GUIDELINES FOR RAINFALL ANALYSIS AS UTILISED FOR THE DUNEDIN CITY COUNCIL 3 WATERS STRATEGY

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ABSTRACT

As part of the 3 Waters Strategy project for the Dunedin City Council, URS New Zealand Ltd undertook a rainfall analysis for incorporation into storm water, wastewater and potable water models being prepared for Dunedin. This paper outlines the derivation of the rainfall information that was used to provide a robust rainfall analysis, critical to achieving better quality and site specific storm water modelling. Although it is based on the Dunedin 3 Waters Strategy, this methodology could be applied to any urban area in New Zealand, taking local requirements into consideration.

This paper provides a guide to the derivation of rainfall data for use in urban storm water modelling and is aimed primarily at younger practitioners. It will also assist decision makers regarding outcomes that should be achieved by a rainfall analysis.

The paper focuses on the basic steps for rainfall analysis including:

- Consideration of intended use, evaluation of available data
- Development of Depth-Duration-Frequency (DDF) curves
- Development of a design storm hyetograph
- Consideration of storm shape and peak intensities
- Analysis of the spatial variation
- The effects of climate change and climate variability on rainfall data
- Determination of Areal Reduction Factor (ARF)

KEYWORDS

Integrated Catchment Management Planning, urban hydrology, storm water modelling inputs.

1 INTRODUCTION

1.1 DUNEDIN 3 WATERS STRATEGY

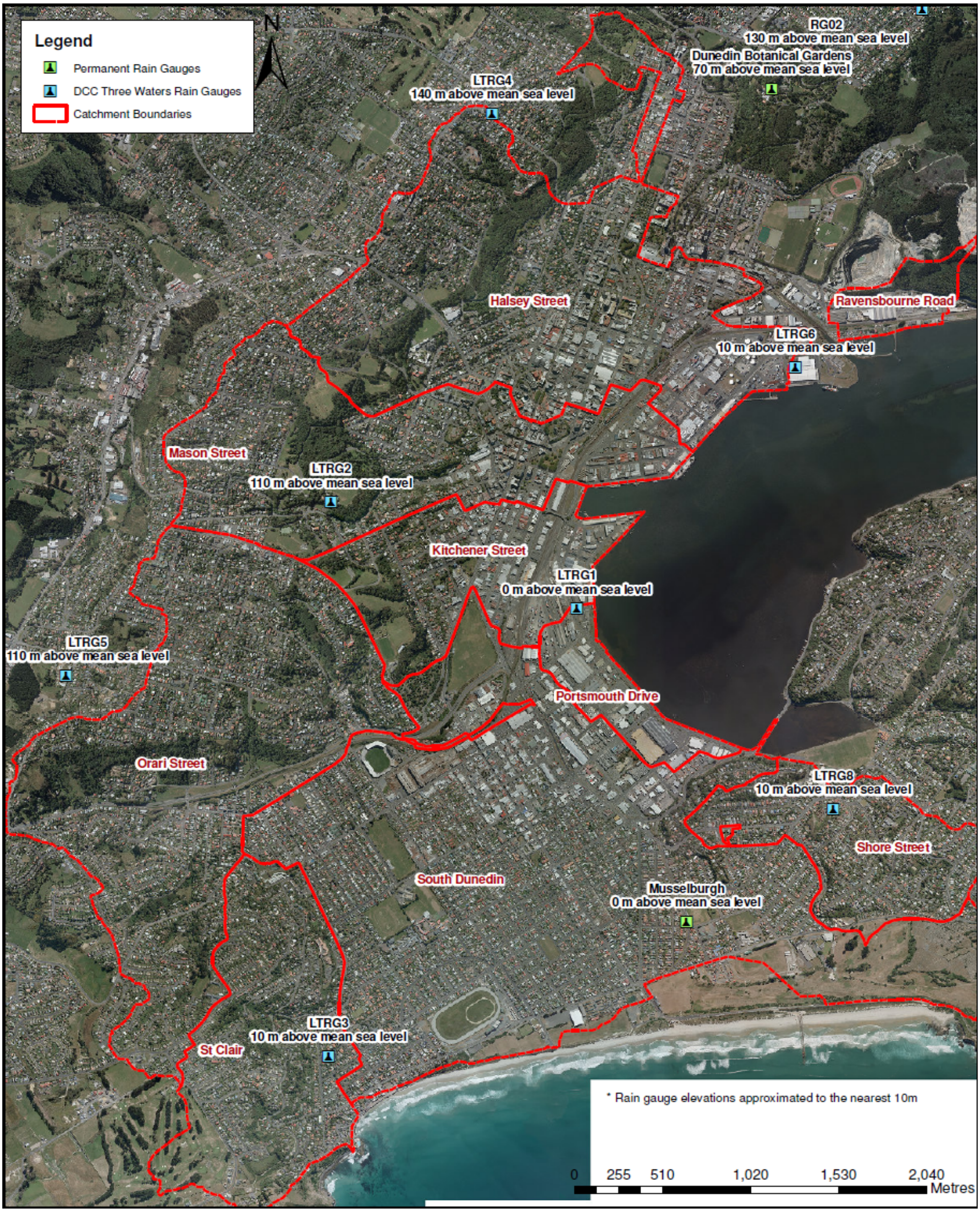
The Dunedin 3 Waters Strategy (DCC 3W) is an exercise in Integrated Catchment Management Planning (ICMP) being undertaken for Dunedin City Council (DCC) by URS New Zealand Limited (URS) and Opus International Consultants Limited (OPUS).

ICMP is a widely used tool, both in New Zealand and internationally, which can deliver holistic planning of the operation, maintenance and capital expenditure requirements for potable, waste and storm water infrastructure. The value of integrated planning is the ability to prioritise often limited funding expenditure, to determine the impact of changes to one water type on another, identify areas suitable for development (in terms of available infrastructure capacity) and to inform budget forecasting processes undertaken by all infrastructure operators.

DCC has adopted the ICMP approach for its potable water, waste water and storm water infrastructure with each requiring the creation of hydraulic system models and associated boundary conditions. One of the key boundary conditions for the system models is the rainfall received by the systems; the focus of this paper. For ease of presentation only the rainfall boundary conditions associated with storm water modelling, are considered here.

This ICMP study is limited to nine storm water catchments having an outfall into Dunedin Harbour (shown in Figure 1, excluding Port Chalmers).

Figure 1: Storm Water Catchments within the Dunedin Three Waters Strategy



1.2 DEVELOPMENT OF RAINFALL ANALYSIS GUIDELINES

Synthetic rainfall event data used to test the system Level of Service (LoS) will be considered. The analysis covers a number of sequential steps to develop the ultimate data set used in the system hydraulic models representing the storm water networks of Dunedin.

Although these steps are presented in the context of the DCC 3W they are applicable, with appropriate modifications to any urban study across New Zealand. In many cases, information from other parts of New Zealand can be adapted for a local study, however consideration of site-specific factors is essential. For instance, a study in Northland would still require a storm shape to be developed (Section 2.10), but it is unlikely that the shape used for DCC 3W assessment (which was taken from *CCC, 2003*) due to similarities in rainfall event shape, would be representative of the rainfall patterns encountered there and an alternative source would be required.

The following are the key steps followed in the development of synthetic rainfall events for the DCC 3W:

- Intended Use
- Base Data
- Climate Change
- Climate Variation
- Areal Reduction
- Spatial Variation
- Storm Profile

Each of the above steps are considered in turn with discussions on (i) why the data is required, (ii) what options are available in terms of data and methodology and (iii) the data / methodology selected for the DCC 3W project.

2 KEY STEPS

2.1 INTENDED USE

Before any effort is put into the subsequent steps of deriving a suitable data set, careful consideration must be given to the intended use of the data as this can have a significant impact upon:

1. The required data type (synthetic / recorded event / recorded time series)
2. The required extent of data (temporally & spatially)
3. The accuracy of data required to meet the ultimate objectives

2.1.1 NEED

In the context of DCC 3W the intended use of the data was to assess the performance of the storm water infrastructure, identifying areas which may cause flooding, and/or require improvement works such as maintenance, operational changes or capital expenditure. To enable comparison of systems in different catchments, and to maintain consistency with the wastewater modelling, it was decided to consider synthetic rainfall events of particular return periods. LoS is a measure of the ability of a system to convey a certain return period storm within set performance criteria (eg without causing flooding (street or floor level), or without causing surcharge). In the DCC 3W project it was identified that a number of different return periods would be considered.

2.1.2 OPTIONS

DCC have a requirement that new storm water infrastructure is designed to convey a 1:10 yr event storm, and that no habitable floor flooding occurs in events up to the 1:50 yr event, and both these events were included in the analysis. In reality it is expected that some existing system components will fall short of the 1:10 yr standard, and to try and quantify the LoS offered by these areas the 1:2 yr and 1:5 yr events were also considered.

The 1:100 yr event was also considered as an indication of the flooding generated by an extreme event. Whilst it is not expected that primary infrastructure would be designed to accommodate such an event, assessing such an extreme event is useful for emergency planning purposes and to determine where secondary flood routes are occurring or where they may be required.

For each return period event the required storm durations also need to be determined. The main driver for these is the time of concentration (T_C) of the catchments. In this case the actual T_C of the catchments was not known as the system modelling was being undertaken in parallel with the development of rainfall data. As such the T_C of the catchments in question was estimated using empirical methods that can give a reasonable first pass estimation of the T_C, which in turn provides likely critical storm durations for the system analysis.

2.1.3 SELECTION

For the DCC 3W project synthetic storms representing the 2 yr, 5 yr, 10yr, 50 yr and 100 yr events were required. The durations selected for each of these events were the 20 min, 40 min, 60 min and 24 hr events, these being related to the expected T_C of the catchments. Results for the 10 yr, 50 yr and 100 yr events are discussed below.

2.2 BASE DATA

2.2.1 NEED

Depth Duration Frequency (DDF) data is required to develop the synthetic storm events chosen for the project. The DDF data provides the total rainfall depth (in mm) which is expected to fall during a rainfall event of particular duration and frequency. This can then be manipulated to take into account other factors before being converted to a synthetic hyetograph for use in system modelling.

2.2.2 OPTIONS

Three main sources were used to obtain DDF information for this study:

1. High Intensity Rainfall Design System (HIRDS) V3
2. Analysis of local rain gauge information
3. Previous studies

The HIRDS system is a nationwide tool produced by NIWA which provides DDF information for any point in New Zealand. HIRDS V3 is the most current version of the tool now available as a web-based program (http://hirds.niwa.co.nz). It uses rainfall data records from across New Zealand to estimate rainfall at points not at rain gauges site. It is an excellent tool where no other records exist; however, it is generally preferable to use a good quality local record if one exists.

Local rain gauge records are the preferred source of DDF information, although there needs to be a long record with good data integrity. In Dunedin the Musselburgh rain gauge (Figure 1) has a data record stretching back to 1918 and hence is a candidate for such use.

The client does not always have the budget to undertake in-depth studies, previous work may be suitable for use in full or in part. This will depend on the way in which the previous work has been investigated, reviewed and presented, however if it can be confirmed that it is of suitable quality there is no reason that previous studies cannot be used.

In the DCC 3W case a previous study carried out by *Raineffects (2006)*, was identified as suitable for use. This study provides DDF data for a range of return periods and durations, although data for some durations required for this study was not available from this source.

2.2.3 SELECTION

For the DCC 3W project a combination of two of the above sources were used. HIRDS was discounted as reasonable local records existed in the form of the record from the Musselburgh rain gauge. Furthermore it was identified that the previous *Raineffects* study had already developed DDF information for the city.

This existing data was investigated and deemed to be of sufficient quality to use in the DCC 3W study, however, it extended only to the 2 hr duration. As such this data was combined with the outcome of a statistical analysis of the Musselburgh rain gauge data to create a DDF table covering all of the data required (Table 1).

Table 1: Complete DDF Data Table

Source	***Raineffects (2006) Rainfall Depth (mm)***								***URS (2010) Rainfall Depth (mm)***			
ARI	**10 (min)**	**20 (min)**	**30 (min)**	**40 (min)**	**50 (min)**	**1 (hr)**	**1.5 (hr)**	**2 (hr)**	**4 (hr)**	**6 (hr)**	**12 (hr)**	**24 (hr)**
10	11.69	13.52	15.22	16.78	18.23	19.6	23.35	26.72	38.7	46.2	62.6	82.5
50	16.28	18.35	20.36	22.23	23.97	25.61	30.1	34.13	47.7	58.9	83.6	109
100	18.16	20.38	22.55	24.56	26.43	28.2	33.04	37.38	51.5	64.3	92.5	120.2

2.3 CLIMATE CHANGE

The depths defined above in Table 1 represent the estimated rainfall depths only at the location of the Musselburgh raingauge, and do not necessarily represent the rainfall which may fall in adjacent catchments or at different points in climatic cycles or trends. As such the data must be manipulated to account for these factors before modelling can be undertaken. The first factor considered is climate change, which was considered separately from climate variability to emphasis these different aspects of climate.

2.4 NEED

It is widely accepted that climate change arising from ongoing increase in global temperatures as a result of anthropogenic influences is occurring and will continue into the future. It is considered that there is a robust enough link between increasing temperatures and increasing storminess (storms of higher intensity) to warrant consideration of climate change impacts within studies which plan for the future. Given that the DCC 3W study looks out to 2060, it is important to take climate change into consideration.

2.5 OPTIONS

In New Zealand, The Ministry for the Environment has interpreted international climate change information to provide guidelines for local government. MfE (2008) states, 'Climate change effects due to the increase in greenhouse gases in the atmosphere will be felt over time at regional and local levels differently in various parts of New Zealand.'. The uncertainty in the scale and spatial occurrence of effects presents a number of challenges for future infrastructure planning and management.

Predictions of temperature change (annual) were taken from *MfE (2008)* for the 2040 and 2090 horizons reported (Table 2 & 3). Average and upper prediction limits for the scenarios considered by MfE were selected. These are referred to in this document as *mean* and *max* scenarios.

A linear interpolation was then used to obtain estimates of temperature increase for the DCC planning horizons of 2031 and 2060.

Table 2: Temperature Change Predictions 2040 (MfE, 2008)

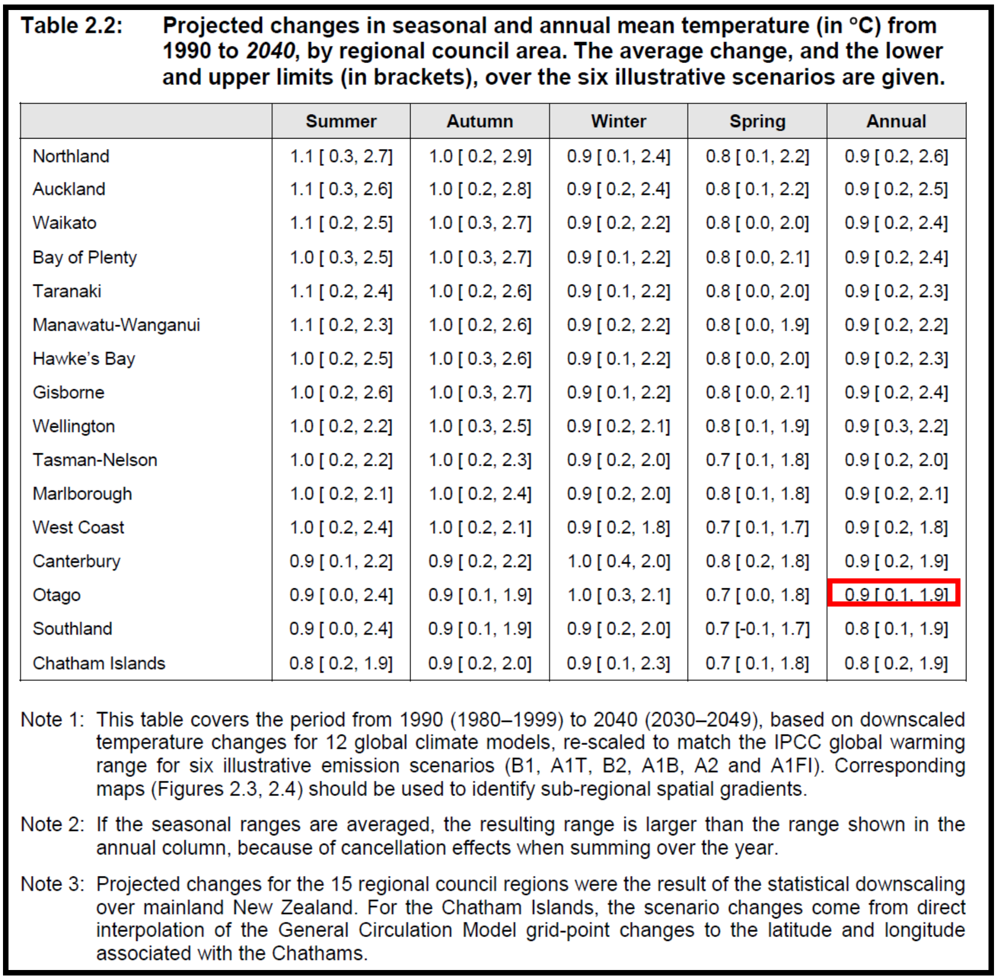


Table 2.2: Projected changes in seasonal and annual mean temperature (in °C) from 1990 to *2040*, by regional council area. The average change, and the lower and upper limits (in brackets), over the six illustrative scenarios are given.

	Summer	Autumn	Winter	Spring	Annual
Northland	1.1 [0.3, 2.7]	1.0 [0.2, 2.9]	0.9 [0.1, 2.4]	0.8 [0.1, 2.2]	0.9 [0.2, 2.6]
Auckland	1.1 [0.3, 2.6]	1.0 [0.2, 2.8]	0.9 [0.2, 2.4]	0.8 [0.1, 2.2]	0.9 [0.2, 2.5]
Waikato	1.1 [0.2, 2.5]	1.0 [0.3, 2.7]	0.9 [0.2, 2.2]	0.8 [0.0, 2.0]	0.9 [0.2, 2.4]
Bay of Plenty	1.0 [0.3, 2.5]	1.0 [0.3, 2.7]	0.9 [0.1, 2.2]	0.8 [0.0, 2.1]	0.9 [0.2, 2.4]
Taranaki	1.1 [0.2, 2.4]	1.0 [0.2, 2.6]	0.9 [0.1, 2.2]	0.8 [0.0, 2.0]	0.9 [0.2, 2.3]
Manawatu-Wanganui	1.1 [0.2, 2.3]	1.0 [0.2, 2.6]	0.9 [0.2, 2.2]	0.8 [0.0, 1.9]	0.9 [0.2, 2.2]
Hawke's Bay	1.0 [0.2, 2.5]	1.0 [0.3, 2.6]	0.9 [0.1, 2.2]	0.8 [0.0, 2.0]	0.9 [0.2, 2.3]
Gisborne	1.0 [0.2, 2.6]	1.0 [0.3, 2.7]	0.9 [0.1, 2.2]	0.8 [0.0, 2.1]	0.9 [0.2, 2.4]
Wellington	1.0 [0.2, 2.2]	1.0 [0.3, 2.5]	0.9 [0.2, 2.1]	0.8 [0.1, 1.9]	0.9 [0.3, 2.2]
Tasman-Nelson	1.0 [0.2, 2.2]	1.0 [0.2, 2.3]	0.9 [0.2, 2.0]	0.7 [0.1, 1.8]	0.9 [0.2, 2.0]
Marlborough	1.0 [0.2, 2.1]	1.0 [0.2, 2.4]	0.9 [0.2, 2.0]	0.8 [0.1, 1.8]	0.9 [0.2, 2.1]
West Coast	1.0 [0.2, 2.4]	1.0 [0.2, 2.1]	0.9 [0.2, 1.8]	0.7 [0.1, 1.7]	0.9 [0.2, 1.8]
Canterbury	0.9 [0.1, 2.2]	0.9 [0.2, 2.2]	1.0 [0.4, 2.0]	0.8 [0.2, 1.8]	0.9 [0.2, 1.9]
Otago	0.9 [0.0, 2.4]	0.9 [0.1, 1.9]	1.0 [0.3, 2.1]	0.7 [0.0, 1.8]	0.9 [0.1, 1.9]
Southland	0.9 [0.0, 2.4]	0.9 [0.1, 1.9]	0.9 [0.2, 2.0]	0.7 [-0.1, 1.7]	0.8 [0.1, 1.9]
Chatham Islands	0.8 [0.2, 1.9]	0.9 [0.2, 2.0]	0.9 [0.1, 2.3]	0.7 [0.1, 1.8]	0.8 [0.2, 1.9]

Note 1: This table covers the period from 1990 (1980–1999) to 2040 (2030–2049), based on downscaled temperature changes for 12 global climate models, re-scaled to match the IPCC global warming range for six illustrative emission scenarios (B1, A1T, B2, A1B, A2 and A1FI). Corresponding maps (Figures 2.3, 2.4) should be used to identify sub-regional spatial gradients.

Note 2: If the seasonal ranges are averaged, the resulting range is larger than the range shown in the annual column, because of cancellation effects when summing over the year.

Note 3: Projected changes for the 15 regional council regions were the result of the statistical downscaling over mainland New Zealand. For the Chatham Islands, the scenario changes come from direct interpolation of the General Circulation Model grid-point changes to the latitude and longitude associated with the Chathams.

Table 3: Temperature Change Predictions 2090 (MfE, 2008)

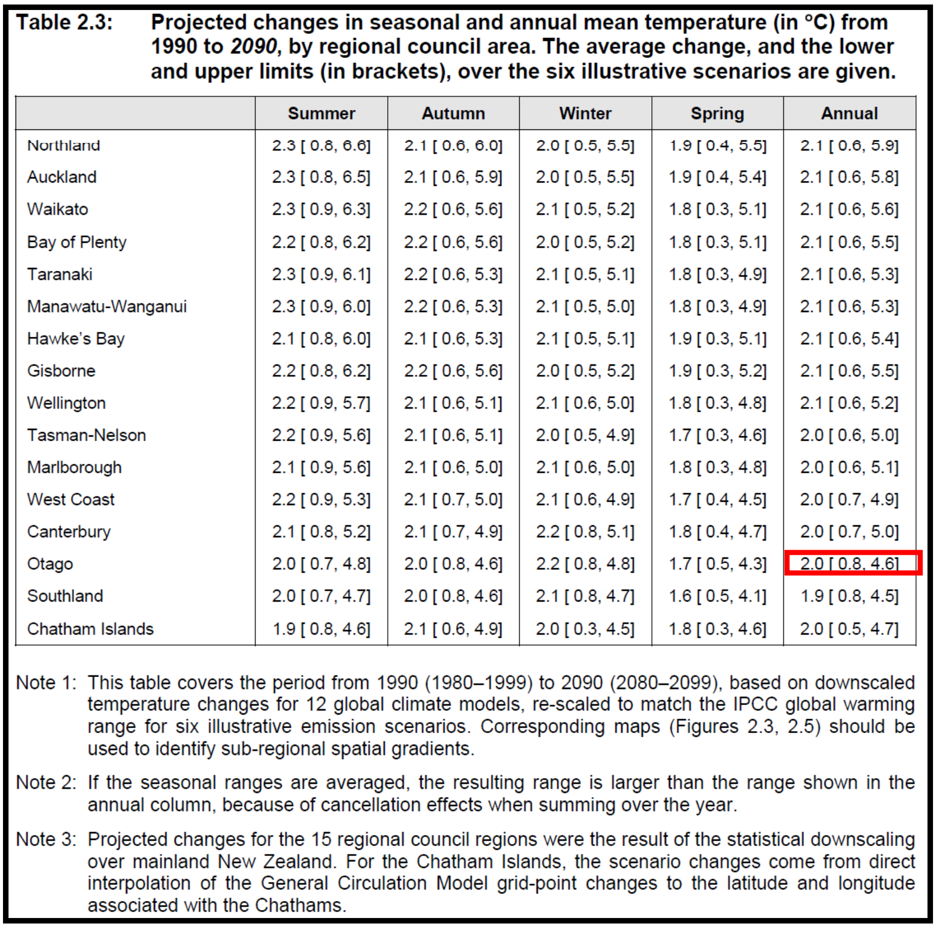


Table 2.3: Projected changes in seasonal and annual mean temperature (in °C) from 1990 to *2090*, by regional council area. The average change, and the lower and upper limits (in brackets), over the six illustrative scenarios are given.

	Summer	Autumn	Winter	Spring	Annual
Northland	2.3 [0.8, 6.6]	2.1 [0.6, 6.0]	2.0 [0.5, 5.5]	1.9 [0.4, 5.5]	2.1 [0.6, 5.9]
Auckland	2.3 [0.8, 6.5]	2.1 [0.6, 5.9]	2.0 [0.5, 5.5]	1.9 [0.4, 5.4]	2.1 [0.6, 5.8]
Waikato	2.3 [0.9, 6.3]	2.2 [0.6, 5.6]	2.1 [0.5, 5.2]	1.8 [0.3, 5.1]	2.1 [0.6, 5.6]
Bay of Plenty	2.2 [0.8, 6.2]	2.2 [0.6, 5.6]	2.0 [0.5, 5.2]	1.8 [0.3, 5.1]	2.1 [0.6, 5.5]
Taranaki	2.3 [0.9, 6.1]	2.2 [0.6, 5.3]	2.1 [0.5, 5.1]	1.8 [0.3, 4.9]	2.1 [0.6, 5.3]
Manawatu-Wanganui	2.3 [0.9, 6.0]	2.2 [0.6, 5.3]	2.1 [0.5, 5.0]	1.8 [0.3, 4.9]	2.1 [0.6, 5.3]
Hawke's Bay	2.1 [0.8, 6.0]	2.1 [0.6, 5.3]	2.1 [0.5, 5.1]	1.9 [0.3, 5.1]	2.1 [0.6, 5.4]
Gisborne	2.2 [0.8, 6.2]	2.2 [0.6, 5.6]	2.0 [0.5, 5.2]	1.9 [0.3, 5.2]	2.1 [0.6, 5.5]
Wellington	2.2 [0.9, 5.7]	2.1 [0.6, 5.1]	2.1 [0.6, 5.0]	1.8 [0.3, 4.8]	2.1 [0.6, 5.2]
Tasman-Nelson	2.2 [0.9, 5.6]	2.1 [0.6, 5.1]	2.0 [0.5, 4.9]	1.7 [0.3, 4.6]	2.0 [0.6, 5.0]
Marlborough	2.1 [0.9, 5.6]	2.1 [0.6, 5.0]	2.1 [0.6, 5.0]	1.8 [0.3, 4.8]	2.0 [0.6, 5.1]
West Coast	2.2 [0.9, 5.3]	2.1 [0.7, 5.0]	2.1 [0.6, 4.9]	1.7 [0.4, 4.5]	2.0 [0.7, 4.9]
Canterbury	2.1 [0.8, 5.2]	2.1 [0.7, 4.9]	2.2 [0.8, 5.1]	1.8 [0.4, 4.7]	2.0 [0.7, 5.0]
Otago	2.0 [0.7, 4.8]	2.0 [0.8, 4.6]	2.2 [0.8, 4.8]	1.7 [0.5, 4.3]	2.0 [0.8, 4.6]
Southland	2.0 [0.7, 4.7]	2.0 [0.8, 4.6]	2.1 [0.8, 4.7]	1.6 [0.5, 4.1]	1.9 [0.8, 4.5]
Chatham Islands	1.9 [0.8, 4.6]	2.1 [0.6, 4.9]	2.0 [0.3, 4.5]	1.8 [0.3, 4.6]	2.0 [0.5, 4.7]

Note 1: This table covers the period from 1990 (1980–1999) to 2090 (2080–2099), based on downscaled temperature changes for 12 global climate models, re-scaled to match the IPCC global warming range for six illustrative emission scenarios. Corresponding maps (Figures 2.3, 2.5) should be used to identify sub-regional spatial gradients.

Note 2: If the seasonal ranges are averaged, the resulting range is larger than the range shown in the annual column, because of cancellation effects when summing over the year.

Note 3: Projected changes for the 15 regional council regions were the result of the statistical downscaling over mainland New Zealand. For the Chatham Islands, the scenario changes come from direct interpolation of the General Circulation Model grid-point changes to the latitude and longitude associated with the Chathams.

To convert the temperature increases in the above tables to a change in rainfall, the corresponding increases in rainfall intensity were also taken from *MfE (2008) (Table 4)*.

Table 4: Extreme Rainfall Factors per 1 ºC Warming (MfE, 2008)

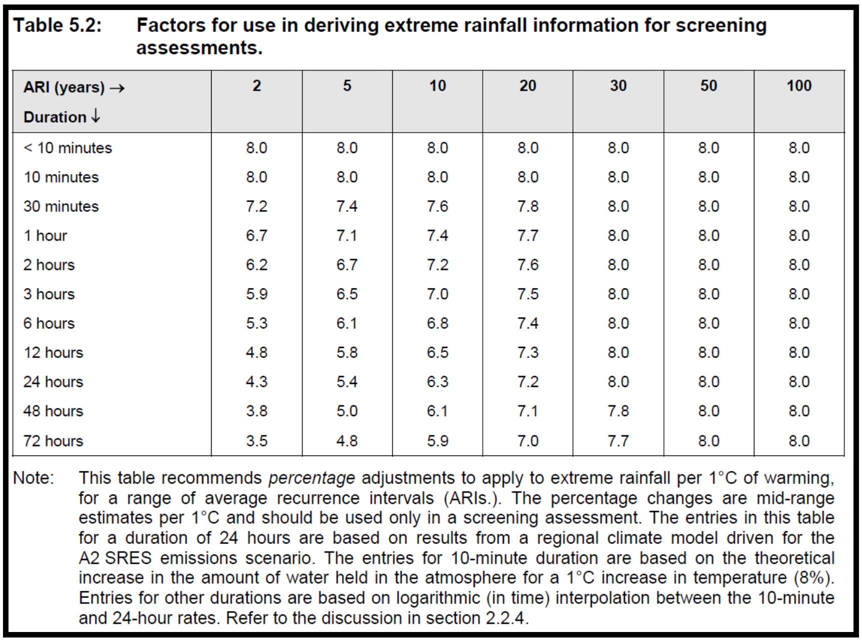


Table 5.2: Factors for use in deriving extreme rainfall information for screening assessments.

ARI (years) → Duration ↓	2	5	10	20	30	50	100
< 10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
30 minutes	7.2	7.4	7.6	7.8	8.0	8.0	8.0
1 hour	6.7	7.1	7.4	7.7	8.0	8.0	8.0
2 hours	6.2	6.7	7.2	7.6	8.0	8.0	8.0
3 hours	5.9	6.5	7.0	7.5	8.0	8.0	8.0
6 hours	5.3	6.1	6.8	7.4	8.0	8.0	8.0
12 hours	4.8	5.8	6.5	7.3	8.0	8.0	8.0
24 hours	4.3	5.4	6.3	7.2	8.0	8.0	8.0
48 hours	3.8	5.0	6.1	7.1	7.8	8.0	8.0
72 hours	3.5	4.8	5.9	7.0	7.7	8.0	8.0

Note: This table recommends *percentage* adjustments to apply to extreme rainfall per 1°C of warming, for a range of average recurrence intervals (ARIs.). The percentage changes are mid-range estimates per 1°C and should be used only in a screening assessment. The entries in this table for a duration of 24 hours are based on results from a regional climate model driven for the A2 SRES emissions scenario. The entries for 10-minute duration are based on the theoretical increase in the amount of water held in the atmosphere for a 1°C increase in temperature (8%). Entries for other durations are based on logarithmic (in time) interpolation between the 10-minute and 24-hour rates. Refer to the discussion in section 2.2.4.

2.6 SELECTION

This analysis produced a set of amendments to the base DDF data to account for climate change impacts (Table 5), as aligned to the DCC planning horizons.

Table 5: Dunedin 3 Waters Strategy Climate Change Scenarios

Scenario	Temp Increase (°C)	Intensity Increase (%)
2030_{mean}	0.6	5
2030_{max}	1.3	10
2060_{mean}	1.3	11
2060_{max}	2.9	23

2.7 CLIMATE VARIATION

Climate variability is the natural variation of climate driven by quasi-cyclic changes in large scale meteorological factors such as air pressure and sea-surface temperatures. These cycles generally operate over periods of years / decades, and can have both positive and negative phases that cause increases or decreases in rainfall of other climate parameters.

2.7.1 NEED

In this assessment of rainfall for storm water only the positive (enhancing) effect on rainfall is considered in order to remain conservative when assessing rainfall effects. Positive effects on rainfall can increase peak rainfall for any given event and as such can produce an increased peak flow within the storm water system. Not taking these effects into account could lead to an underestimation of rainfall depths from an event and therefore impact upon decisions made in the ICMP process.

2.7.2 OPTIONS

Climate variability is driven by global scale processes and the only feasible option is to revert to published scientific research on the impacts of climate variability at a national or regional level.

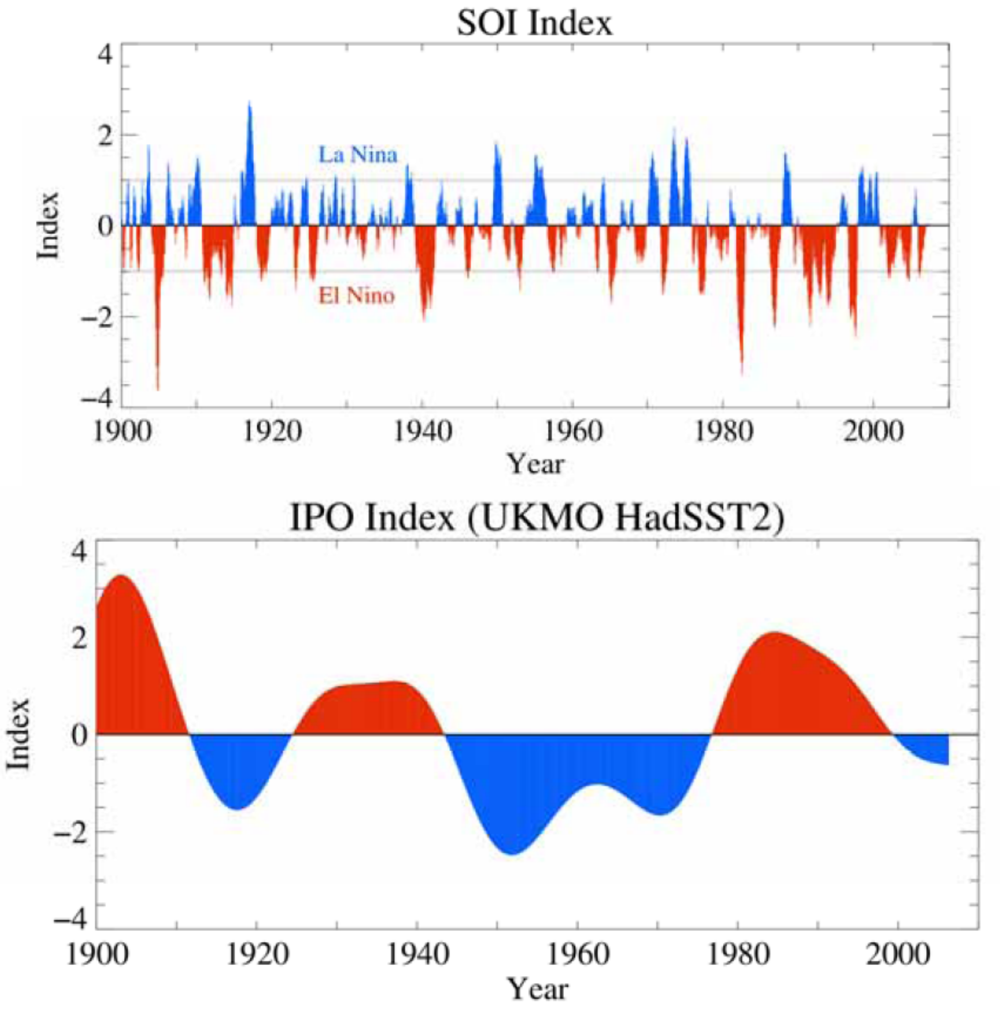
The two key quasi-cyclic variations which impact upon New Zealand's climate are the Interdecadal Pacific Oscillation (IPO) and the El Niño-Southern Oscillation (ENSO).

Through the IPO (Figure 2) New Zealand experiences decadal climate variations. Research is still in progress on the cause and predictability of the IPO and its local climatic impacts. Historically, there was a shift to the 'negative phase' of the IPO around 1999, so more La Niña (and less El Niño) activity may be expected compared to 1978–1998, with a period of higher temperatures for New Zealand. This is likely to favour reduced westerlies and southwesterlies, rainfall reductions in the southwest of the country but increases in the northeast, and faster rises in air temperature and sea level. These conditions could last for the next 20 to 30 years.

ENSO is a tropical Pacific-wide oscillation that affects pressure, winds, sea-surface temperature (SST) and rainfall. It is split into two opposite extremes of the cycle; the El Niño phase, where the easterly trade winds weaken and Sea Surface Temperatures (SST) in the eastern tropical Pacific can become several degrees warmer than normal, and the La Niña; essentially the opposite in the tropical Pacific; New Zealand experiences more north easterly flows, higher temperatures and wetter conditions in the north and east of the North Island.

The ENSO cycle, represented by the Southern Oscillation Index (SOI) (Figure 2) varies between about 3 and 7 years and there is large inter-annual variability in the intensity of individual events.

Figure 2: IPO and ENSO Index (MfE 2008)



The impact on New Zealand's weather by these cycles, in terms of prevailing winds, rainfall totals and ability for ex-cyclones to reach the islands, means that careful consideration must be given to the implications for Dunedin, and elsewhere, in terms of predicted future rainfall.

A literature review was undertaken to determine the extent of influence climate variability is likely to have on Dunedin's extreme rainfall.

A number of studies have been undertaken to asses the impact of ENSO / IPO on rainfall across New Zealand. In particular *McKerchar & Henderson (2003)* investigated the shifts in flood flow and low flow regimes in New Zealand rivers. It compared annual peak flows and annual minimum flows for two periods (1947-1977 & 1978-1999). This analysis was based on evidence that an IPO phase shift occurred in 1977.

The study found that for rivers in the north-east of the North Island and for those draining the Main Divide in the South Island, interdecadal shifts were evident, however, no consistent pattern of shifts was evident elsewhere. Importantly the Taieri River was included in the study which drains the local area around Dunedin but does not extend towards the Main Divide. *McKerchar & Henderson* found no evidence of a phase shift in flows of the Taieri River.

The pattern identified by *McKerchar & Henderson* of shifts in the north-east of the North Island and rivers draining the Main Divide of the South Island had also been identified in *Mosley (2000)*, however, that study did not contain data which could be specifically related to Dunedin.

Given the above, it is considered unnecessary to include any allowances for climate variation within the rainfall analysis for Dunedin.

The lack of any climatic oscillation also supports the use of long historic records in estimating rainfall as it supports the requirement to have stationarity in the data when estimating probability distributions.

2.7.3 SELECTION

Given the analysis discussed above it was considered that for Dunedin it was not necessary to include any adjustments for climatic variability. However, as is also discussed this would not necessarily hold true for other parts of New Zealand and as such could not be discounted across the country.

2.8 AREAL REDUCTION

2.8.1 NEED

The rainfall data used by this study is based on the Musselburgh rain gauge, as amended by a number of factors. The data from the rain gauge is representative of the rainfall occurring in a very limited area around the rain gauge and the average rainfall depth over an entire catchment is likely to be less than that recorded by the gauge. An Areal Reduction Factor (ARF) can be used to account for the difference between point rainfall and catchment rainfall.

2.8.2 OPTIONS

Comprehensive investigations into areal reduction factors do not appear to have been undertaken at a national level in New Zealand. However, *Thompson (1980)* has suggested that the method proposed by *NERC (1975)* for use in the United Kingdom is suitable for use in New Zealand. No other options for ARF could be identified and as such *NERC (1975)* would be the preferred reference.

2.8.3 SELECTION

The use of ARF’s was investigated but deemed to have a negligible impact upon the rainfall intensities derived for the project and these were not used within the analysis. The exclusion of what would have been at most a 5 % reduction in rainfall depth was considered to maintain a degree of conservatism within the work.

For larger catchments, however, the impact of an areal reduction factor is more pronounced and may not be discounted so easily in which case *NERC (1975)* would be worth considering.

2.9 SPATIAL VARIATION

The rainfall across Dunedin is known anecdotally not to be uniform. It is considered that this variation is driven primarily by topography.

2.9.1 NEED

The variation of rainfall totals across Dunedin means that the DDF data from the Musselburgh rain gauge, as amended for the factors discussed above, cannot be applied elsewhere without considering the spatial variation in rainfall between the donor gauge (Musselburgh) and each of the subject catchments.

This would be true of many cities where there is a distinct change in elevation across the area or where some other factor is present which may change the amount of rain falling. In cities with little or no elevation change, consideration of spatial variation may not be required, however it is always important to try and prove this assumption through collection of field data.

2.9.2 OPTIONS

In Dunedin, spatial variation is considered to be driven primarily by topography through orographic enhancement of rainfall. To test this theory and to quantify the extent of orographic enhancement, data from a network of rain gauges was considered. For the DCC 3W study short term rain gauges (1 year) were installed across the city (Figure 1). This kind of rain gauge deployment is extremely useful but is realistically limited to larger studies.

For the DCC 3W study rainfall totals were compared across the gauges installed (Table 6). The results shown generally agree with the theory that rainfall totals increase with increasing elevation.

Table 6: 12 Month Rainfall Totals

Rain gauge	Catchment	Rainfall Total (mm)	Ground Elevation at Gauge (to nearest 10m) (m OD)
LTRG1	Kitchener St	747	0
Sawyers Bay STP	Port Chalmers	806	0
Musselburgh	South Dunedin	775	0
LTRG3	St Clair	757	10
LTRG6	Halsey St	804	10
LTRG8	Shore St	721	10
Sawyers Bay	Port Chalmers	1037	70
LTRG2	Mason St	906	110
LTRG5	Orari	950	110
LTRG4	Halsey St	772	140

Although there is only a 4 km horizontal separation between the Musselburgh gauge and the LTRG2 gauge, the ~ 90 m difference in elevation resulted in a 17 % increase in annual rainfall during the study period (1 year). The limited distance over which such a large difference in rainfall occurs confirms that a single set of hyetographs generated using data from the Musselburgh gauge cannot be used to represent rainfall events in every catchment in Dunedin.

Rain gauge LTRG 4 was disregarded for the purposes of determining spatial variation, as it had considerably lower rainfall than would be expected for the elevation. It is possible that due to its elevated and exposed position, wind shear across the top of the gauge has reduced the amount of water falling into the collection bucket, however, this could not be confirmed. Had this gauge been taken into account there would have been little effect on the weighted AAR of surrounding catchments.

In considering the spatial variation across the city it is assumed that the pattern and occurrence of rainfall remains constant. This is considered a reasonable assumption given the relatively small size if the city.

The AAR for each rain gauge in the city was plotted on a map and isohyets manually created. The isohyets (Figure 4) were used to determine a weighted average AAR for each catchment which was compared to the AAR for the donor gauge (Musselburgh). A factor used to modify the donor data was then created.

It should be noted that a number of these gauges were only installed during Phase 1 of the project and have, therefore, only been in operation for a short time (1 year). Consequently, it is possible that the data used may not be entirely typical of an average rainfall year but nevertheless is useful in establishing a scaling factor.

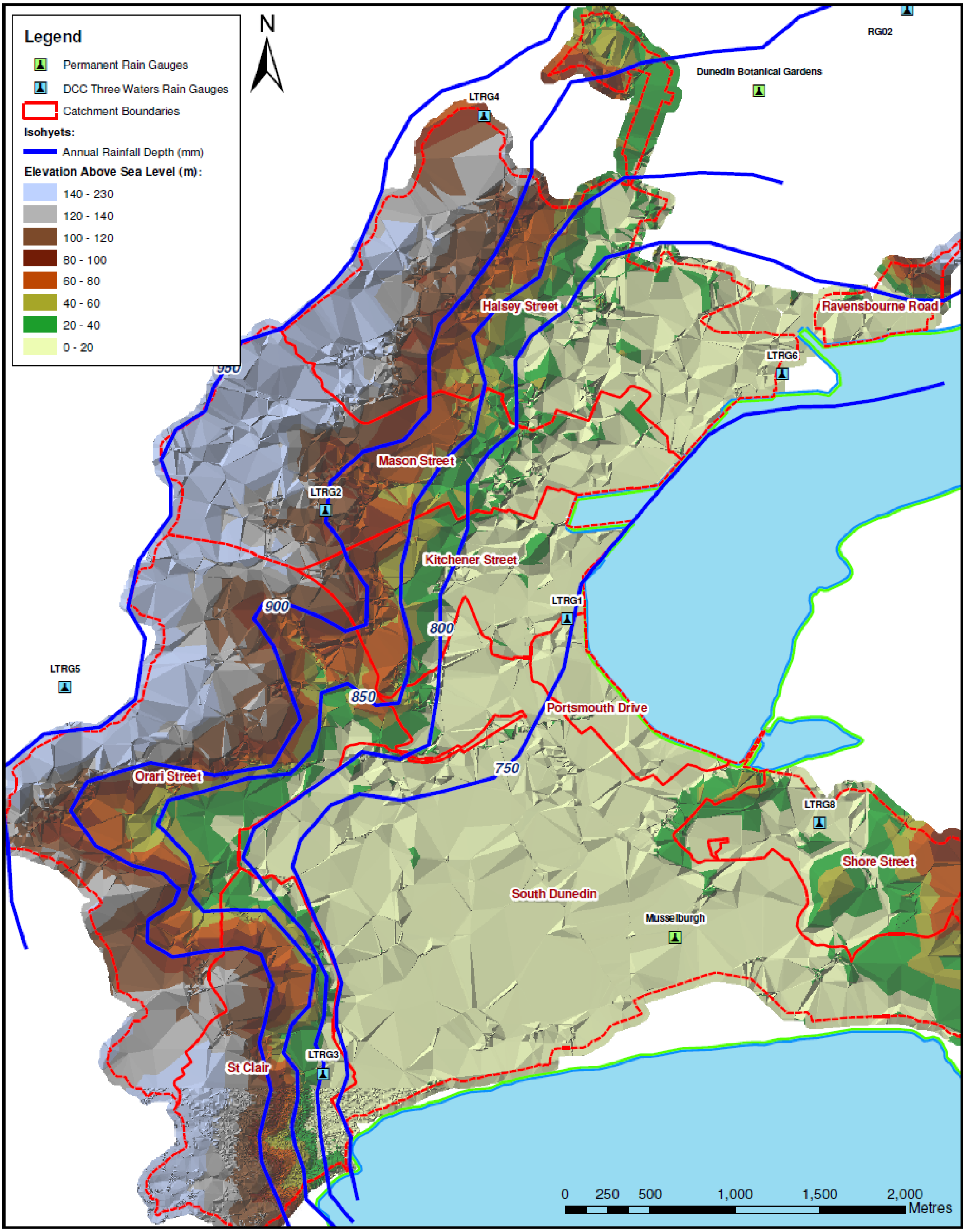
2.9.3 SELECTION

The factors applied to modify the donor data to represent variations in location are shown as Spatial Variation Factors (SVF) (Table 7).

Table 7: Spatial Variation Factors

Catchment	**Total Area (km^2)**	**Weighted Catchment AAR Rainfall (mm)**	**Spatial Variation Factor** ***(Base Musselburgh AAR: 775 mm)***
Halsey	3.36	855	1.10
Mason	2.21	858	1.11
Kitchener	1.18	816	1.05
Portsmouth	0.38	725	0.94
Orari	3.46	898	1.16
St Clair	1.59	877	1.13
Ravensbourne	0.25	791	1.02
South Dunedin	5.69	750	0.97
Shore	0.99	725	0.94
Port Chalmers	0.58	921	1.19

Figure 3: Catchments and Isohyet Banding



2.10 STORM PROFILE

2.10.1 NEED

All of the work detailed above has been undertaken to manipulate the base DDF rainfall depths to take into account a variety of elements which impact on the actual rain which could be encountered during a given event. Rainfall, expressed as a depth, however, cannot be used for the system modelling without applying it as a temporal spread of the rainfall. This is achieved by applying the total depth over a storm profile. One of the most critical elements to the storm profile is the peak intensity.

By applying a storm profile to the depth of rainfall a synthetic storm event can be created.

2.10.2 OPTIONS

There are a number of options available when selecting a storm profile:

1. Analysis of recorded events at site
2. Generic hyetograph from standard texts
3. Hyetograph developed for elsewhere

The option which would give the most site-specific storm profile would be an analysis of the actual recorded events. This however, has the potential to become a time-intensive task. A generic hyetograph could also be used, provided a justification can be made as to its relevance to the site. The third method can be an efficient method of selecting a suitable profile for the site under consideration.

For Dunedin the closest location for which a storm profile was available was Christchurch, as published in their Waterways, Wetlands and Drainage Guide. It was considered that Dunedin would in general experience similar types of rainfall events to Christchurch, and a visual inspection of a number of storms confirmed that the peak of a number of historic storms also occurred approximately 2/3 of the way through the event. As such the Christchurch storm profile could be used for Dunedin.

2.10.3 SELECTION

The hyetograph chosen was that presented within CCC (2003) which has a triangular form, with peak intensity two times the average intensity, occurring at 0.7 through the event (Figure 4 & Figure 5).

Figure 4: Dimensionless Hyetograph for Rainfall Intensity (CCC, 2003)

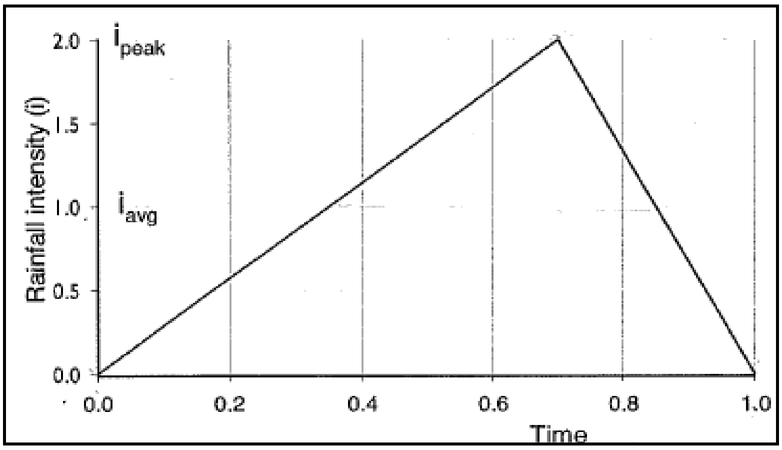
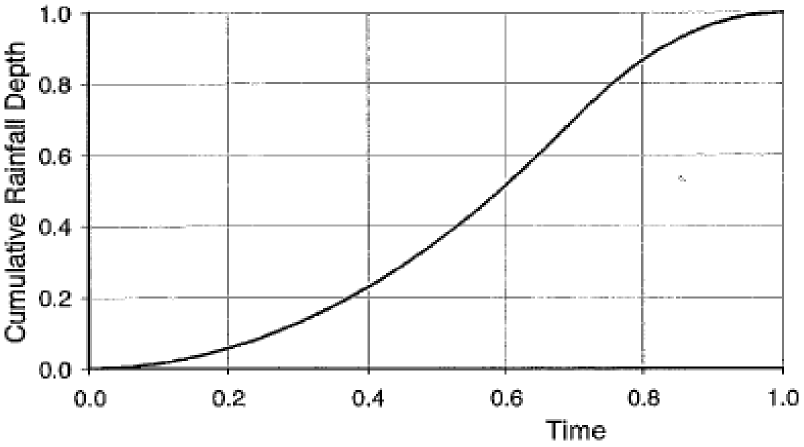


Figure 5: Cumulative Depth Hyetograph for Rainfall Intensity (CCC, 2003)



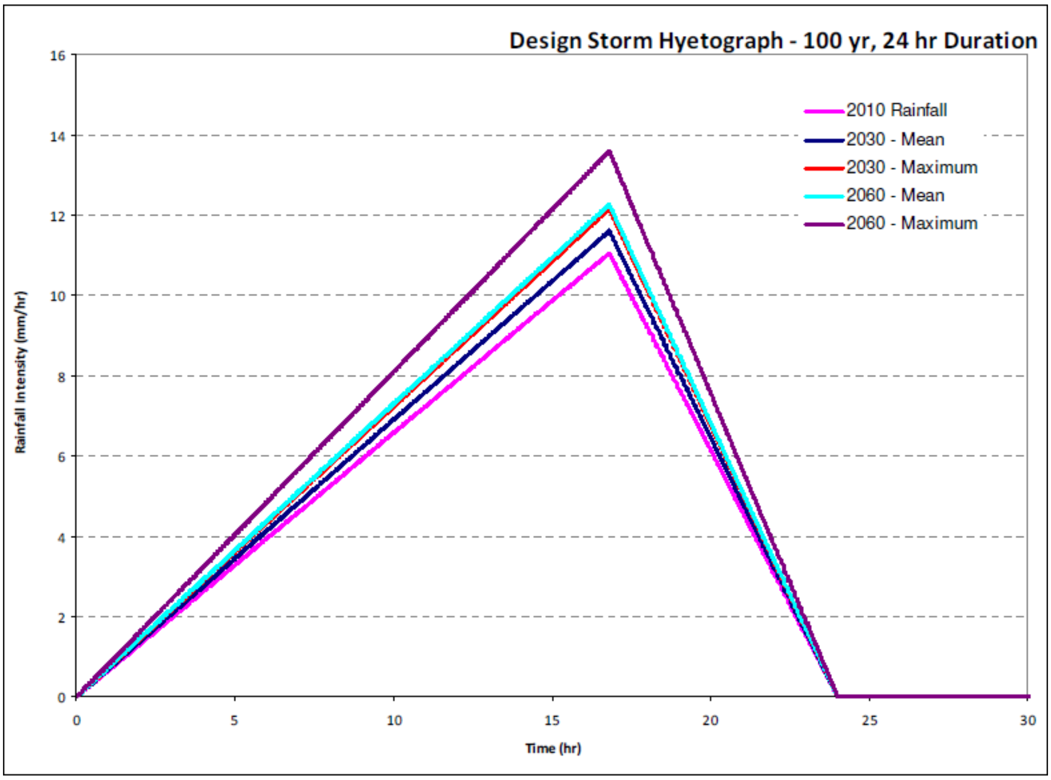
The dimensionless hyetograph was applied to each of the rainfall depths determined from the DDF analysis (as amended by the factors discussed herein). This produced 20, 40 and 60 minute base hyetographs for the 10, 50 and 100 yr events for use in the hydraulic modelling.

2.11 OUTCOME

The outcome of the above work is a series of synthetic hyetographs (Figure 6) which can be used to assess the LoS provided by storm water infrastructure in Dunedin. The synthetic events have been created such that they take into account the main factors which can influence rainfall in the Dunedin area to ensure that they allow a robust analysis of the performance of the storm water infrastructure.

This assessment, undertaken through system (hydraulic) modelling of the storm water infrastructure can then assist in planning of upgrades, infrastructure replacement and feed into future development planning.

Figure 6: Example of Synthetic Hyetographs


Design Storm Hyetograph - 100 yr, 24 hr Duration
Rainfall Intensity (mm/hr)
Time (hr)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
2010 Rainfall
2030 - Mean
2030 - Maximum
2060 - Mean
2060 - Maximum

3 CONCLUSIONS

This paper has summarised the steps taken in creating synthetic storm event hyetographs for use in the ICMP process undertaken for the Dunedin 3 Waters Strategy. The creation of these hyetographs in a robust, considered manner was essential to achieve excellence in the subsequent storm water modelling.

The main elements which lead to the success of this work, and which should be considered when replicating this elsewhere include the following:

1. Of great importance is to define the intended use of the data being created, in this case the synthetic hyetographs, before starting. A full understanding of the end-use of the data greatly helps to focus efforts on producing highly relevant and applicable data.

2. Comprehensive literature / data reviews are essential to capture suitable data and methodologies. Reviews should extend beyond references specifically related to the local area as studies from other parts of the country may be applied to the subject site, provided suitable justification for use can be made. Developing a list of factors which may have an influence on the study (e.g. climate change, spatial variation, etc) can help focus any review, capturing any data which is available.

3. Any use of previously published data / data developed by others must be suitably reviewed prior to use, but can lead to efficient use of project time if identified as being suitable.

4. The separation of work, such as the development of synthetic design hyetographs, into key elements, can assist greatly in developing an understanding of the task at hand and can assist in the peer review and ultimate publication of the work.

Through the application of the methodologies and processes discussed above, rainfall data for projects, such as the development of synthetic design hyetographs for the Dunedin 3 Waters Strategy, can be created efficiently and accurately, and within the budgetary and scheduling constrains of typical commercial contracts.

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