# USE OF AREAL REDUCTION FACTOR IN MODELLING AND ITS IMPLICATION

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**ABSTRACT**

Many observational studies of rainfall identify both high intensity rainfall clustering in small areas and rainfall intensity decreasing with distance from the point of highest intensity. It is also found that as the rainfall intensity increases, the variation of intensity over distance also decreases.

The reduction of high intensity rainfalls with increasing areas is a key issue in many hydrological problems and small scale variability can lead to biases. There seems to be differing views on how Areal Reduction Factors are applied to point rainfall which can lead to under estimation of flows at subcatchment level in large catchments (over 1,000 ha).

The areal distribution of rainfall in a large catchment can be accounted for by selecting several points for rainfall input to catchment model which reflect elevation range and orographic characteristics of catchment. In detailed modelling, a large catchment is divided into smaller sub-catchments, then, any areal reduction factor should be related to the subcatchment size. If the hydraulics of the conveyance system is then addressed accurately, some separation of sub-catchment peaks will be achieved that partly addresses the effects of distributed catchments.

A number of project examples from Auckland and Northland are used to demonstrate the application of Areal Reduction Factors.

**KEYWORDS**

**RAINFALL VARIABILITY, AVERAGE RECURRENCE INTERVAL (ARI), TIME OF CONCENTRATION, LAG TIME, AND CATCHMENT.**

**PRESENTER PROFILE**

Habib has extensive professional experience in the field of water resources engineering. This includes extensive knowledge of hydrological analysis of catchment; river and estuary modelling using MIKE 21; river modelling, MIKE 11; stormwater modelling, MIKE FLOOD; stormwater quality management including the preparation of catchment management plans and design of stormwater quality treatment devices. Habib is Team Leader – Stormwater modeling and leads a group of modelers.

Toby Kay is a natural hazards officer employed with the Northland Regional Council. He has over 10 years international experience in water resource management, water supply engineering and natural hazards assessment. His current focus is on providing technical input to the development of river management plans, including the verification of flood models, and advising on natural hazards related policy.

# 1 INTRODUCTION

## 1.1 BACKGROUND

During the last few years the authors have experienced several situations where a question has arisen in the application of the ARF factor. This paper uses several case studies in Auckland and Northland to demonstrate the impacts of ARF in detailed modelling using DHI software packages.

## 1.2 AREAL REDUCTION FACTOR AND ITS USE

The rationale for the use of an ARF is well established. ARF applied to probabilistic rainfall data should account for the lower probability that a predicted point rainfall depth, of a given ARI, will occur across an entire catchment. ARFs decrease both with increasing catchment area, and with shorter duration reflecting that a greater reduction should be made to predicted point rainfall to generate probabilistic areal rainfall for larger catchments as well as over shorter duration storms.

In relation to the modeled simulation of previous recorded storm events, for the purposes of model calibration and verification, the same rationale is not generally applied, and areal rainfall is commonly derived through the interpolation of recorded point rainfall data across a catchment. Use of Thiessen polygon method or Arithmetic Average method is often made for deriving areal rainfall for running model simulations of previous events.

In New Zealand, the primary source of probabilistic rainfall data is the HIRDS package produced by NIWA on the basis of a statistical analysis of point rainfall data across the country. New releases of this data are made approximately every ten years, with the most recent version HIRDS v3, released in early 2010. It is also common practice in New Zealand to apply an appropriate ARF to point rainfall of a given ARI from HIRDS, and then use the derived areal rainfall as input to flood models, to generate a probabilistic flood of the same ARI.

Application of ARF should not be considered in isolation from other design storm parameters, in particular, storm profile may have a greater influence on peak flow, especially for smaller catchments. However, the focus of this paper is on the practical implications of applying ARFs, especially at the sub-catchment level where the overall catchment area is relatively large.

## 1.3 AREAL REDUCTION FACTORS USED IN VARIOUS COUNTRIES

The method for applying an ARF is different in various countries, as are the actual reduction factors to be used. Whilst there are national guidelines available in a number of countries which relate to flood estimation, New Zealand does not have an equivalent set of standards that could guide, and bring consistency to best practice. In the northern part of the country, the former Auckland Regional Council's TP108 (1999) is often referred to for stormwater modeling. Section 2 of that technical paper, on rainfall, includes a design storm temporal pattern and ARFs to be used based on catchment area and time of concentration. For comparative purposes, ARF from a number of different guidelines are given in Table 1 below, based on a catchment area of 100 km2.

**Table 1 ARFs expressed as percentages of point rainfall for 100 km$^2$ catchment area**

| Source | Storm Duration | | | | | | Comment |
|---|---|---|---|---|---|---|---|
| | 30m | 60m | 2h | 6h | 12h | 24h | |
| UKFSR (NERC 1975) | 72% | 79% | 84% | 90% | 92% | 94% | Time intervals relate to storm duration, from fig 4.1, Shamseldin 2008 |
| UKFEH (NERC 2008) | 74% | 80% | 85% | 90% | 93% | 95% | Time intervals relate to storm duration, from fig 3.4 FEH Vol 4 |
| TP108 1999 | 71% | 74% | 79% | 86% | 89% | 90% | ARF based on Time of Concentration, from Table 2.2 TP108 1999 |
| Shamseldin TP108 Review | 74% | 80% | 85% | 90% | 93% | 95% | ARF based on Time of concentration / lag time from Table 3.1 Shamseldin 2008 |
| ARR 1987, revised 1998 | 79% | 87% | 92% | 95% | 96% | 97% | Time intervals relate to storm duration From Australian Rainfall and Runnoff Book II section I, Fig 1.6 |

Direct comparison between these ARFs is slightly complicated by the use of time of concentration for TP108, and storm duration for other guidelines. The TP108 promotes use of a 24 hour storm with a rainfall profile given in TP108. The ARF is then applied to the 24-hour rainfall depth, based on the Time of concentration of the catchment. The UK ARFs contained in the Flood Studies Report (FSR 1975), and the Flood Estimation Handbook (FEH 2008) are applied to storm duration, so different ARFs could be applied to any given catchment depending on what storm duration is being used.

It can be seen from the Table 1 above that the TP108 ARFs are significantly lower than ARF used in the UK and Australia. The TP108 is currently being revised and a small pilot study undertaken by Shamseldin has indicated that observed Auckland ARFs are much closer to UK ARFs than those of the TP108 ARFs, which originate from TP19 (ARC 1992). The TP108 ARFs were based largely on a study of UK rainfall by Tomlinson in 1980, who cautioned against over reliance on these ARF for events with long return period in New Zealand. Within the review of the TP108, Shamseldin recommended adoption of ARFs that are closer to the UK FEH ARFs, as can be seen in Table 1 above (Shamseldin 2008).

There are other significant differences of approach taken in the UK FEH, including the use of winter and summer storm profiles. The summer storm profile has higher peak rainfall intensity, at approximately 500% of mean storm intensity (fig 3.5, Vol 4) and is intended for use on urban catchments. By comparison, the TP108 peak 10 minute intensity is 1,620% of mean storm intensity over 24 hours. UK FEH also uses higher rainfall for a flood of any given return period as shown in Table 3.1 of the FEH and worked example 3.1b. Thus to generate a flood with ARI of 50 years, a point rainfall ARI of 81 years should be used with an ARF applied, based on storm duration to be modeled and catchment size (Houghton-Carr 1999).

# 2 PROJECT EXAMPLES

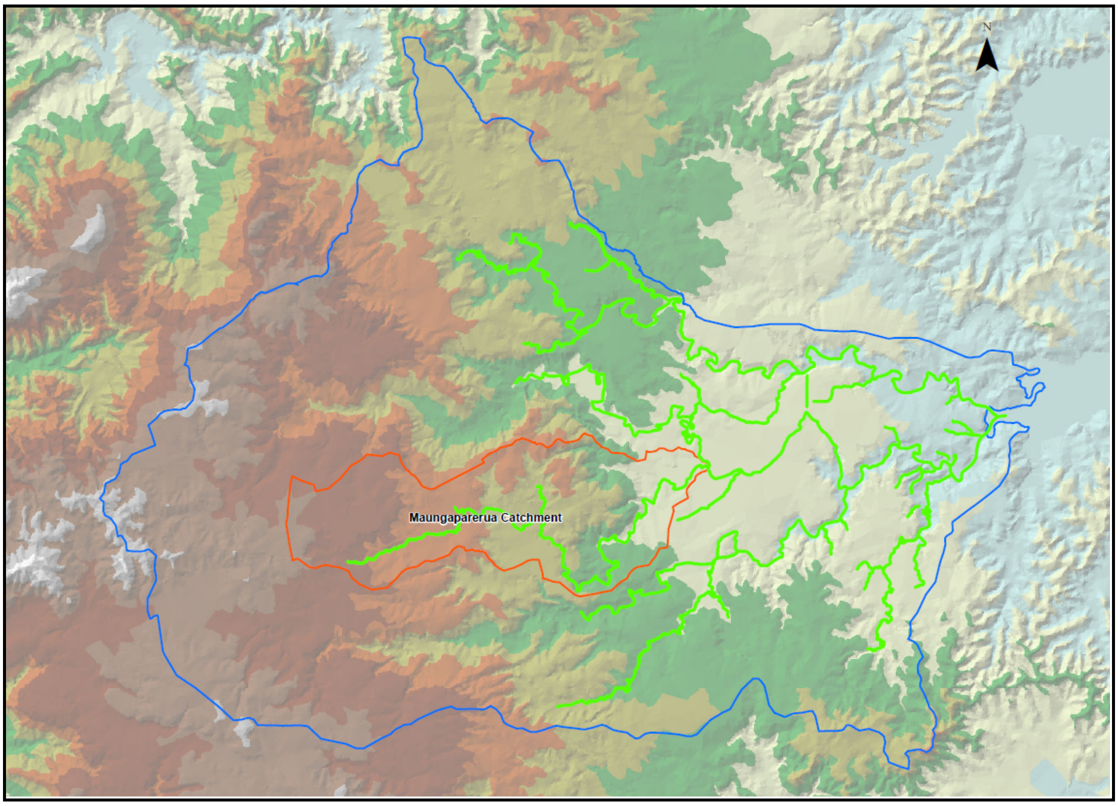
## 2.1 KERIKERI RIVER CATCHMENT

### 2.1.1 CATCHMENT

The Kerikeri catchment drains to the Kerikeri Inlet on the East coast of Northland at 174° 00'E, 35° 13'S. The catchment area is 93 km$^2$ to the NIWA Peacock Gardens river gauge site (3515), which is 1.5 kilometres upstream of the Kerikeri Basin. The main tributaries are the Puketotara and Kerikeri Rivers, and their confluence is located 1.3 kilometers upstream of the Peacock Gardens gauge. The Maungaparerua stream joins the Kerikeri River West of the SH10 at Waipapa. The Maungaparerua catchment is located centrally within the Kerikeri catchment, and has a NIWA automatic rainfall recorder and river gauge site at Tyrees Ford, with a catchment area of 11.1 km$^2$.

The catchment geology is characterised by underlying Waipapa group greywacke overlain by basalts that have formed as a series of flows sloping eastwards toward the coast. Basement greywacke outcrops in some of the river valleys, and in the headwaters of Kerikeri catchment. The elevation at the western edge of the catchment, which borders the Puketi Forest, is up to 370m. Steep sided valleys are typical of the upper catchment from which the tributaries emerge onto large flat interfluves overlying the basalt layer in the middle of the catchment, upstream of the main waterfalls. This level area is characterised by overland flows in times of flood, which sometimes result in overflow to the Waipapa Stream, north of the Kerikeri catchment. An overview of the Kerikeri River Catchment showing the Maungaparerua Stream Catchment is shown in

Figure 1 Overview of the Kerikeri River Catchment




### 2.1.2 ESTIMATION OF ARF

The ARF for this catchment was estimated by estimating time of concentration for the entire catchment. This was based on estimating the longest flowpath for the catchment and determining the average slope along the longest flowpath by equal area method utilizing the LiDAR and 20 m contour data. The time of concentration was estimated to be approximately 6 hours. The ARF based on ARC TP108 is estimated to be 0.86. The point rainfall for various return periods are shown in Table 2 below.

### 2.1.3 RAINFALL

The point rainfall for the Maungaparerua Catchment at Tyrees Ford using NIWA HIRDS Version 2 for various return period and duration are shown in Table 2 below:

**Table 2 HIRDS v2 data relating to the NIWA automatic rain gauge site at Tyrees Ford**

| ARI | Storm Duration | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **10m** | **20m** | **30m** | **60m** | **2h** | **6h** | **12h** | **24h** | **48h** | **72h** |
| 2 | 10.3 | 15.2 | 19.1 | 28.2 | 38.9 | 64.8 | 89.4 | 123.4 | 148.1 | 164.7 |
| 10 | 14.4 | 21.4 | 27.0 | 40.1 | 55.1 | 91.3 | 125.6 | 172.7 | 206.9 | 230 |
| 20 | 16.5 | 24.6 | 31.1 | 46.3 | 63.6 | 105.2 | 144.5 | 198.4 | 237.6 | 264.1 |
| 30 | 17.9 | 26.7 | 33.8 | 50.5 | 69.3 | 114.5 | 157.1 | 215.5 | 258.1 | 286.8 |
| 40 | 19.0 | 28.4 | 36.0 | 53.8 | 73.7 | 121.6 | 166.8 | 228.8 | 273.9 | 304.3 |
| 50 | 19.9 | 29.8 | 37.7 | 56.5 | 77.4 | 127.6 | 174.9 | 239.7 | 286.9 | 318.8 |
| 60 | 20.7 | 31.0 | 39.3 | 58.8 | 80.6 | 132.7 | 181.9 | 249.2 | 298.2 | 331.2 |
| 80 | 22.0 | 33.0 | 41.8 | 62.7 | 85.9 | 141.4 | 193.6 | 265.0 | 317.1 | 352.2 |
| 100 | 23.1 | 34.7 | 44.0 | 66.0 | 90.3 | 148.5 | 203.3 | 278.2 | 332.9 | 369.7 |
| 125 | 24.3 | 36.4 | 46.3 | 69.5 | 95.0 | 156.2 | 213.7 | 292.3 | 349.6 | 388.2 |
| 150 | 25.3 | 38.0 | 48.2 | 72.5 | 99.1 | 162.8 | 222.6 | 304.4 | 364 | 404.2 |

The areal rainfall depths for a 100 year ARI storm at this location can be computed as follows, based on the ARF given in Table 1 above, and different duration rainfall depths given in Table 2 above. The rainfall depth used in the analysis is highlighted for the 100 year ARI event. The TP108 ARF for a catchment area of 100 km$^2$ and time of concentration of 6 hours is applied to all durations. With the ARF proposed by Shamseldin, areal rainfall has been calculated based on storm duration.

**Table 3 Areal Rainfall for Tyrees Ford to be applied for 100 Year ARI event on 100 km$^2$ catchment Area**

| Source | Storm Duration 30m | 60m | 2h | 6h | 12h | 24h | Comment |
|---|---|---|---|---|---|---|---|
| UKFSR (NERC 1975) | 32 | 52 | 76 | 134 | 187 | 262 | ARF based on duration |
| UKFEH (NERC 2008) | 33 | 53 | 77 | 134 | 189 | 264 | ARF based on duration |
| TP108 (1999) | 38 | 57 | 78 | 128 | 175 | 239 | ARF of 0.86 applied to all time intervals |
| Shamseldin (2008) TP108 review | 33 | 53 | 77 | 134 | 189 | 264 | ARF based on duration |
| ARR (1987) | 35 | 57 | 83 | 141 | 195 | 270 | ARF based on duration |

Using Table 3 above, indicative point rainfall equivalents have been derived for the 100 year ARI Areal rainfall data and are given in Table 4 below. For flood modeling, the storm duration used for the overall Kerikeri catchment is likely to fall in the range 6 hours to 24 hours depending on the storm profile used. The rainfall depth used in the analysis is highlighted for the 100 year ARI event. The intensity at shorter time intervals will be determined by the storm profile used. In relation to the 6 hours to 24 hours storm duration range, it can be seen that the existing TP108 ARFs result in lower areal rainfall depths for the Maungaparerua sub-catchment, with point rainfall equivalent ARIs of just 50 years.

**Table 4 ARI of HIRDS v2 Point Rainfall equivalent for Areal Rainfall to be applied (closest ARI)**

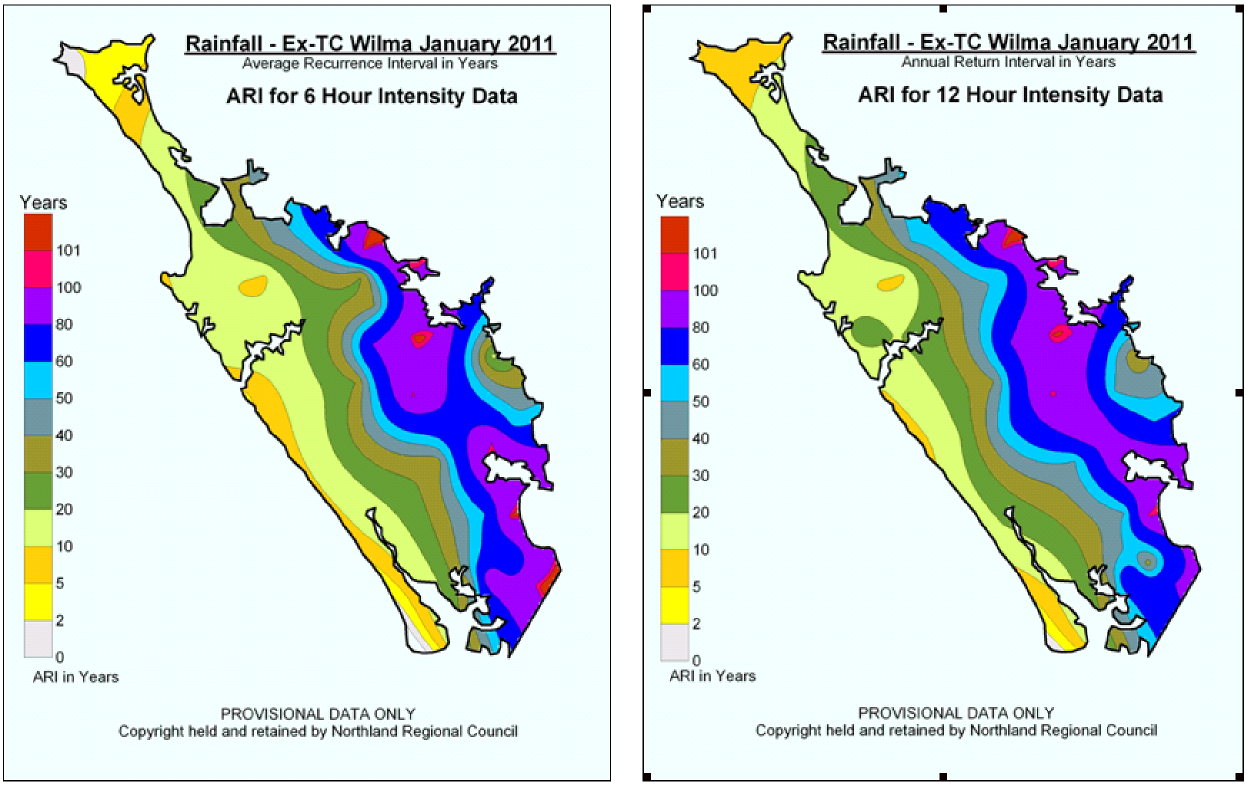
| Source | Area (km2) | Storm Duration 30m | 60m | 2h | 6h | 12h | 24h | Comment |
|---|---|---|---|---|---|---|---|---|
| UKFSR (NERC 1975) | 100 | >20 | >30 | <60 | >60 | >60 | <80 | ARF based on duration |
| UKFEH (NERC 2008) | 100 | 30 | 40 | 50 | >60 | >60 | 80 | ARF based on duration |
| TP108 (1999) | 100 | 50 | 50 | 50 | 50 | 50 | 50 | ARF of 0.86 applied to all time intervals |
| Shamseldin (2008) TP 108 Review | 100 | 30 | 40 | 50 | 60 | <80 | 80 | ARF based on duration |
| ARR 1987 | 100 | >40 | 50 | >60 | 80 | 80 | >80 | ARF based on duration |

The 100 year 24-hour areal rainfall of 239 mm derived above from the TP108 ARF, has a point rainfall equivalent of just over 20 years, when compared with HIRDS v3 point rainfall data. This could have significant implications for catchment modeling based on HIRDSv2 data, where a TP108 ARF was used.

Were the Maungaparerua sub-catchment to be modeled as a discrete catchment of 11 km$^2$, with an actual time of concentration around 2 hours, a higher TP108 ARF in the range 0.93 – 1.0 could be used, but the intention here is to assess the implications of ARFs at the sub-catchment level, where a universal ARF has been applied to the overall catchment.

Recent events in Northland, including the March 2007, July 2007 and January 2011 storms have shown that weather systems can bring sustained rainfall over wide areas. The NRC has produced provisional plots of rainfall ARI associated with the recent ex Tropical cyclone Wilma, relative to HIRDS v3 point rainfall (see **Figure 2**). These show extensive areas which experienced point rainfall in excess of an 80 year ARI over the 6 and 12 hour time intervals.

Figure 2 **Northland Ex-Cyclone Wilma: Provisional ARI for 6-hour and 12-hour time intervals**




### 2.1.4 FLOWS AND FLOOD LEVELS WITH AND WITHOUT ARF

The peak flows and peak flood levels at upper end, middle and lower end of the Maungaparerua Stream catchment were extracted for the 100 year ARI storm event from detailed modelling of the catchment and are shown in Table 5 below.

**Table 5 Peak Flows and Peak Flood Levels at various Locations along Maungaparerua stream**

| Location | Peak Flood Flow ($m^3/s$) | | | Peak Flood Level (m RL) | | |
|---|---|---|---|---|---|---|
| | Without ARF | With ARF | % Reduction | Without ARF | With ARF | % Depth Reduction |
| Upper most | 23.9 | 19.9 | 16.7 | 251.20 | 251.01 | 6.3 |
| Middle | 196.0 | 164.2 | 16.2 | 167.06 | 166.93 | 6.7 |
| Weir | 238.4 | 204.4 | 14.3 | 154.75 | 154.38 | 6.0 |
| Outfall | 303.7 | 260.5 | 14.2 | 78.08 | 77.54 | 7.4 |

It can be seen from the above table that the flow reduction at various locations due to the application of ARF lies in the range 14.2% to 16.7% with largest reduction being at the upper most end of the catchment.

The peak flow at the lower most location of the Maungaparerua Stream using a single catchment concept using the average slope, longest flowpath and lumping all the impervious area into a single catchment was found to be approximately 307.8 $m^3/s$ without ARF while that with ARF was estimated to be 250.2 $m^3/s$. The effect of incorporating detailed modelling for the Maungaparerua catchment is not particularly pronounced relative to representing it as a single catchment. It is possible that this is due to limited catchment area and gentle gradient. The effects of Tyrees Ford weir might has an impacts on the hydraulics of the channel system under detailed modelling producing higher flow at the downstream of the weir.

### 2.1.5 ASSESSMENT OF IMPACTS

The flow using ARF for single catchment is approximately 18% lower than that found (303.7 $m^3/s$) in Table 5 without ARF. On the other hand, applying ARF on detailed computer modelling of a catchment the peak flow was found to be 14.2% lower at the lower end of the catchment and 16.7% lower at the upper most catchment. The effects of using ARF at subcatchment level will have significant impacts in sizing the stormwater asset which will have significant impact on the flooding at the property level and is not desirable.

## 2.2 AWANUI RIVER CATCHMENT

### 2.2.1 CATCHMENT

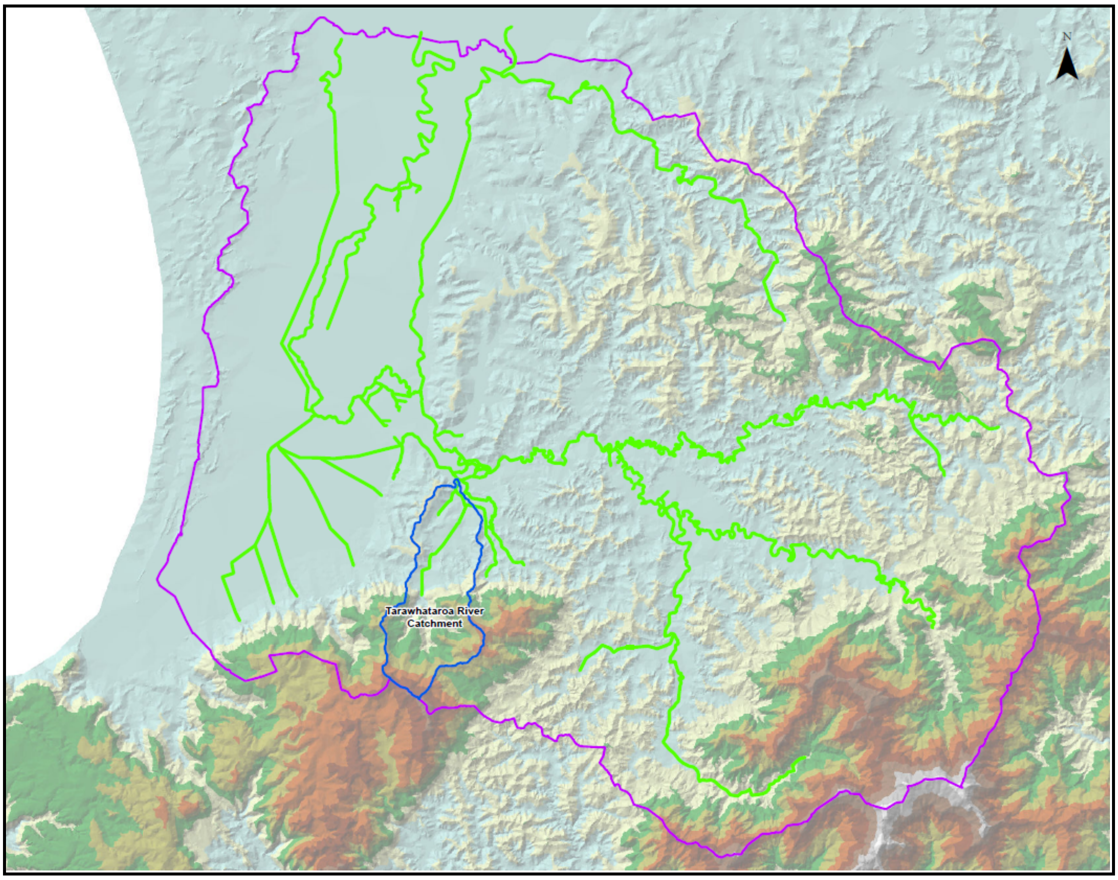
The Awanui catchment drains to the Rangaunu harbour on the North coast of Northland at 173°16'E, 35°00'S. The overall modeled catchment area is 455 $km^2$, a large part of which is an extensive flood plain located between Kaitaia and the harbour. The catchment area of the Awanui River at Kaitaia is 222 $km^2$ to the NIWA river gauge at School Cut. The main tributaries of the Awanui upstream of Kaitaia are the Takahue and Victoria Rivers, and the Karemuhako Stream. The headwaters of these tributaries are on the northern slopes of the Maungataniwha range South of Kaitaia. The geology is characterized by Tangihua volcanics, a complex of several basic volcanic rocks of submarine origin, and accompanying sedimentary material originating from the Northland allochthon (NRC 2005).

The Tarawhataroa stream joins the Awanui River downstream of Kaitaia, by way of the Tangonge drain and Waihoe channel. Through Kaitaia, the Awanui River and Tarawhataroa stream run parallel towards the northwest, approximately 350 metres apart through the narrow gap on which the Kaitaia CBD is located. In moderately large flood events, the Awanui River overflows across the SH1 and into the Tarawhataroa catchment, just upstream of Kaitaia. The Tarawhataroa catchment has an area of 22 $km^2$ to the NRC river gauge at Puriri Place located on the South side of the town.

Lag times of the Awanui and Tarawhataroa catchments are approximately 12 hours and 2-3 hours respectively. In a storm of short duration, the peak of the Tarawhataroa generally arrives at Kaitaia approximately 9 - 10 hours before the peak of the Awanui, however it is not unusual for the Tarawhataroa to have several peaks, reflecting intermittent bursts of rainfall within the catchment. In July 2007, the Tarawhataroa overflowed it banks flooding numerous properties alongside the stream. This occurred due to overflow from the Awanui River at a time when flood levels in the Tarawhataroa were still high, at 4 metre staff gauge. The flood risk presented by the Tarawhataroa stream is therefore a significant component of overall flood risk to Kaitaia. It follows that the design storm assumptions made for the Tarawhataroa are also of critical interest to flood risk assessment.

Down stream of Kaitaia, flood waters from the Awanui river can take a number of different routes through the flood plain: The Awanui River itself, the Whangatane spillway, which has an intake from the Awanui River located on the north side of Kaitaia, and the Tarawhataroa Stream channels overflow from the Awanui through Lake Tangonge and back into the Awanui north west of Kaitaia at the Waihoe channel outfall. There are no river gauges near the estuary to record overall catchment lag time, though there is an NRC coastal water level gauge at Ben Gunn wharf at Unahi. From assessment of this record, it appears that the lag time to this point lies in the range 24 – 30 hours for the Awanui River, although it will be significantly less for the Whangatane spillway. An overview of the Awanui River Catchment along with the Tarawhataroa River Catchment is shown in **Figure 3** below.

Figure 3 Overview of the Awanui River Catchment




### 2.2.2 ESTIMATION OF ARF

The ARF for this catchment was estimated by estimating time of concentration for the entire catchment. This was based on estimating the longest flowpath for the entire catchment and determining the average slope along the longest flowpath by equal area method utilizing the LiDAR and 20 m contour data. The time of concentration was estimated to be approximately 20 hours. The ARF based on ARC TP108 is estimated to be 0.81. The point rainfall for various return periods are shown in Table 7 below.

### 2.2.3 RAINFALL

ARF from a number of different guidelines are given in Table 6 below, based on a catchment area of 500 km$^2$, which is slightly larger than the overall modeled catchment size.

**Table 6 ARFs expressed as percentages of point rainfall for a 500 km$^2$ catchment area**

| Source | Storm Duration | | | | | | Comment |
|---|---|---|---|---|---|---|---|
| | 30m | 60m | 2h | 6h | 12h | 24h | |
| UKFSR (NERC 1975) | 57% | 67% | 76% | 85% | 88% | 91% | Comment |
| UKFEH (NERC 2008) | 61% | 70% | 77% | 85% | 88% | 91% | Time intervals relate to storm duration, from fig 4.1, Shamseldin 2008 |
| TP108 1999 | 68% | 70% | 72% | 76% | 79% | 81% | Time intervals relate to storm duration, from fig 3.4 FEH Vol 4 |
| Shamseldin TP108 Review | 60% | 65% | 77% | 85% | 88% | 93% | ARF based on Time of Concentration, from Table 2.2 TP108 1999 |
| ARR 1987, revised 1998 | 57% | 72% | 81% | 89% | 92% | 93% | ARF based on Storm duration from Table 3.1 Shamseldin 2008 |

Estimated HIRDS v3 rainfall depths increase from North to South and reach a range of 275 mm – 300 mm (100 year ARI, 24-Hour) in the catchment headwaters of the Tarawhataroa. Maximum HIRDS v3 rainfall depths in the South East of the Awanui catchment reach a range of 325 – 350 mm (100 year ARI, 24-Hour).

The HIRDS v2 data relating to the mid-point of the Tarawhataroa catchment is shown in Table 7 below. HIRDS v2 is referred to in this paper as much of the related runoff modeling pre-dates the introduction of HIRDS v3. The HIRDS v3 100 year ARI 24-Hour predicted rainfall depth is 30% higher than the HIRDS v2 equivalent for this site, 246.8 mm against 189.5 mm for HIRDS v2.

**Table 7 HIRDS v2 data relating to a mid-point for the Tarawhataroa sub-catchment, Awanui**

| ARI | Storm Duration | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10m | 20m | 30m | 60m | 2h | 6h | 12h | 24h | 48h | 72h |
| 2 | 10.2 | 15.0 | 18.7 | 27.5 | 35.4 | 53.0 | 68.3 | 88.1 | 103 | 112.9 |
| 10 | 14.4 | 21.3 | 26.8 | 39.8 | 50.8 | 74.6 | 95.0 | 121.1 | 143.5 | 158.5 |
| 20 | 16.6 | 24.6 | 31.1 | 46.4 | 58.8 | 85.8 | 108.8 | 138.1 | 164.5 | 182.3 |
| 30 | 18.0 | 26.9 | 34.0 | 50.8 | 64.2 | 93.2 | 118.0 | 149.2 | 178.4 | 198.0 |
| 40 | 19.1 | 28.6 | 36.2 | 54.2 | 68.4 | 99.0 | 125.0 | 157.8 | 189.1 | 210.2 |
| 50 | 20.0 | 30.0 | 38.0 | 57.0 | 71.9 | 103.7 | 130.8 | 164.9 | 197.9 | 220.2 |
| 60 | 20.8 | 31.2 | 39.6 | 59.5 | 74.9 | 107.8 | 135.8 | 171.0 | 205.5 | 228.9 |
| 70 | 21.6 | 32.3 | 41.0 | 61.6 | 77.5 | 111.5 | 140.2 | 176.3 | 212.2 | 236.6 |
| 80 | 22.2 | 33.3 | 42.3 | 63.6 | 79.9 | 114.7 | 144.2 | 181.1 | 218.3 | 243.4 |
| 100 | 23.3 | 35.0 | 44.5 | 67.0 | 84.1 | 120.4 | 151.1 | 189.5 | 228.8 | 255.5 |
| 125 | 24.5 | 36.9 | 46.9 | 70.7 | 88.6 | 126.5 | 158.4 | 198.4 | 240.1 | 268.3 |

The areal rainfall depths for a 100 year ARI storm at this location are shown in Table 8 below, based on the ARF given in Table 6 above, and different duration rainfall depths given in Table 7 above. The rainfall depth used in the analysis is highlighted for the 100 year ARI event. For the purposes of calculating aerial rainfall with the TP108 ARF a time of concentration of 24 hours is applied to all time intervals, giving a reduction factor of 0.81 for a 500 km$^2$ catchment. With the ARF proposed by Shamseldin, areal rainfall has been calculated based on storm duration.

**Table 8 Areal Rainfall for Tarawhataroa to be applied for 100 Year ARI event on catchment of 500 km$^2$**

| Source | Storm Duration | | | | | | Comment |
|---|---|---|---|---|---|---|---|
| | 30m | 60m | 2h | 6h | 12h | 24h | |
| UKFSR (NERC 1975) | 25 | 45 | 64 | 102 | 133 | 172 | ARF based on duration |
| UKFEH (NERC 2008) | 27 | 47 | 65 | 102 | 133 | 172 | ARF based on duration |
| TP108 (1999) | 36 | 54 | 68 | 98 | 122 | 153 | ARF of 0.81 applied to all time intervals |
| Shamseldin (2008) TP108 review | 27 | 44 | 65 | 102 | 133 | 176 | ARF based on duration |
| ARR (1987) | 25 | 48 | 68 | 107 | 139 | 176 | ARF based on duration |

Using Table 8 above, Point rainfall equivalents have been derived for the 100 year ARI areal rainfall based on rainfall data as shown in Table 7 above. These are shown in Table 9 below. The rainfall depth used in the analysis is highlighted for the 100 year ARI event. For flood modeling, the storm duration used for the overall Awanui catchment is likely to fall in the range 12 hour to 48 hour depending on the storm profile used. The Awanui River at Kaitaia, which is the most critical area in terms of risk assessment, has a time of concentration of less than 12 hours which is a justification for considering shorter design storm durations. The intensity at shorter time intervals will be determined by the storm profile used. In relation to the 12 hour to 24 hour storm duration range, it can be seen that the existing TP108 ARFs result in lower areal rainfall depths for the Tarawhataroa sub-catchment, with point rainfall equivalent ARIs of less than 40 yrs.

**Table 9 ARI of HIRDS v2 Point Rainfall equivalent for Areal Rainfall to be applied (closest ARI)**

| Source | Area (km2) | Storm Duration | | | | | | Comment |
|---|---|---|---|---|---|---|---|---|
| | | 30m | 60m | 2h | 6h | 12h | 24h | |
| UKFSR (NERC 1975) | 100 | 10 | 20 | 30 | 50 | <60 | 60 | ARF based on duration |
| UKFEH (NERC 2008) | 100 | 10 | 20 | 30 | 50 | <60 | 60 | ARF based on duration |
| TP108 (1999) | 100 | 40 | 40 | 40 | 40 | <40 | <40 | ARF of 0.81 applied to all time intervals |
| Shamseldin (2008) TP 108 Review | 100 | 10 | <20 | 30 | 50 | <60 | <80 | ARF based on duration |
| ARR 1987 | 100 | 10 | <30 | 40 | 60 | >60 | <80 | ARF based on duration |

### 2.2.4 FLOWS AND FLOOD LEVELS WITH AND WITHOUT ARF

The peak Flows and peak flood levels at upper end, middle and lower end of the Tarawhataroa River catchment were estimated for the 100 year ARI storm event using the DHI software packages and are shown in Table 10 below.

**Table 10 Peak Flows and Peak Flood Levels at various Locations along Tarawhataroa River**

| Location | Peak Flood Flow ($m^3/s$) | | | Peak Flood Level (m RL) | | |
|---|---|---|---|---|---|---|
| | Without ARF | With ARF | % Reduction | Without ARF | With ARF | % Depth Reduction |
| Upper most | 87.6 | 65.7 | 25.0 | 41.94 | 41.79 | 11.1 |
| Middle | 121.6 | 93.2 | 23.4 | 31.20 | 30.77 | 9.7 |
| Outfall | 153.5 | 117.2 | 23.6 | 20.40 | 20.02 | 8.2 |

It can be seen from the above table that the flow reduction at various locations due to the application of ARF varies from 23.4% to 25.0% with largest reduction being at the upper most end of the catchment.

The peak flow at the lower end of Tarawhataroa River catchment before meeting a side channel a single catchment concept using average slope, longest flowpath and lumping all the impervious area into single catchment was found to be approximately 193.1 $m^3/s$ without ARF while that with ARF was estimated to be 146.9 $m^3/s$.

### 2.2.5 ASSESSMENT OF IMPACTS

The flow with ARF for single catchment is approximately 4% higher than that found (153.5 $m^3/s$) in Table 12 without ARF. It can be noted that the single catchment concept doesn't consider the volume in Tarawhataroa River and if it is considered the difference will be reduced. On the other hand, applying ARF on detailed computer modelling of the catchment the peak flow with ARF was found to be 23.6% lower at the lower end of the catchment and 25.0% lower at the upper most catchment. The effects of using ARF at subcatchment level will have significant impacts on the size of the stormwater asset which will impact the flooding at the property level and is not desirable.

## 2.3 PUHINUI CATCHMENT

### 2.3.1 CATCHMENT

The Puhinui Catchment covers a total land area of some 2,960 hectares including the area of the proposed Manukau City Growth Centre which is approximately 153 hectares.

The Puhinui Catchment has its headwaters rising from the eastern ridge which follows Redoubt Road. The Puhinui Catchment is roughly bounded by:

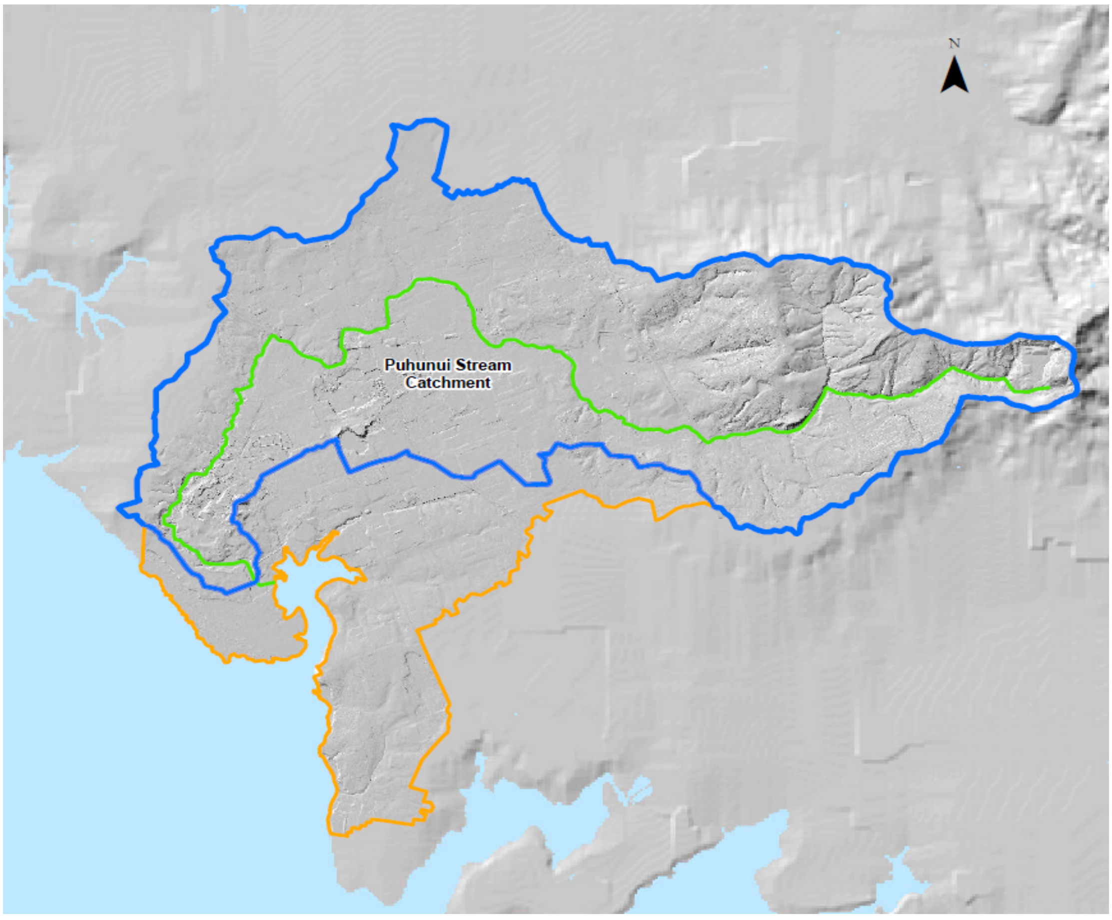
- Redoubt Road, Great South Road, Fairview Road and Pah Road in the north bounding Pukaki Waokauri and Papatoetoe Tamaki Catchment
- Weymouth Road, Wordsworth Road, Browns Road, Hill Road and Grande Vue Road in the south along the ridgeline bounding the Pahurehure ICMP Catchment
- Redoubt Road in the east
- Manukau Harbour and a ridge line in the west bounding Papatoetoe and Tamaki ICMP Catchment

The Puhinui Catchment maintains a westerly aspect. Catchment elevation ranges from 165 mRL along the eastern ridgeline to approximately mean sea level at the western boundary. It slopes steeply down from its eastern boundary to the Botanical Garden/Southern Motorway area then gently slopes until its outfall at the Manukau Harbour.

The proposed Manukau City Growth Centre is roughly bounded by Ryan Place and Cavendish Drive in the north, Puhinui Stream and the proposed motorway extension in the south, the Southern Motorway in the east and Lambie Drive in the west. An overview of the catchment is shown in **Figure 4** below.

The Institute of Geological & Nuclear Sciences broadly maps the geology of the area within the catchment as comprised of Waitemata Group sediments covering the eastern part, alluvial sediments in the central part, and basalt flows and tuffs of Auckland Volcanic fields covering the lower part of the catchment.

Figure 4 Overview of the Puhinui Stream Catchment



### 2.3.2 ESTIMATION OF ARF

The ARF for the catchment was estimated based on original TP108 of the previous Auckland Regional Council (ARC). This is based on catchment area and time of concentration. Puhinui Catchment has a total area of approximately 2960 ha of which about 2160 ha contributes to Puhinui Stream discharging into Manukau Harbour and the remaining area discharges into the harbour directly. The catchment characteristic of the area that discharges into the Puhinui Stream was used for estimating the time of concentration. This was based on estimating the longest flowpath for this catchment and determining the average slope along the longest flowpath by equal area method utilizing the LiDAR contour data. The time of concentration was estimated to be approximately 3 hours. The ARF based on ARC TP108 is estimated to be 0.91. The point rainfall for various return periods with ARF are shown in Table 11 below.

### 2.3.3 RAINFALL

The rainstorm profiles adopted for this investigation were derived following the procedures outlined in the Auckland Regional Council Technical Publication 108 (TP108). The calibrated Puhinui Creek Catchment model was used to simulate the 100 year ARI TP108 design storms both for the Maximum Probable Development landuse scenarios. The 24-hour TP108 total rainfall for different ARI rain storms used for the flood hazard mapping is shown in the following Table 11.

**Table 11 ARC TP108 24-hour total Rainfall Depth for various ARI Rain Storms for Puhinui Catchment**

| ARI Rain Storm | 24-hour total Rainfall Depth (mm) | 24-hour total Rainfall Depth (mm) with ARF |
|---|---|---|
| 2 Year | 80 | 72.8 |
| 5 Year | 115 | 104.7 |
| 10 year | 145 | 132.0 |
| 100 Year | 225 | 204.8 |

### 2.3.4 FLOWS AND FLOOD LEVELS WITH AND WITHOUT ARF

The peak Flows and peak flood levels at upper end, middle and lower end of the catchment were estimated using computer model and are shown in Table 12 below.

**Table 12 Peak Flows and Peak Flood Levels at various Locations along Puhinui stream**

| Location | Peak Flood Flow ($m^3/s$) | | | Peak Flood Level (m RL) | | |
|---|---|---|---|---|---|---|
| | Without ARF | With ARF | % Reduction | Without ARF | With ARF | % Depth Reduction |
| Upper most | 5.3 | 4.7 | 11.3 | 53.01 | 52.96 | 5.0 |
| Upper | 26.1 | 22.3 | 14.6 | 38.44 | 38.34 | 1.1 |
| Middle | 76.0 | 65.9 | 13.3 | 20.61 | 20.45 | 3.0 |
| Lower | 137.4 | 126.4 | 8.0 | 1.80 | 1.75 | 1.7 |

It can be seen from the above table that the flow reduction at various locations due to the application of ARF is in the range 8% to 14.6% with largest reduction being at the upper end of the catchment.

The peak flow at the lower most location of the catchment using a single catchment concept using the average slope, longest flowpath and lumping all the impervious area into single catchment was found to be approximately 162.9 $m^3/s$ without ARF while that with ARF was estimated to be 143.5 $m^3/s$.

### 2.3.5 ASSESSMENT OF IMPACTS

The flow with ARF for single catchment is approximately 5% higher than that found (137.4 $m^3/s$) in Table 12 without ARF. It can be noted that the single catchment concept doesn't consider the volume in Puhinui Stream and if it is considered the difference will be reduced. On the other hand, applying ARF on detailed computer modelling of the catchment the peak flow with ARF was found to be 8% lower at the lower end of the catchment and 11.3% at the upper most catchment. The effects of using ARF at subcatchment level will have significant impacts on the size of the stormwater asset which will impact the flooding at the property level and is not desirable.

## 2.4 OPANUKU/ORATIA STREAMS CATCHMENT

### 2.4.1 CATCHMENT

The Opanuku / Oratia Streams Catchment cover a total land area of some 6,000 hectares and has its headwaters located on the eastern and southern slopes of the Waitakere Ranges. The Opanuku and Oratia Streams pass through the alluvial foothills and down to the lowlands where the two major streams join at Cranwell Park (beside Alderman Drive), Henderson. The stream ultimately discharges via the Henderson Creek Estuary to the Upper Waitemata Harbour. All stormwater discharges to the Henderson Creek Estuary with no flow passing to adjacent catchments.

The Opanuku / Oratia Streams Catchment maintains a northerly aspect. It slopes steeply down from its southern and eastern boundaries along the Waitakere Ranges towards the receiving environment at the northern end adjacent to the North Western Motorway. The elevation ranges from 360 mRL along the ridgelines to approximately mean sea level on the northern tidal boundary.

The major tributaries discharging into the major catchment stream reach sections are:

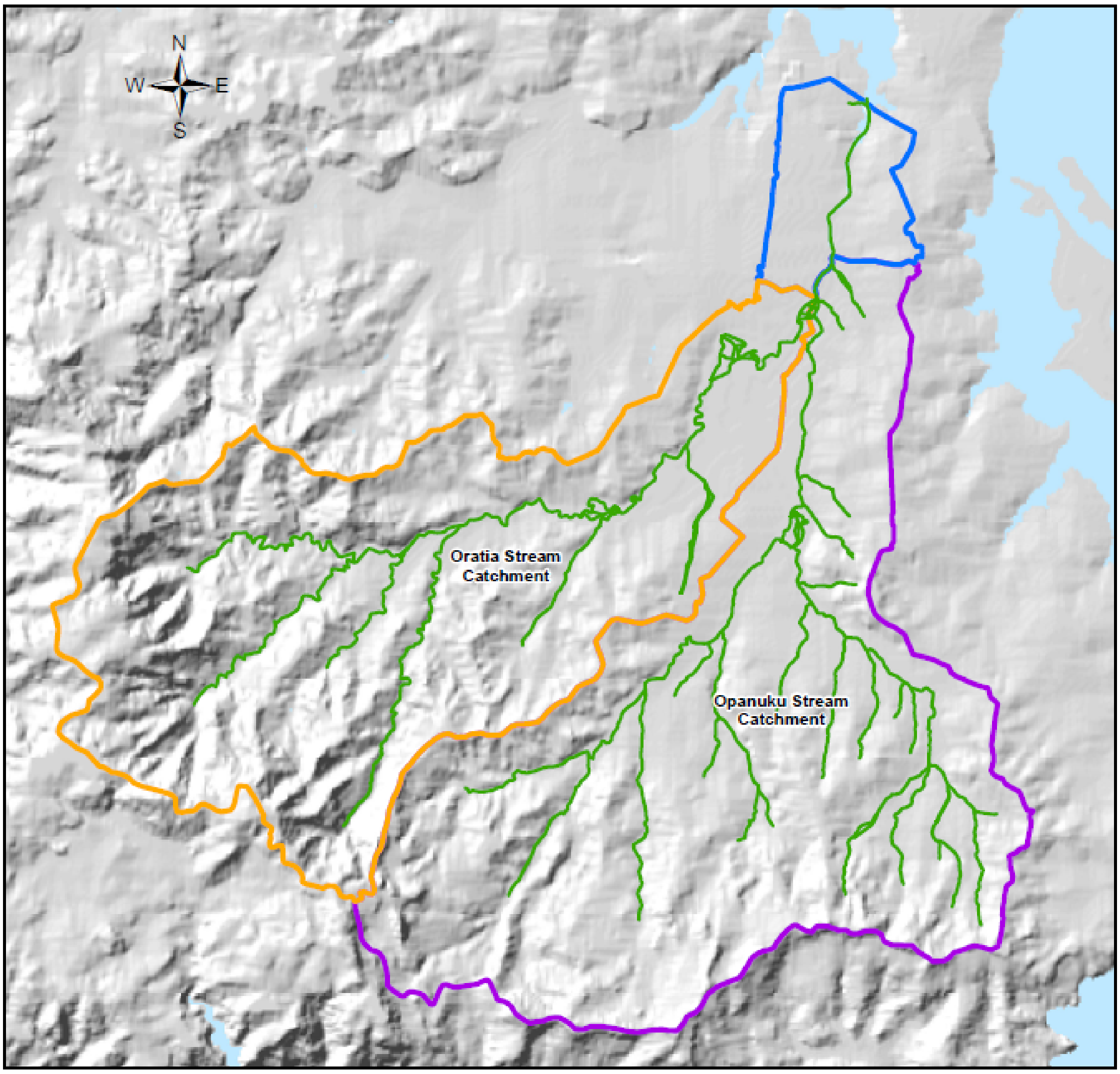
- Opanuku Stream includes: Stoney Creek, Parekura Stream, Driving Stream, Anamata Stream and Waitaro Channel
- Oratia Stream includes: Potters Stream, Cochrane Stream, Kaurimu Stream, Sunde Creek, Cable Stream, Sharpe Stream and Waikumete Stream
- Waikumete Stream includes: Parrs Stream, Tangutu Stream, Waikaukau Stream, Woodvale Stream, Ambler Stream, Whakarina Stream, Hibernia Stream, and Bishop Stream
- Lower Oratia and Lower Opanuku Streams includes: Warri Stream, Millbrook Road Crossing Stream, Edmonton Road Crossing Stream, and Central Park Drive Crossing Stream

Most of the reaches of these tributaries mentioned above have contributing piped stormwater reticulation systems.

The Institute of Geological & Nuclear Sciences broadly maps the geology of the majority of the area within the Opanuku / Oratia Streams Catchment as comprised of both the Cornwallis Formation (Mwc) (covering the Upper Opanuku Stream and its tributaries, Upper Oratia Stream and its tributaries, Upper Waikumete Stream and upper regions of its tributaries) and the East Coast Bays Formation (Mwe) (covering the area east of the Lower Waikumete Stream and Lower Oratia Stream). Both of these are members of the Waitemata Group mudstones and sandstone that dominate much of the Auckland area.

Generally, both members are described as "alternating sandstone and mudstone with variable volcanic content and interbedded, volcanic-clastic grit beds". An overview of the catchment is shown in **Figure 5** below.

Figure 5 Overview of the Opanuku/Oratia Streams Catchment




### 2.4.2 ESTIMATION OF ARF

The ARF for the catchment was estimated using the method stated earlier. Opanuku/Oratia Streams Catchment has a total area of approximately 6,000 ha of which about 2560 ha contributes to Oratia Stream and the remaining area discharges into the Opanuku Stream. Both Opanuku and Oratia Streams discharge into Henderson Creek which ultimately discharges into Waitemata Harbour. The catchment characteristic was used for estimating the time of concentration. This was based in estimating the longest flowpath and determining the average slope along the longest flowpath by equal area method utilizing the LiDAR contour data. The time of concentration was estimated to be approximately 3.2 hours. The ARF based on ARC TP108 is estimated to be 0.85. The point rainfall for various return periods with ARF are shown in Table 13 below.

### 2.4.3 RAINFALL

The rainstorm profiles adopted for this investigation were derived following the procedures outlined in the Auckland Regional Council Technical Publication 108 (TP108). The calibrated Opanuku / Oratia Streams Catchment model was used to simulate the 100 year ARI TP108 design storms for the Maximum Probable Development landuse scenarios. The 24-hour TP108 total rainfall for different ARI rainstorms used for the floodplain mapping is shown in the following Table 13.

**Table 13 ARC TP108 24-hour total Rainfall Depth for various ARI for Opanuku/Oratia**

| ARI Rain Storm | 24-hour total Rainfall Depth (mm) | 24-hour total Rainfall Depth (mm) with ARF |
|---|---|---|
| 2 Year | 85 | 68.9 |
| 5 Year | 120 | 97.2 |
| 50 year | 175 | 141.8 |
| 100 Year | 195 | 158.0 |

### 2.4.4 FLOWS AND FLOOD LEVELS WITH AND WITHOUT ARF

The peak Flows and peak flood levels at upper end, middle and lower end of the catchment were estimated for the 100 year ARI storm event using computer model and are shown in Table 14 below.

**Table 14 Peak Flows and Peak Flood Levels at various Locations along Oratia stream**

| Location | Peak Flood Flow ($m^3/s$) | | | Peak Flood Level (m RL) | | |
|---|---|---|---|---|---|---|
| | Without ARF | With ARF | % Reduction | Without ARF | With ARF | % Depth Reduction |
| Upper most | 49.7 | 33.6 | 32.4 | 88.36 | 88.20 | 21.1 |
| Middle | 234.3 | 167.4 | 28.6 | 18.64 | 18.42 | 4.7 |
| Vintage Res. | 233.6 | 167.8 | 28.2 | 12.42 | 12.03 | 5.3 |
| Outfall | 206.2 | 158.9 | 22.9 | 6.71 | 5.98 | 10.0 |

It can be seen from the above table that the flow reduction at various locations due to the application of ARF various from 22.9% to 32.4% with largest reduction being at the upper end of the catchment.

The peak flow at the lower most location of the Oratia Stream using a single catchment concept using the average slope, longest flowpath and lumping all the impervious area into single catchment was found to be approximately 287.2 $m^3/s$ without ARF while that with ARF was estimated to be 217.4 $m^3/s$.

### 2.4.5 ASSESSMENT OF IMPACTS

The flow using ARF for single catchment is approximately 5% higher than that found (206.2 $m^3/s$) in Table 14 without ARF. It can be noted that the single catchment concept doesn't consider the volume in the Stream and doesn't involving any hydraulic. If these are considered then the difference will certainly reduce. On the other hand, applying ARF on detailed computer modelling of a catchment the peak flow was found to be 22.9% lower at the lower end of the catchment and 32.4% lower at the upper most catchment. The effects of using ARF at subcatchment level will have significant impacts in sizing the stormwater asset which will have significant impact on the flooding at the property level and is not desirable.

# 3 RAINFALL VARIABILITY ACROSS A CATCHMENT

There are spatial and temporal variability of rainfall across a catchment. The magnitude of variability depends of the size and orographic characteristics of a certain catchment. This section describes an analysis of the spatial variability of rainfall across the Opanuku /Oratia Streams Catchment.

Frequency analysis of precipitation over an area is not well developed compared to the analysis of point precipitation. In absence of information on the true probability distribution of areal precipitation, this analysis was undertaken comparing the event total rainfall depth and event 10-minute maximum intensity at all 18 raingauges located in and around this catchment. A total of seven rainfall events up to a 5 year ARI event including the four events used for the calibration/validation of the Opanuku/Oratia Model were investigated. The duration of the selected rainfall events are provided in the following Table 15.

Table 15 Duration of Rainfall Events Selected for variability Analysis

| **Event No.** | **Start Date and Time** | **End Date and Time** |
|---|---|---|
| 1 | 28/06/2000 07:20:00 | 29/06/2000 05:28:00 |
| 2 | 04/09/2001 12:22:00 | 04/09/2001 22:00:00 |
| 3 | 08/06/2003 22:50:00 | 09/06/2003 05:00:00 |
| 4 | 01/05/2004 06:35:00 | 02/05/2004 03:00:00 |
| 5 | 01/02/2004 15:00:00 | 02/02/2004 09:00:00 |
| 6 | 11/07/2005 13:30:00 | 12/07/2005 01:00:00 |
| 7 | 01/10/2006 11:30:00 | 03/10/2006 00:00:00 |

Total rainfall depth (D) and 10-minute maximum intensity (I) for each event are presented in the following Table 16.

**Table 16 Event Total Depth and 10-Minute Maximum Intensity for various Rainfall Events**

| **Gauge No.** | **Event Total Depth (mm) and 10-Minute Maximum Intensity (mm/hr)** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Event 1 | | Event 2 | | Event 3 | | Event 4 | | Event 5 | | Event 6 | | Event 7 | |
| | D | I | D | I | D | I | D | I | D | I | D | I | D | I |
| 648513 | 87.4 | 48.9 | 61.8 | 67.5 | 52.4 | 65.7 | 124.2 | 69.8 | 51.6 | 15.3 | 64.3 | 51.2 | 136.5 | 77.8 |
| 648515 | 84.4 | 44.6 | 58.1 | 89.8 | 71.5 | 73.8 | 92.5 | 44.5 | Nil | Nil | 53.6 | 53.6 | 96.8 | 37.6 |
| 648516 | 74.4 | 28.1 | 59.6 | 99.4 | 45.0 | 38.2 | 101.2 | 50.6 | 44.7 | 18.7 | 63.4 | 40.9 | 113.3 | 86.1 |
| 648517 | 86.7 | 62.0 | 58.1 | 88.0 | 50.6 | 58.2 | 114.6 | 64.0 | 53.8 | 19.5 | 58.1 | 52.4 | 97.8 | 39.3 |
| 648612 | 89.9 | 52.1 | 54.3 | 62.0 | 47.4 | 61.2 | 98.2 | 44.6 | 57.7 | 22.8 | 50.2 | 34.9 | 106.4 | 29.2 |
| 648613 | 84.0 | 55.7 | 61.9 | 104.3 | 49.0 | 55.7 | 91.4 | 46.2 | 50.2 | 24.6 | 40.4 | 36.9 | 117.5 | 43.9 |
| 648614 | 87.9 | 57.6 | 38.1 | 15.0 | 21.8 | 25.5 | 94.9 | 42.2 | 82.8 | 46.6 | 43.1 | 34.7 | 133.5 | 52.4 |
| 648625 | 93.2 | 78.5 | 56.3 | 77.2 | 25.2 | 29.6 | 84.1 | 37.5 | 59.4 | 33.3 | 31.6 | 25.2 | 123.9 | 75.8 |
| 648626 | 88.1 | 60.5 | 51.3 | 60.2 | 38.0 | 60.6 | 94.0 | 44.9 | 58.3 | 22.7 | 42.9 | 32.2 | 113.6 | 60.3 |

| | Event Total Depth (mm) and 10-Minute Maximum Intensity (mm/hr) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 648627 | Nil | Nil | 42.5 | 26.4 | 39.2 | 54.3 | 95.9 | 38.7 | 61.8 | 19.1 | 47.6 | 30.8 | 117.1 | 38.2 |
| 649509 | 98.6 | 32.9 | 71.6 | 60.0 | 47.4 | 40.1 | 126.5 | 50.9 | 44.3 | 11.0 | 59.0 | 33.6 | 112.6 | 48.2 |
| 649516 | 85.2 | 59.5 | 57.7 | 78.6 | 61.2 | 84.0 | 150.4 | 76.9 | 58.2 | 20.4 | Nil | Nil | 112.8 | 47.0 |
| 649517 | 88.1 | 60.6 | 58.1 | 93.1 | 58.9 | 73.3 | 136.3 | 62.2 | 54.0 | 16.0 | 60.3 | 55.2 | 107.4 | 48.4 |
| 649518 | 87.0 | 58.3 | 57.4 | 70.1 | 56.1 | 56.1 | 132.9 | 57.7 | 53.5 | 16.5 | 62.5 | 65.4 | 125.0 | 76.7 |
| 649625 | 81.8 | 51.8 | 36.8 | 18.9 | 47.1 | 47.1 | 138.5 | 51.3 | 71.6 | 30.0 | 47.8 | 32.7 | 123.3 | 32.7 |
| 649636 | 83.4 | 43.8 | 45.1 | 46.3 | 54.8 | 54.8 | 115.1 | 59.7 | 60.7 | 26.5 | 55.5 | 56.0 | 102.9 | 34.1 |
| 649637 | 87.7 | 64.6 | 37.7 | 24.1 | 16.8 | 16.8 | 106.1 | 58.8 | 79.6 | 32.3 | 35.4 | 33.3 | 111.8 | 48.1 |
| 649638 | 80.6 | 69.5 | 43.7 | 51.8 | 51.3 | 51.3 | 130.0 | 54.0 | 62.0 | 21.7 | 62.0 | 69.0 | 124.0 | 39.0 |

It should be noted that raingauges. 648515, 648516, 648613, 648625, 649509, 649637 and 648614 as listed in Table 16 are located outside the study catchment while the remaining 11 stations are located inside the catchment.

The rainfall depth factor (DF) and 10-minute maximum intensity factor (IF) at each raingauge relative to the event total rainfall depth (D) and 10-minute maximum intensity (I) at Gauge No. 648626 (Te Pai Park) were estimated and are shown in Table 17 below. This gauge was selected as it is located at the outlet of the Opanuku / Oratia Catchment. Contour plots of the relative depth factor (DF) and relative intensity factor (IF) for the event 4, the largest recorded rainfall event in the catchment, at each gauge location have been prepared and are shown in **Figure 6** below.

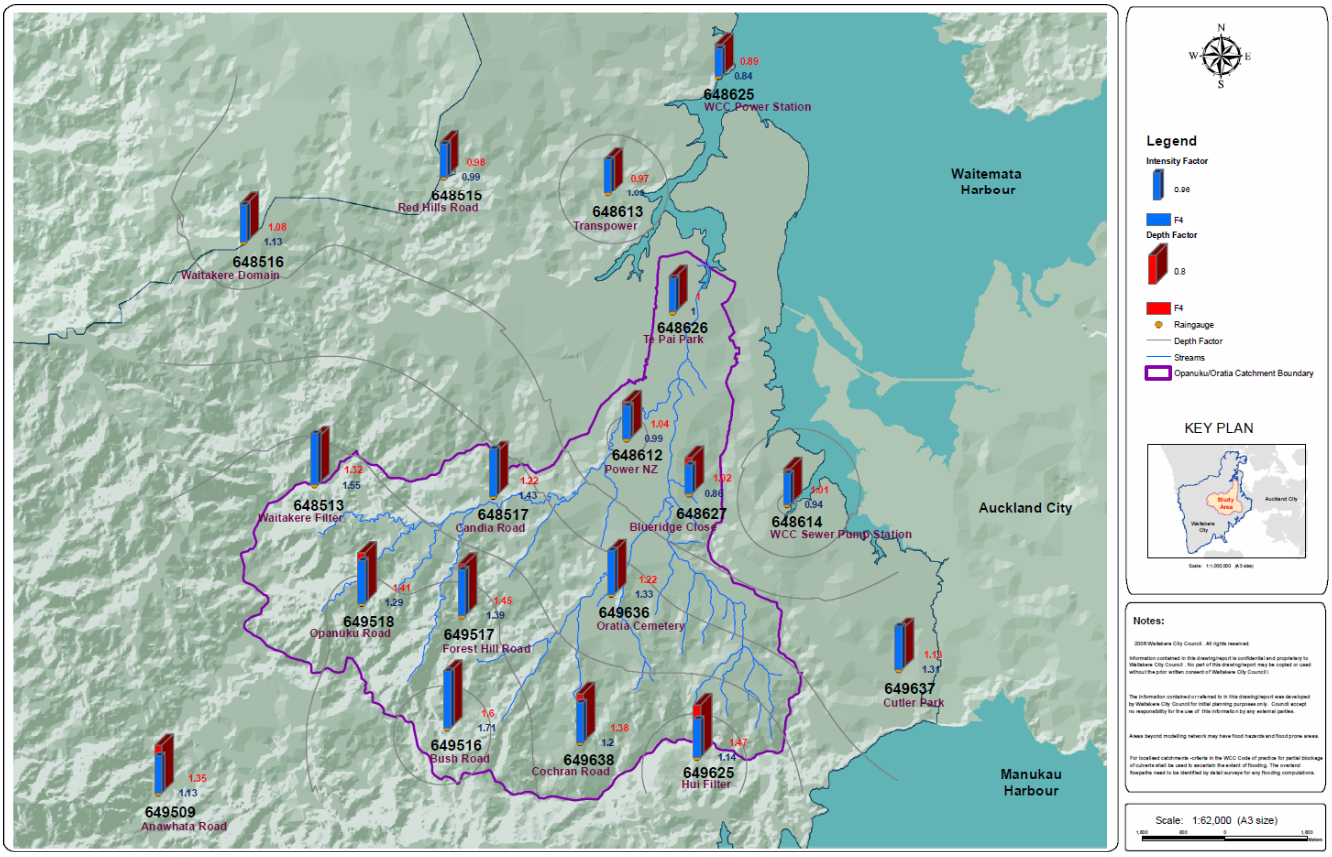
**Table 17 Relative Depth and Maximum 10-Minute Intensity for various Rainfall Events**

| **Gauge No.** | **Relative Depth and Intensity for Various Event** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Event 1 | | Event 2 | | Event 3 | | Event 4 | | Event 5 | | Event 6 | | Event 7 | |
| | DF | IF | DF | IF | DF | IF | DF | IF | DF | IF | DF | IF | DF | IF |
| 648513 | 0.99 | 0.81 | 1.20 | 1.12 | 1.38 | 1.08 | 1.32 | 1.55 | 0.89 | 0.67 | 1.50 | 1.59 | 1.20 | 1.29 |
| 648515 | 0.96 | 0.74 | 1.13 | 1.49 | 1.88 | 1.22 | 0.98 | 0.99 | N/A | N/A | 1.25 | 1.66 | 0.85 | 0.62 |
| 648516 | 0.84 | 0.46 | 1.16 | 1.65 | 1.18 | 0.63 | 1.08 | 1.13 | 0.77 | 0.82 | 1.48 | 1.27 | 1.00 | 1.43 |
| 648517 | 0.98 | 1.02 | 1.13 | 1.46 | 1.33 | 0.96 | 1.22 | 1.43 | 0.92 | 0.86 | 1.35 | 1.63 | 0.86 | 0.65 |
| 648612 | 1.02 | 0.86 | 1.06 | 1.03 | 1.25 | 1.01 | 1.04 | 0.99 | 0.99 | 1.00 | 1.17 | 1.08 | 0.94 | 0.48 |
| 648613 | 0.95 | 0.92 | 1.21 | 1.73 | 1.29 | 0.92 | 0.97 | 1.03 | 0.86 | 1.08 | 0.94 | 1.15 | 1.03 | 0.73 |
| 648614 | 1.00 | 0.95 | 0.74 | 0.25 | 0.57 | 0.42 | 1.01 | 0.94 | 1.42 | 2.05 | 1.00 | 1.08 | 1.18 | 0.87 |
| 648625 | 1.06 | 1.30 | 1.10 | 1.28 | 0.66 | 0.49 | 0.89 | 0.84 | 1.02 | 1.47 | 0.74 | 0.78 | 1.09 | 1.26 |
| 648626 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 648627 | N/A | N/A | 0.83 | 0.44 | 1.03 | 0.90 | 1.02 | 0.86 | 1.06 | 0.84 | 1.11 | 0.96 | 1.03 | 0.63 |
| 649509 | 1.12 | 0.54 | 1.40 | 1.00 | 1.25 | 0.66 | 1.35 | 1.13 | 0.76 | 0.48 | 1.38 | 1.04 | 0.99 | 0.80 |
| 649516 | 0.97 | 0.98 | 1.12 | 1.31 | 1.61 | 1.39 | 1.60 | 1.71 | 1.00 | 0.90 | N/A | N/A | 0.99 | 0.78 |
| 649517 | 1.00 | 1.00 | 1.13 | 1.55 | 1.55 | 1.21 | 1.45 | 1.39 | 0.93 | 0.70 | 1.41 | 1.71 | 0.95 | 0.80 |
| 649518 | 0.99 | 0.96 | 1.12 | 1.16 | 1.48 | 0.93 | 1.41 | 1.29 | 0.92 | 0.73 | 1.46 | 2.03 | 1.10 | 1.27 |

**Relative Depth and Intensity for Various Event**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 649625 | 0.93 | 0.86 | 0.72 | 0.31 | 1.24 | 0.78 | 1.47 | 1.14 | 1.23 | 1.32 | 1.11 | 1.02 | 1.09 | 0.54 |
| 649636 | 0.95 | 0.72 | 0.88 | 0.77 | 1.44 | 0.90 | 1.22 | 1.33 | 1.04 | 1.17 | 1.29 | 1.74 | 0.91 | 0.57 |
| 649637 | 1.00 | 1.07 | 0.73 | 0.40 | 0.44 | 0.28 | 1.13 | 1.31 | 1.37 | 1.42 | 0.83 | 1.03 | 0.98 | 0.80 |
| 649638 | 0.91 | 1.15 | 0.85 | 0.86 | 1.35 | 0.85 | 1.38 | 1.20 | 1.06 | 0.96 | 1.45 | 2.14 | 1.09 | 0.65 |

Figure 6 **Relative Depth Factor (DF) and Relative Intensity Factor (IF) of Event 4**




It can be seen from Figure 6 that both event total rainfall depth and intensity factor for the raingauges located along the higher elevation of the Waitakere Ranges are greater than those at the other gauges. It can also be noted that the catchment experienced fairly uniform rainfall during events 1, 3, 4, 5 and 6 while the catchment area of Opanuku Stream experienced slightly higher rainfall from events 2 and 7 than the Oratia Stream Catchment. It can be seen from Figure 6 that the rainfall from Event 4 (the largest recorded event) is relatively uniform across the entire catchment for all raingauges.

Standard deviations of the rainfall depth factors for the seven events at the 11 raingauge stations located inside the catchment were found to vary from 0.03 to 0.20 with an average of standard deviation of approximately 0.1.

It can be concluded from the above assessment that there is a variability of rainfall over the entire catchment area but the variation is not so significant and the rainfall appears to be uniform over the entire catchment during higher events.

# 4 CONCLUSIONS

Based on our research and experiences the following conclusion can be made:

- If a large catchment is divided into smaller sub-catchments, then any areal reduction factor should be related to the subcatchment size. If the hydraulics of the conveyance system is then addressed accurately, some separation of sub-catchment peaks will be achieved that partly addresses the effects of distributed catchments (i.e. the combined flow from the subcatchments at the main catchment discharge point will be less than the sum of the individual sub-catchments hydrograph peaks).

- Use of an areal reduction factor appropriate for the total catchment area which is then applied to a model broken down into small subcatchments will provide too low flows at a subcatchment level.

- Areal reduction should be used based on subcatchment size not the size of the entire catchment.

- There is variability of rainfall across large catchment and the variability can be considered by generating several point rainfall across the catchment. In case Auckland region TP108 while for other area HIRDS can be utilized to generate point rainfall. Most computer model can generate contribution of point rainfalls to a subcatchment based on geographical location.

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