, across all durations 10% (average)
- 17% for Albert Park 1440 min, across all durations 15% (average)
- 10% for NSCC07 1440 min, across all durations 15% (average)

The maximum 2 year ARI difference was 23% between the partial series ARI and the annual Maxima series ARI.

3.1.2 WHENUAPAI

Whenuapai has a rainfall record 64 years long. The trends on Figures 1 & 2 are the same with the partial series ARI having a greater depth than the annual maxima series ARI for events 5 years and less.

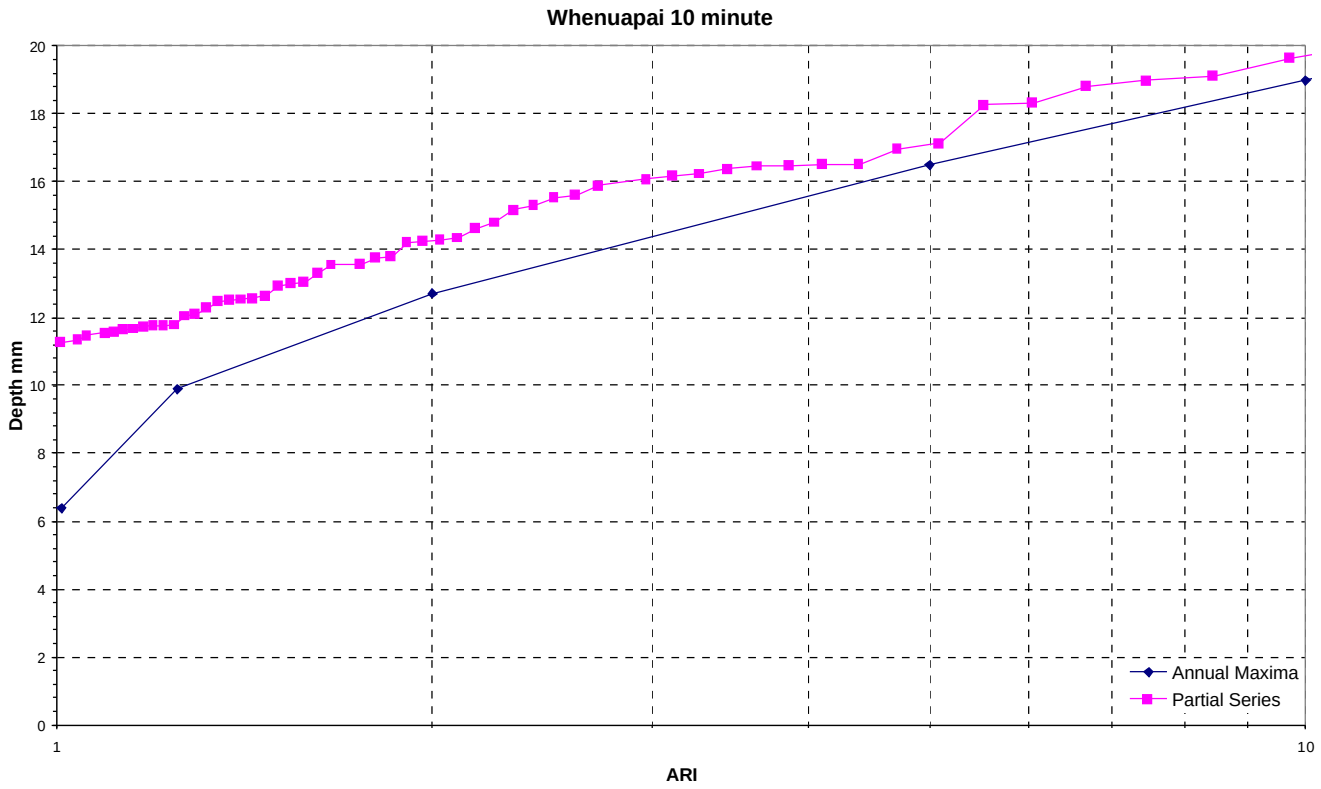

Figure 1: ARI of events – Partial Series compared to Annual Maxima (10 min)

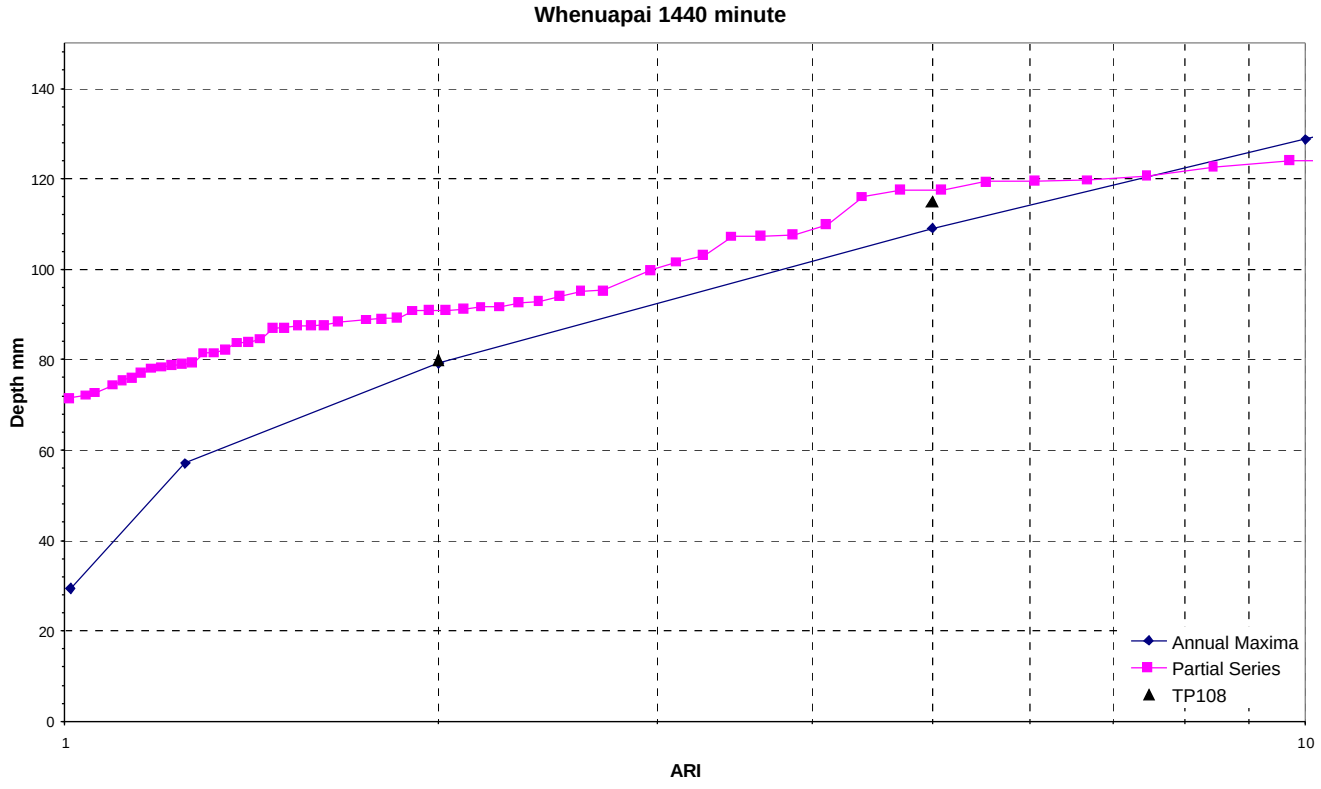

Figure 2: ARI of events – Partial Series compared to Annual Maxima (1440 min)

3.1.3 ALBERT PARK

Albert Park has a rainfall record 47 years long (daily data for the site exists for much longer). The trends on Figures 3 & 4 are the same with the partial series ARI having a greater depth than the annual maxima series ARI for events 5 years and less.

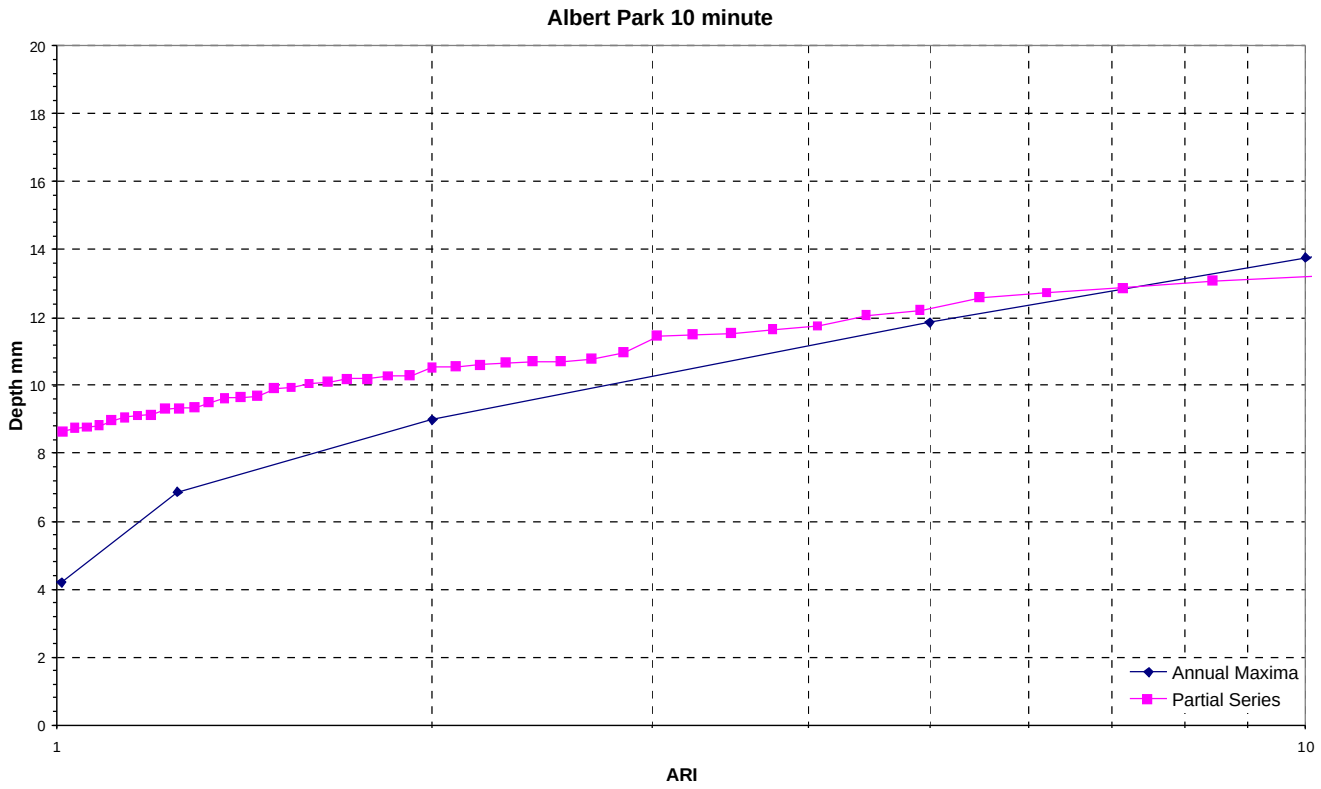

Figure 3: ARI of events – Partial Series compared to Annual Maxima (10 min)

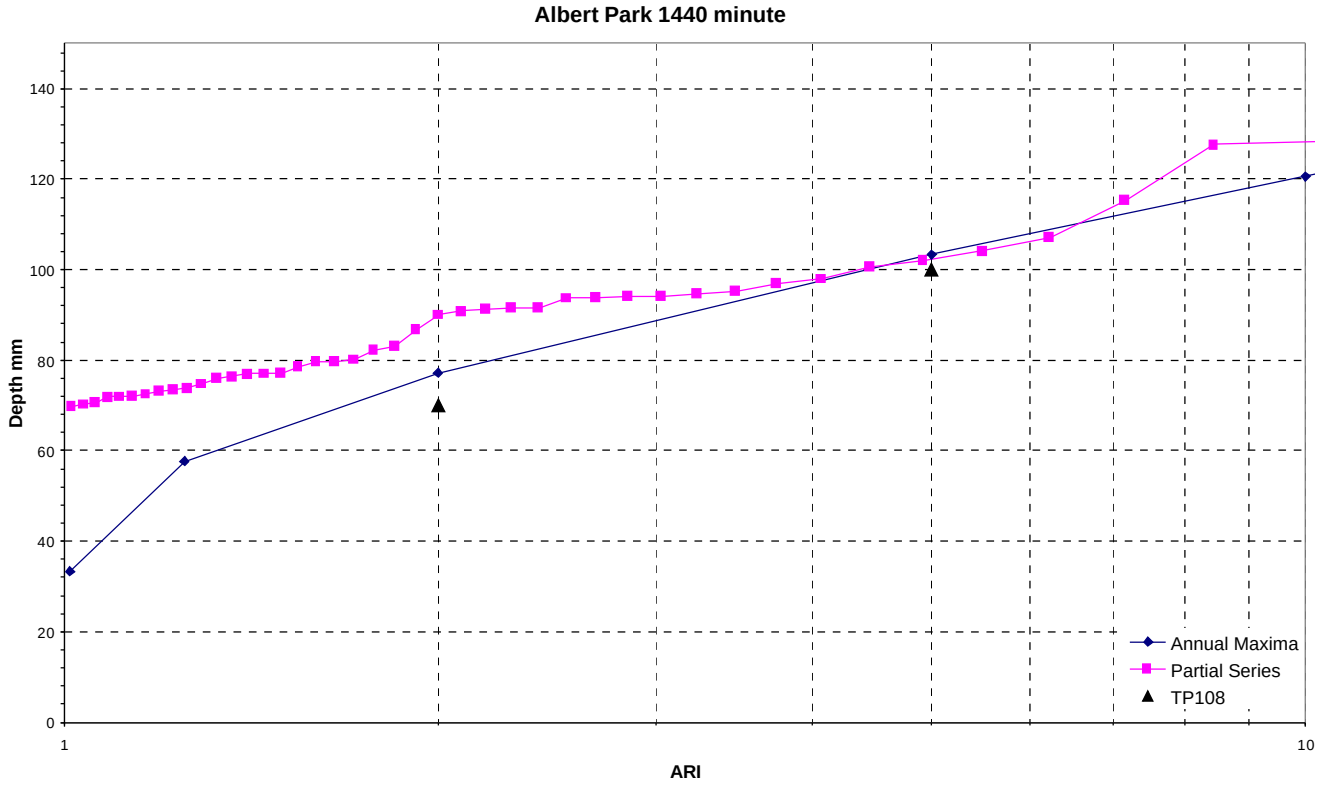

Figure 4: ARI of events – Partial Series compared to Annual Maxima (1440 min)

3.1.4 NSCC07

NSCC07 has a rainfall record 37 years long. The trends on Figures 5 & 6 are the same with the partial series having a greater depth than the annual maxima series for all ARI's.

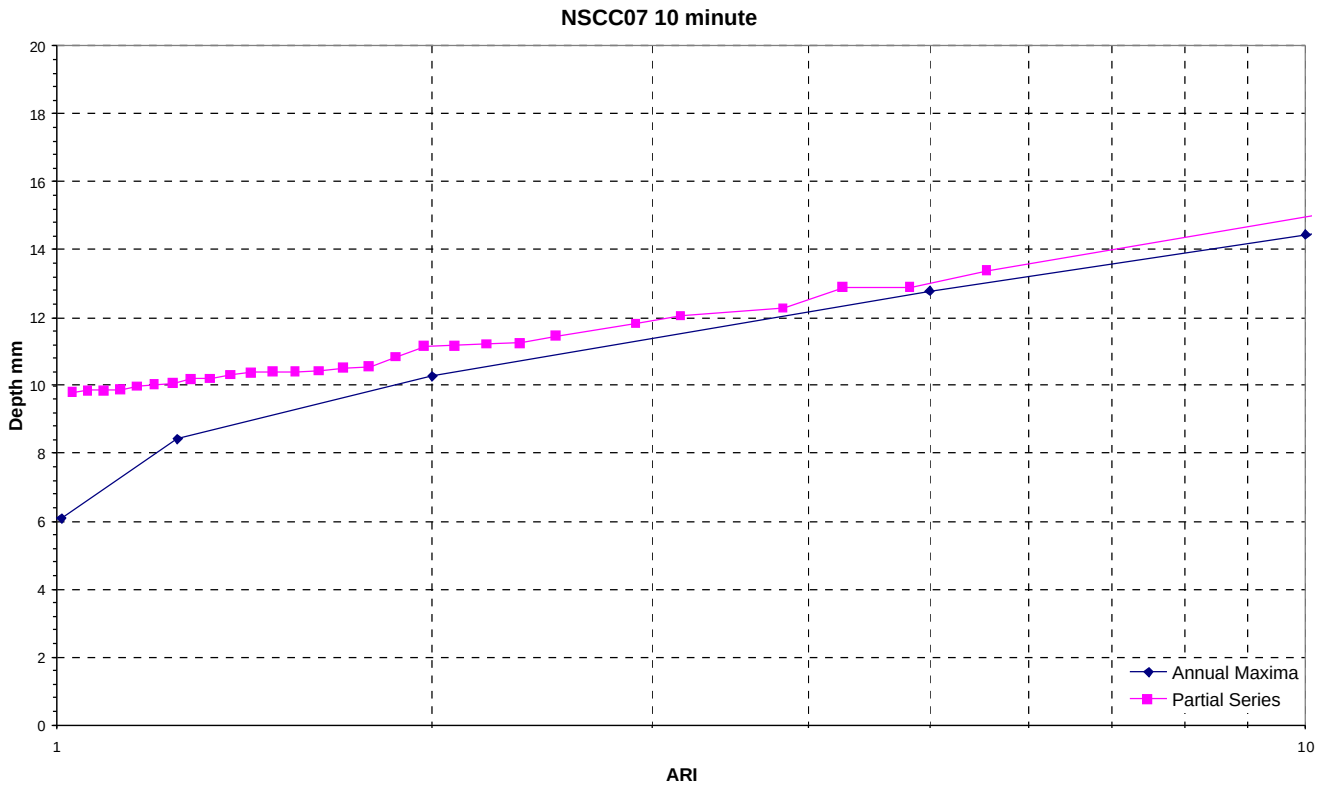

Figure 5: ARI of events – Partial Series compared to Annual Maxima (10 min)

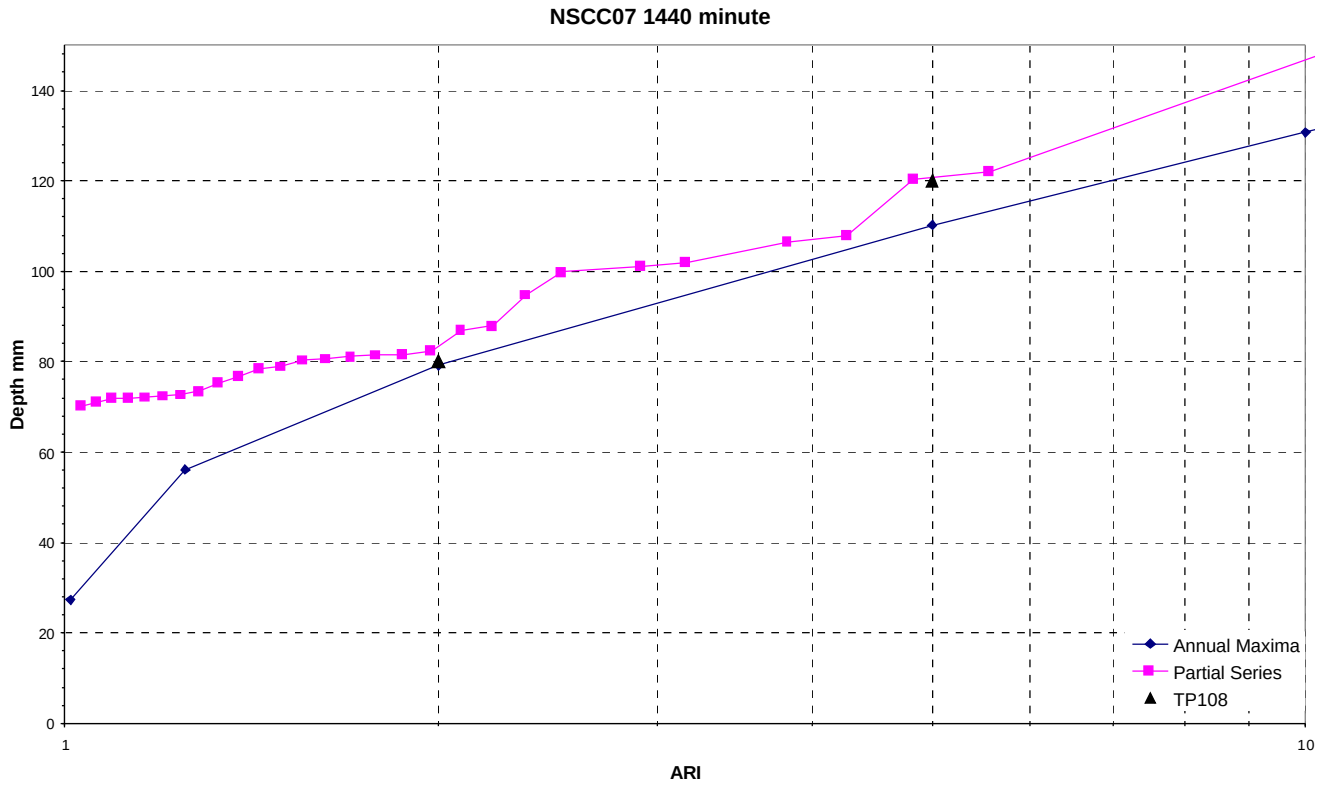

Figure 6: ARI of events – Partial Series compared to Annual Maxima (1440 min)

3.1.5 SUMMARY

Analysis using a partial series approach for determination of extreme event (>= 2yr ARI) size gives a more accurate representation of the rainfall depths which are likely to occur. The partial series approach gives consistently higher depths for ARI's 5 years and less.

For frequent extreme events there is no need to use extreme value theory based on annual maxima data.

The longer the period of record the higher the confidence in ARI's derived from each method.

3.2 EXTREME RAIN EVENT INDEPENDENCE

3.2.1 ANNUAL MAXIMA RESULTS - NORTH SHORE CITY RAIN GAUGES

The eight North Shore City Council rain gauges were assessed for the 10.5 years of record where all gauges were operating simultaneously. Each gauge was assessed for the following durations:

10 min, 20min, 30 min, 60 min, 120 min, 180 min, 360 min, 720 min, 1440 min.

Over the recorded ten and a half year period five extreme events (>= 2yr ARI) would be expected to be recorded at each gauge location. If each gauge was fully independent, forty two separate extreme events would be expected to be recorded across the city.

During the ten and a half year period of record ~31 extreme events per duration (2yr ARI or greater) were recorded across the city. Of the 31 events recorded at all gauges there were ~10 separate events.

Over a 10.5 year period 42 extreme events are expected to be recorded; the total number is less than 42 due to rainfall variability. Most of the 8 rain gauges assessed have records longer than the 10.5 years assessed. Only assessing part of the rainfall records means the period being assessed may have greater or fewer extreme events than the long term average.

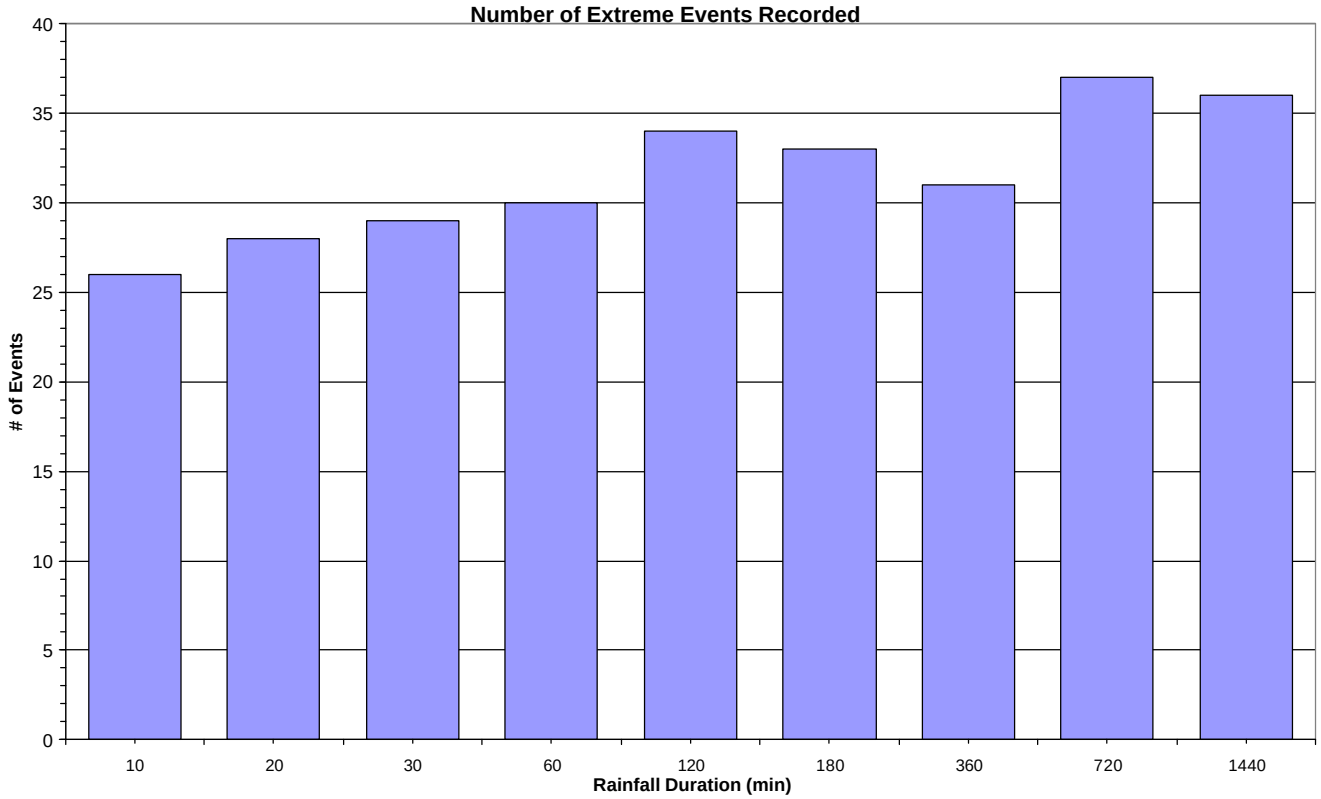

Figure 7: Annual Maxima Number of Extreme Events Recorded

Figure 7 shows the number of extreme events from the annual maxima series for each duration. Across all eight gauges an extreme event was recorded for the 10 minute duration event 26 times in 10.5 years. For the 24 hour duration (1440 min) 36 events extreme events were recorded in 10.5 years.

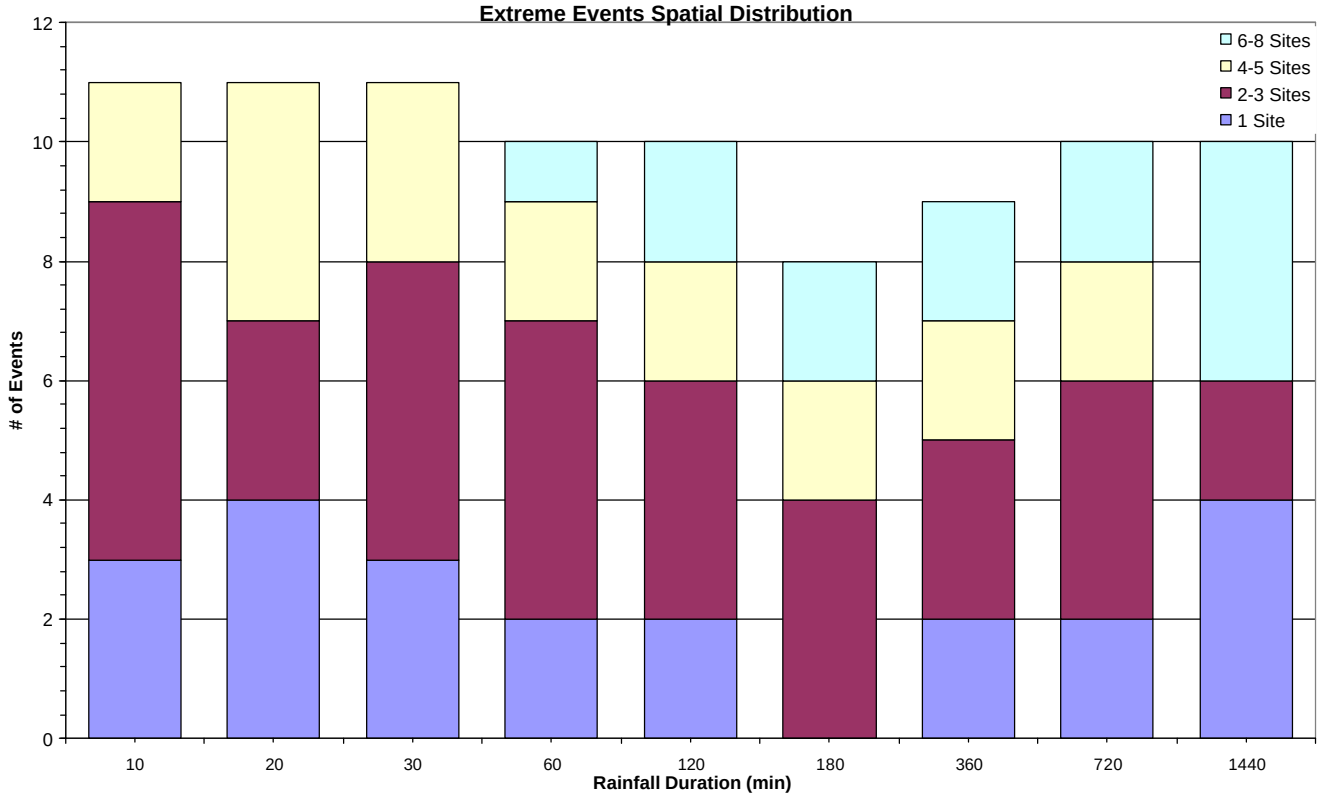

Figure 8: Annual Maxima Number of Coincident Extreme Events

Figure 8 shows the number of individual extreme events from the annual maxima series for each duration. Across all eight gauges an individual extreme event was recorded for the 10 minute duration event 11 times in 10.5 years. 3 of the events were recorded in the annual maxima series as extreme events at only one gauge location. 6 of the annual maxima events were recorded at between 2 to 3 rain gauge sites concurrently. Two of the annual maxima events occurred for between 4 to 5 rain gauge sites concurrently.

For the 24 hour duration (1440 min) 10 extreme events were recorded in 10.5 years. Of these 10 events 4 were independent, only recorded in the annual maxima series by one location. 2 annual maxima events were recorded by 2 to 3 rain gauges. 4 annual maxima events were recorded by 6 to 8 rain gauges concurrently.

There is little if any change in the independence of rain gauges as duration increases.

The above assessment was done using 8 gauges for 10.5 years and across 9 durations. If all durations and gauges were independent the number of extreme event durations would be

$$\frac{8(No.Gauges)\times 9(No.Durations)\times 10.5(years)}{2(ARI)} = 378$$

Due to some of the durations being nested inside each other, i.e. the 10min 2yr ARI event being with the 30min 2yr ARI event 139 events were recorded across all gauges. Once the 139 events are assessed to determine if they occur at the same time as each other the total number of events becomes 31.

31 extreme events occur (>=2yr ARI) over a 10.5 year period using the annual maxima series. On average an extreme event occurs in North Shore City 2.95 time's per annum using partial series analysis.

3.2.2 ANNUAL MAXIMA RESULTS - LONG TERM REGIONAL RAIN GAUGES

The same analysis as in section 3.2.1 was carried out using the three long term rain gauges

Whenuapai, Albert Park, NSCC07.

The period assessed was 37 years as this is the period of record from NSCC07. Over the 37 year period ~40 extreme events were recorded at the 3 sites (Figure 9).

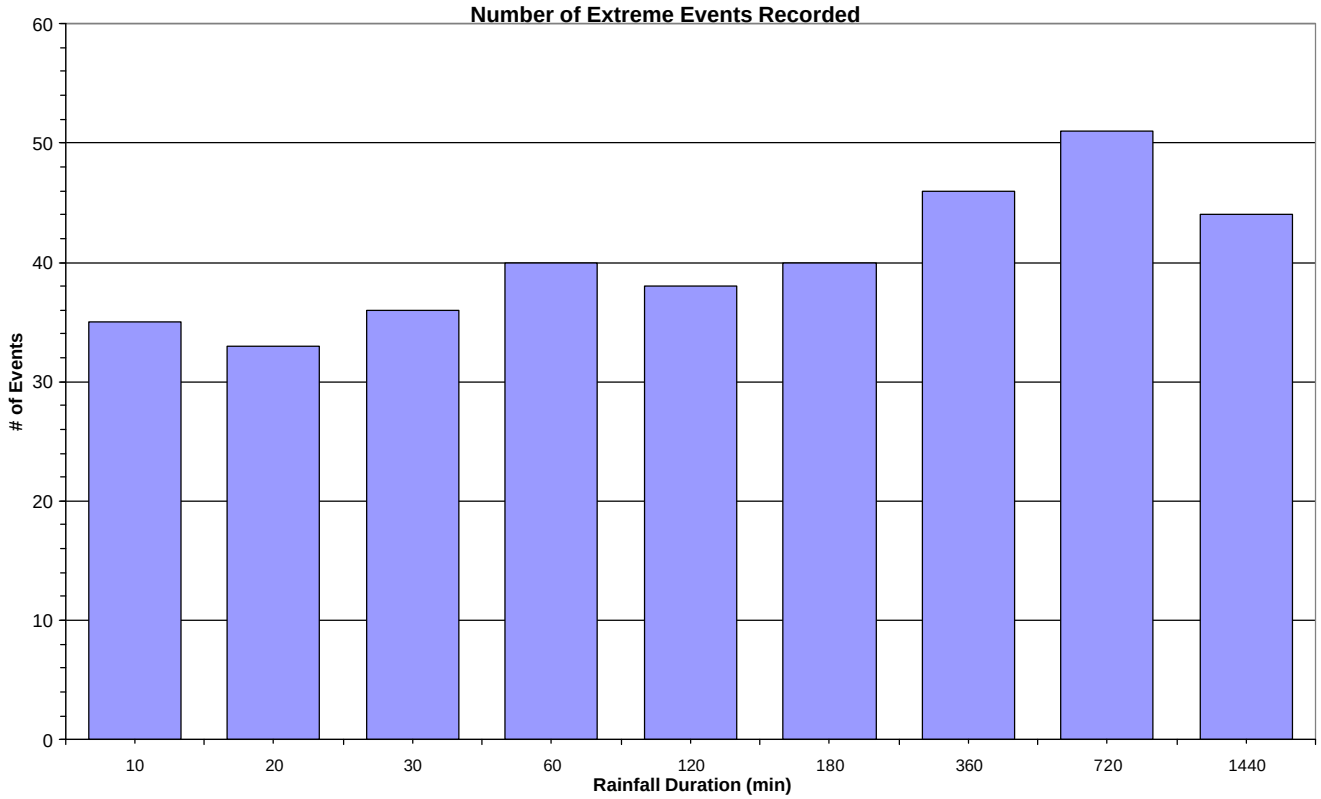

Figure 9: Annual Maxima Number of Extreme Events Recorded

~29 individual events from the annual maxima record made up the ~40 events recorded at the 3 different rain gauges sites (Figure 10).

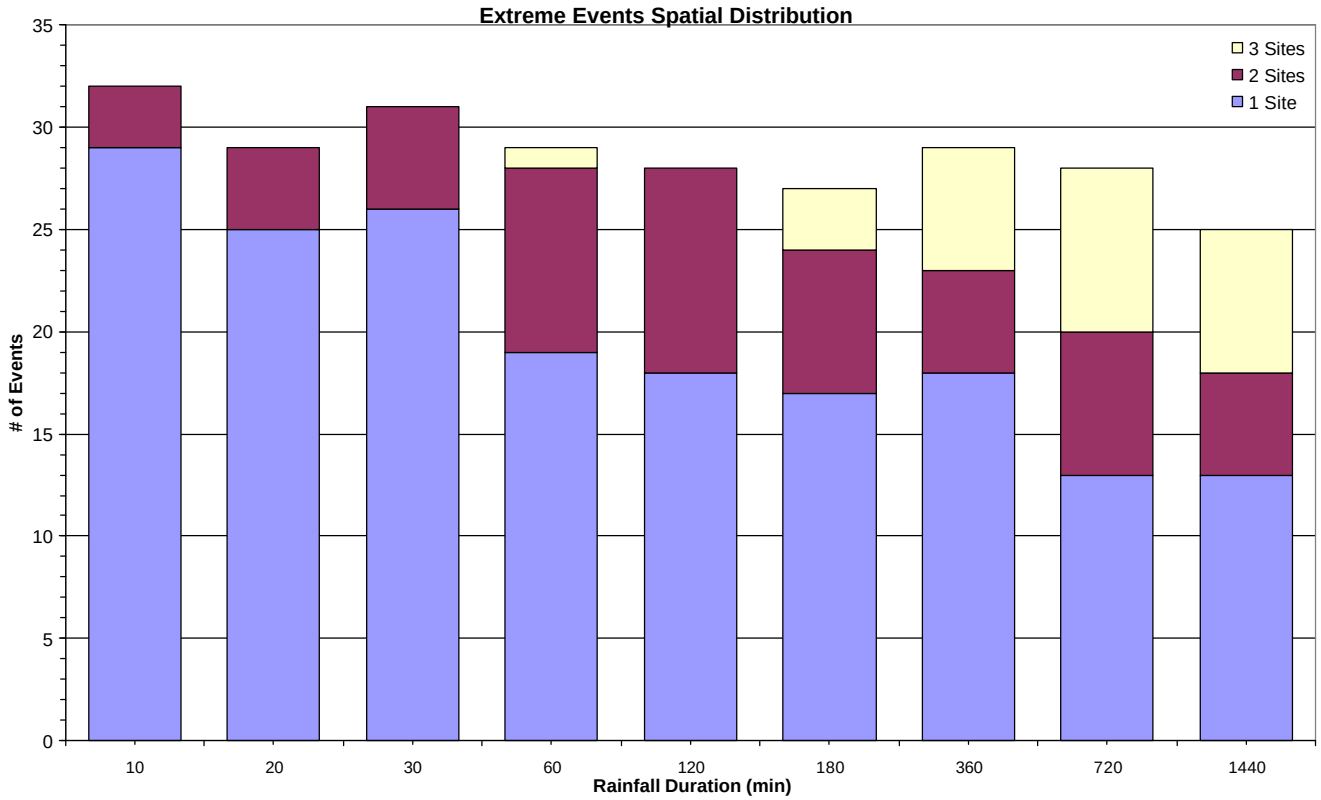

Figure 10: Annual Maxima Number of Coincident Extreme Events

As storm duration increases the number of extreme events from the annual maxima series which are recorded by more than one site also increases.

3.2.3 PARTIAL SERIES RESULTS - NORTH SHORE CITY RAIN GAUGES

The eight North Shore City Council rain gauges were assessed for the 10.5 years of record where all gauges were operating simultaneously. Each gauge was assessed for the following durations:

10 min, 20min, 30 min, 60 min, 120 min, 180 min, 360 min, 720 min, 1440 min.

Over the recorded ten and a half year period five extreme events (>= 2yr ARI) would be expected to be recorded at each gauge location. If each gauge was fully independent, forty two separate extreme events would be expected to be recorded across the city.

During the ten and a half year period of record ~34 extreme events per duration (>= 2yr ARI) were recorded across the city. Of the 34 events per duration recorded at all gauges there were ~18 separate events.

Over a 10.5 year period 42 extreme events are expected to be recorded; the total number is less than 42 due to rainfall variability. Most of the 8 rain gauges assessed have records longer than the 10.5 years assessed. Only assessing part of the rainfall records means the period being assessed may have greater or fewer extreme events than the long term average.

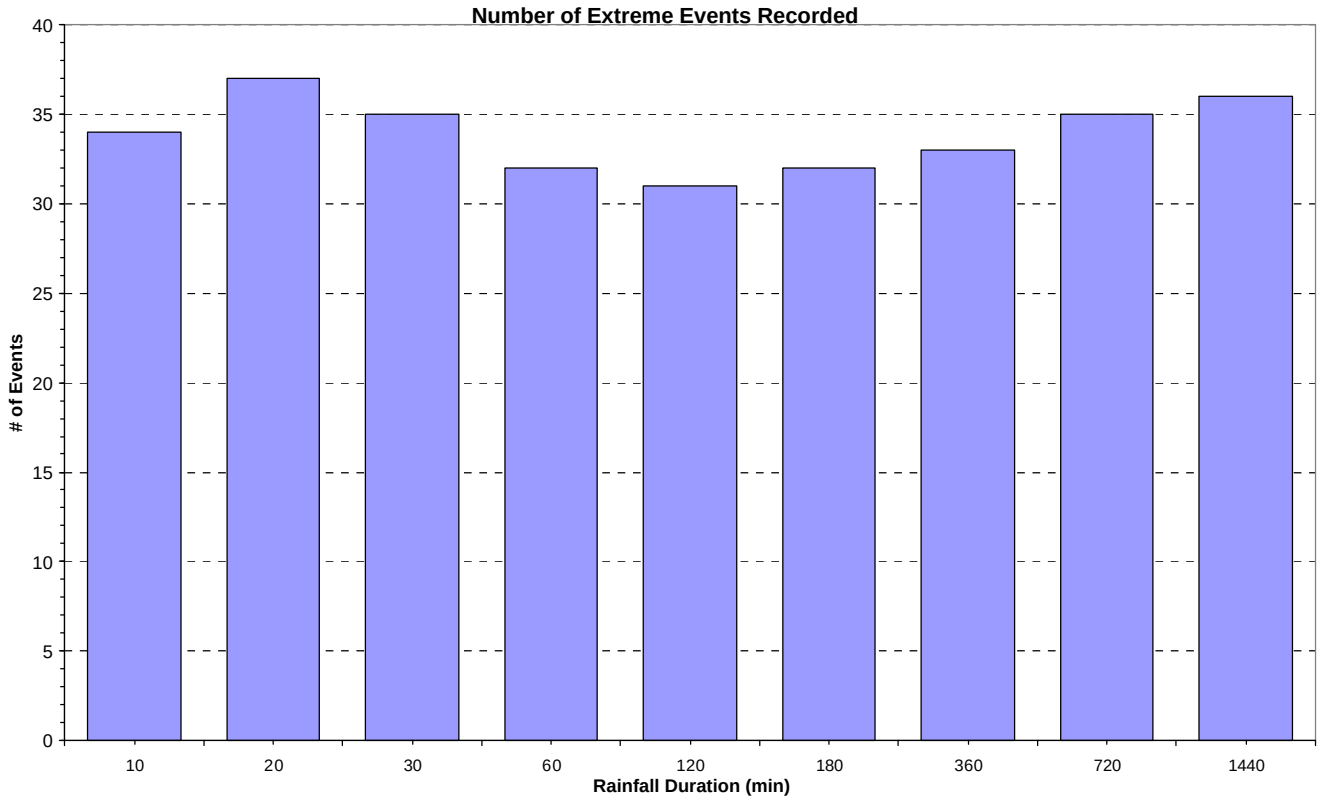

Figure 11: Partial Series Number of Extreme Events Recorded

Figure 11 shows the number of extreme events from the partial series for each duration. Across all eight gauges an extreme event was recorded for the 10 minute duration event 34 times in 10.5 years. For the 24 hour duration (1440 min) 36 events extreme events were recorded in 10.5 years.

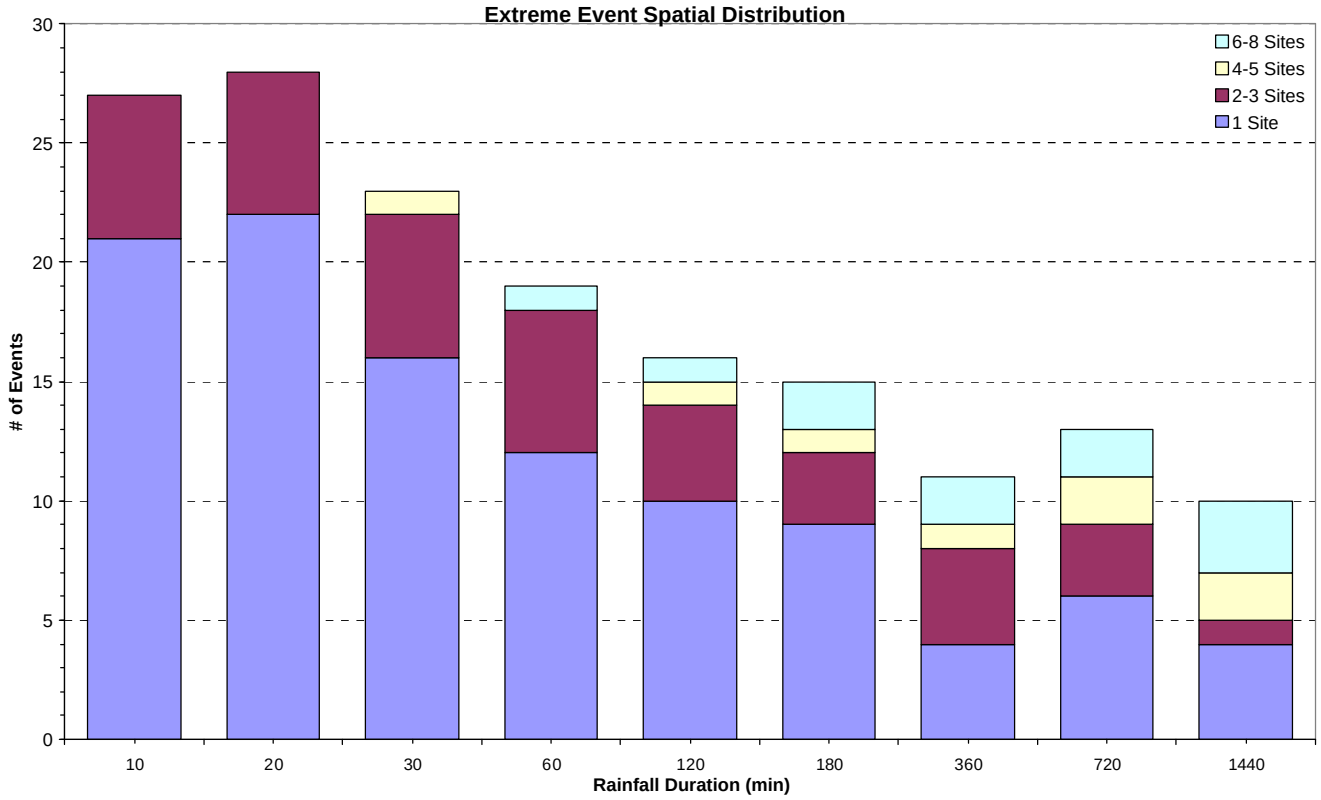

Figure 12: Partial Series Number of Coincident Extreme Events

Figure 12 shows the number of individual extreme events from the partial series for each duration. Across all eight gauges an individual extreme event was recorded for the 10 minute duration event 27 times in 10.5 years. 21 of the events were recorded in the partial series as extreme events at only one gauge location. 6 of the partial series extreme events were recorded at between 2 to 3 rain gauge sites concurrently.

For the 24 hour duration (1440 min) 10 extreme events were recorded in 10.5 years. Of these 10 events 4 were independent, only recorded in the partial series by one location. 1 partial series event was recorded by 2 to 3 rain gauges. 2 partial series events were recorded by 4 to 5 rain gauges concurrently. 3 partial series events were recorded by 6 to 8 rain gauges concurrently.

As duration increases the independence of the rain gauges from each other decreases when comparing data from partial series analysis.

The above assessment was done using 8 gauges for 10.5 years and across 9 durations. If all durations and gauges were independent the number of extreme event durations would be

$$\frac{8(No.Gauges)\times 9(No.Durations)\times 10.5(years)}{2(ARI)} = 378 Durations$$

Due to some of the durations being nested inside each other, i.e. the 10min 2yr ARI event being with the 30min 2yr ARI event 162 events were recorded across all gauges. Once the 162 events are assessed to determine if they occur at the same time as each other the total number of events becomes 46.

46 extreme events occur (>=2yr ARI) over a 10.5 year period using the partial series. On average an extreme event occurs in North Shore City 4.4 time's per annum using partial duration series analysis.

3.2.4 PARTIAL SERIES RESULTS - LONG TERM REGIONAL RAIN GAUGES

The same analysis as in section 3.2.3 was carried out using the three long term rain gauges

Whenuapai, Albert Park, NSCC07.

The period assessed was 37 years as this is the period of record from NSCC07. Over the 37 year period ~49 extreme events were recorded at the 3 sites (Figure 11).

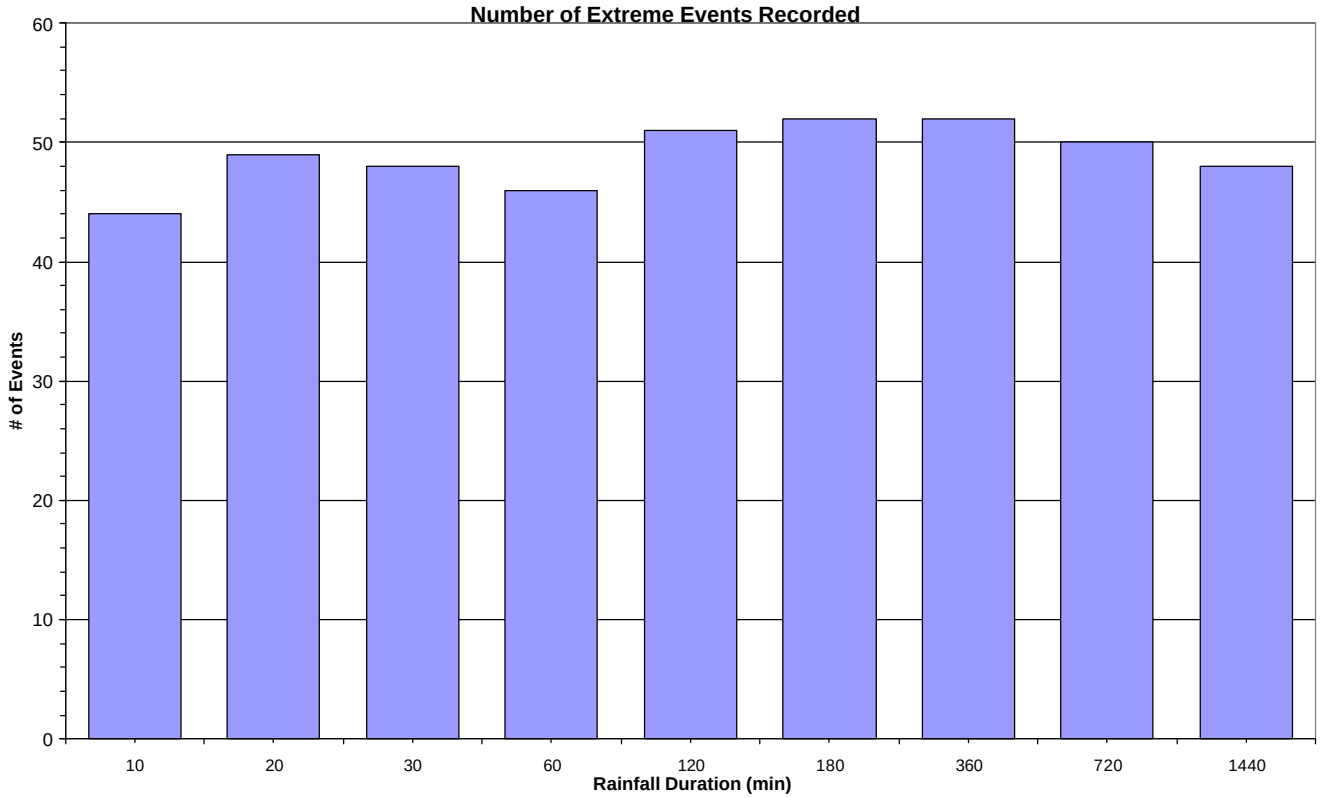

Figure 11: Partial Series of Extreme Events Recorded

37 individual events from the Partial Series record made up the ~47 events recorded at the 3 different rain gauges sites (Figure 12).

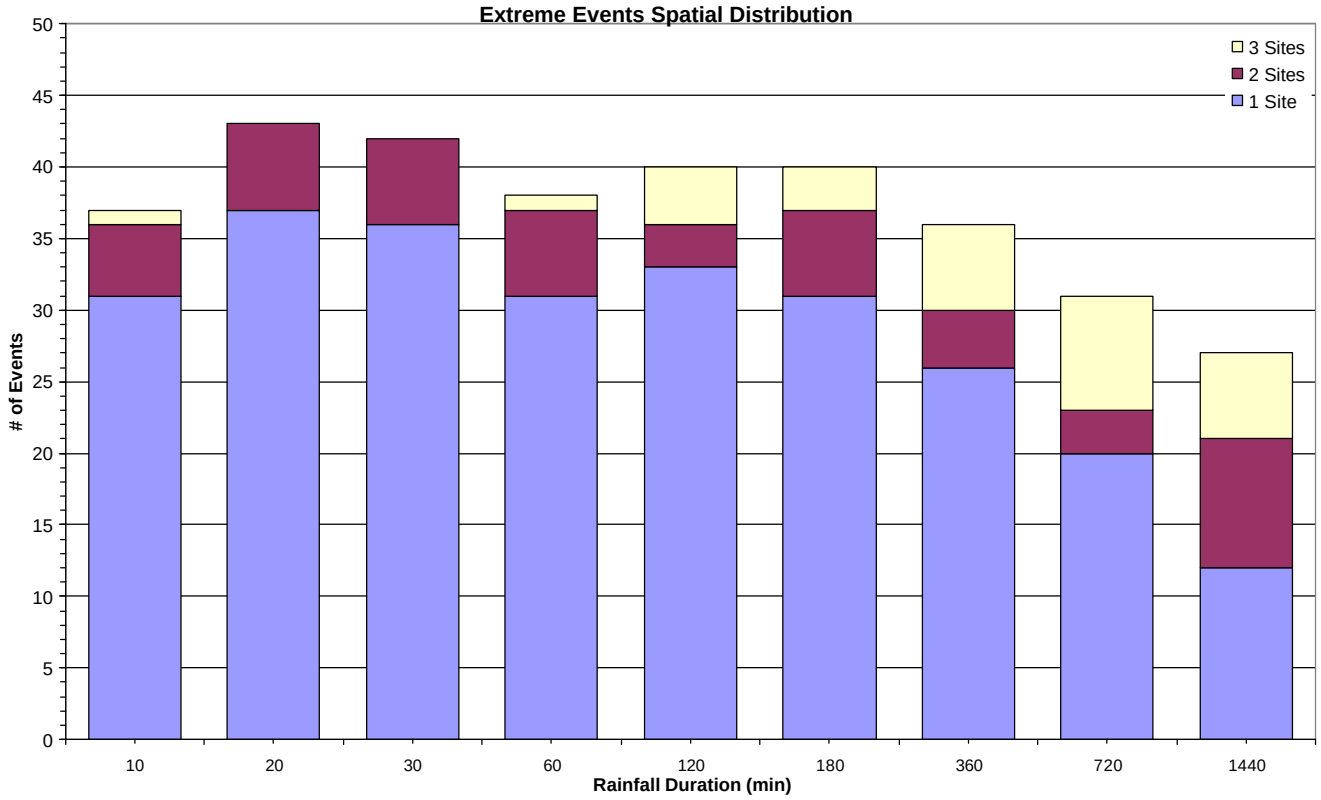

Figure 12: Partial Series Number of Coincident Extreme Events

Again as storm duration increases the number of extreme events from the partial series which are recorded by more than one site also increases.

4 CONCLUSIONS

Based on the eight permanent NSCC rain gauges North Shore City should expect on average to have 4 to 5 events greater than or equal to a 2 year ARI event per annum (from partial duration series). If using an Annual Maxima approach 2.5-3.5 events greater than or equal to a 2 year ARI event per annum would be expected to occur in North Shore City on average.

Regardless of how extreme events are calculated North Shore City clearly experiences extreme events at a frequency many times greater than once every two years.

The use of the annual maxima series and extreme value theory for the prediction of the size of frequently occurring extreme events will give values which are lower than those recorded.

If the annual maxima series is used to determine how often extreme events occur within a given geographic area the number of events will be under predicted.

If the annual maxima series is used to determine whether a rain gauge is independent then the amount of independence will be over predicted.

Use of annual maxima data under predicts rainfall depth, under records the number of extreme events, and under reports coincident extreme events.

Partial duration series should be used when the period of record is long enough to include ARI's of the size required for the analysis.

Annual Maxima should be used to extrapolate to data which has not yet been recorded. Annual Maxima can be used as input to a predictive distribution which allows extrapolation. Partial series data cannot be extrapolated as it is a report on historic data.

5 FUTURE WORK

The next phase of work is to determine as ARI increases (less frequent events) does the degree of independence decrease. I.e. does the 20 yr ARI event have more areal coverage than the 2 yr ARI event.

Check to see if the extreme events from the annual maxima analysis which are independent occur in more than once in the partial duration series as an extreme event. This work would allow further quantification of whether Annual Maxima analysis can be used to check if events are independent.

Check to see if the assumption that the ARI of the rainfall event is the same as the ARI of the resultant runoff event. To do this work would require using a hydrologic & hydraulic model and continuous simulation.

ACKNOWLEDGEMENTS

Tim Lockie is acknowledged for use of the code he wrote which allowed the extraction and bundling of data in such a way as to make the analysis far less problematic than it could have been given the size of the data arrays.

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