**Impacts of Climate Change**
**on Urban Infrastructure**
**& the Built Environment**

**A Toolbox**

# Tool 2.1.2: Modelling future heavy rainfall


## Author(s)

J. Sturman[1], H. McMillan[2], S. Poyck[2], R. Ibbitt[2],
R. Woods[2], A. Tait[1] and E. Hreinsson[2]

## Affiliation(s)

1. NIWA, Private bag 14901, Wellington

2. NIWA, PO Box 8602, Christchurch

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# 1. Introduction

## 1.1 Background

Heavy rainfall totals are expected to increase due to climate change and such increases in rainfall will impact river flooding in New Zealand. Coastal river areas will be particularly affected where sea-level rise will also affect inundation. As described in [Tool 2.1.1] the first step in estimating the effects of climate change on river flood flows is to determine future change in rainfall. The Ministry for the Environment's manual "Tools for estimating the effects of climate change on flood flow" (MfE, 2010) provides a range of methods to do this which were summarised in [Tool 2.1.1]. In this tool, the methods will be discussed and demonstrated as they are applied to worked case study examples. The examples are taken from flood risk case studies on the Buller River and Heathcote River [see: Toolbox Overview and Case Study Examples].

### 1.1.1 Purpose of Tool

To demonstrate methods for estimating future rainfall intensity and spatial variation taking into account the effects of climate change.

# 2. Methods

## 2.1 Simple screening methods for determining future rainfall

The simplest method recommended by the Ministry for the Environment is to use a scaling factor by which rainfall is adjusted by each 1°C of temperature change (Section 3.2. MfE, 2010). The scaling factors can be used in combination with local rainfall data to estimate the effect of climate change on future extreme rainfall events. A worked example of this method is presented in Section 3.1, below.

The following steps describe how to apply the simple screening method recommended by the Ministry for the Environment (MfE, 2010).

*Step 1*: Choose the study location and collate current climate data. The climate data may come from raw climate station data, previous investigations of extreme rainfall events undertaken in the chosen research area, NIWA's virtual climate station network, or HIRDS can be used (High Intensity Rainfall System V3, http://hirds.niwa.co.nz/). The HIRDS system can estimate rainfall frequency, depth and average recurrence interval (ARI) extreme rainfall events. Refer to Section 4 (Data Needs) for more detail.

*Step 2*: Projected future changes in seasonal and annual mean temperature over several scenarios of climate warming can be taken directly from the Climate Change Effects manual (Ministry for the Environment, 2008, Tables 2.2 and 2.3; also refer to Tables 2.1 and 2.2 below). Use this information to determine the likely amount of warming in °C due to climate change. The average change is given, and also the range from the six illustrative emissions scenarios (A1B, A1FI, A1B, B1, A2, B2) which describe different future storylines for population growth and technological change.

*Step 3*: Factors used to derive extreme rainfall values for screening assessments can be found in Table 5.2 of the Climate Change Effects manual (Ministry for the Environment, 2008; also refer to Table 2.3 below). Combine these factors with the amount of warming determined in the step above to determine the recommended percentage adjustments used to calculate future extreme rainfall.

*Step 4*: Apply the percentage adjustment determined in Step 3 to the total rainfall for the current climate determined in Step 1. The result is the rainfall total for future climate scenarios.

**Table 2.1: 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 (MfE, 2008)**

| Region | 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] |

**Table 2.2: 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 (MfE, 2008)**

| Region | Summer | Autumn | Winter | Spring | Annual |
|---|---|---|---|---|---|
| Northland | 1.3 [0.6, 2.7] | 1.7 [0.7, 3.5] | 2.1 [0.9, 4.1] | 2.5 [1.1, 5.0] | 3.0 [1.3, 5.9] |
| Auckland | 1.4 [0.6, 2.6] | 1.8 [0.7, 3.4] | 2.1 [0.9, 4.0] | 2.5 [1.1, 4.9] | 3.0 [1.3, 5.8] |
| Waikato | 1.4 [0.6, 2.5] | 1.8 [0.7, 3.3] | 2.1 [0.9, 3.8] | 2.5 [1.0, 4.7] | 3.0 [1.3, 5.5] |
| Bay of Plenty | 1.4 [0.6, 2.5] | 1.8 [0.8, 3.3] | 2.1 [0.9, 3.8] | 2.5 [1.1, 4.7] | 3.0 [1.3, 5.6] |
| Taranaki | 1.4 [0.6, 2.4] | 1.8 [0.7, 3.2] | 2.1 [0.9, 3.7] | 2.5 [1.1, 4.5] | 3.0 [1.3, 5.3] |
| Manawatu-Wanganui | 1.3 [0.6, 2.5] | 1.7 [0.7, 3.3] | 2.1 [0.9, 3.8] | 2.5 [1.0, 4.7] | 3.0 [1.2, 5.5] |
| Hawke's Bay | 1.3 [0.6, 2.4] | 1.7 [0.7, 3.2] | 2.1 [0.9, 3.7] | 2.5 [1.0, 4.5] | 3.0 [1.2, 5.4] |
| Gisborne | 1.4 [0.6, 2.4] | 1.8 [0.8, 3.2] | 2.1 [0.9, 3.6] | 2.5 [1.1, 4.5] | 3.0 [1.3, 5.3] |
| Wellington | 1.3 [0.6, 2.3] | 1.7 [0.8, 3.1] | 2.1 [0.9, 3.6] | 2.5 [1.1, 4.4] | 3.0 [1.3, 5.2] |
| Tasman-Nelson | 1.3 [0.6, 2.3] | 1.7 [0.8, 3.0] | 2.0 [0.9, 3.5] | 2.5 [1.1, 4.3] | 2.9 [1.3, 5.1] |
| Marlborough | 1.3 [0.6, 2.3] | 1.7 [0.8, 3.0] | 2.0 [0.9, 3.5] | 2.5 [1.1, 4.3] | 2.9 [1.3, 5.0] |
| West Coast | 1.3 [0.7, 2.2] | 1.7 [0.8, 2.9] | 2.0 [1.0, 3.4] | 2.4 [1.2, 4.1] | 2.9 [1.4, 4.9] |
| Canterbury | 1.3 [0.7, 2.2] | 1.7 [0.9, 2.9] | 2.0 [1.1, 3.4] | 2.5 [1.3, 4.2] | 2.9 [1.6, 5.0] |
| Otago | 1.3 [0.8, 2.1] | 1.7 [1.0, 2.8] | 2.0 [1.2, 3.2] | 2.4 [1.4, 3.9] | 2.8 [1.7, 4.6] |
| Southland | 1.3 [0.8, 2.0] | 1.6 [1.0, 2.7] | 1.9 [1.2, 3.1] | 2.3 [1.4, 3.8] | 2.8 [1.7, 4.5] |
| Chatham Islands | 1.3 [0.6, 2.7] | 1.7 [0.7, 3.5] | 2.1 [0.9, 4.1] | 2.5 [1.1, 5.0] | 3.0 [1.3, 5.9] |

**Table 2.3: Factors for use in deriving extreme rainfall information for screening assessments (MfE, 2008)**

| ARI (years) → | 2 | 5 | 10 | 20 | 30 | 50 | 100 |
|---|---|---|---|---|---|---|---|
| **Duration ↓** | | | | | | | |
| < 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 |

## 2.2 Advanced methods for determining future rainfall

More advanced methods can be used to estimate the effect of climate change on rainfall time series data. A variety of approaches are discussed in the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010) and are presented in [Tool 2.1.1]. They are summarized below with a link to the Case Study where they are demonstrated.

### 2.2.1 Weather generators

Weather generators are stochastic models which are used for simulating a daily time-series of linked climatic elements. These elements often include rainfall, maximum and minimum temperature, solar radiation and wind. The weather generators are first tuned to current site data prior to any adjustments for future climate change being made (MfE, 2010). A worked example of this method is presented in Section 3.2, below.

### 2.2.2 Empirical adjustment of daily rainfall data

This method is used to estimate rainfall data at a daily or finer time resolution. The *empirical adjustment of daily rainfall data* method uses scenarios of the change in mean rainfall to make adjustments to the distribution of rainfall over a daily time series and to increase the most extreme rainfall volumes. The methodology for this method has been extracted from the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a) and is presented in full in [Tool 2.1.1]. A very brief summary is given here and a worked example of this method is presented in Section 3.3, below.

*Step 1 Adjust the daily data using the monthly rainfall offsets (Climate Change Effects manual, table 2.4 for 2040, table 2.5 for 2090), averaged over many years.*

*Step 2 Allow for the reduction in frequency of low-rainfall days.*

*Step 3 Calculate the additional percentage change in daily rainfall according to rainfall percentile (heavy rain vs. light rain).*

*Step 4 Adjust final totals for consistency with totals calculated in Step 1*

### 2.2.3 Analogue selection from observed data

Analogue selection can be applied to rainfall data at any temporal resolution. For this method a subset of past rainfall data with specific anticipated characteristics in a future climate is selected. For example, a rainfall dataset may be chosen from the warmest years. Refer to section 3.3.3 of the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010) and to Sansom and Renwick (2007).

### 2.2.4 Downscaling of global climate change models

It is possible to obtain estimates of changes in rainfall by downscaling the results from global climate change models (GCMs). The suggested approach from the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010) is to *"…apply adjustments to observed rainfall probability distributions, guided by distributional changes predicted by the GCMs. The statistical distribution of daily rainfall can be fitted to a 'gamma distribution', and GCMs analysed to evaluate how the shape and scale factors of this distribution change under a warming scenario. Similar parameter changes can then be applied to the rainfall distribution at a site."*

### 2.2.5 Regional climate models

A regional climate model (RCM) simulates all the atmospheric processes that are significant to the creation of heavy rainfall events and can allow these processes to change under global warming. Rainfall data output from an RCM can be at a very high temporal resolution (e.g. 3 minutes) and reasonably high spatial resolution (e.g. 20 km) [see Tool 2.4.4 for an example of an application of high temporal resolution RCM data]. The RCM utilized at NIWA is based on the global climate model known as HadCM3 (Drost *et al*., 2007; Baskaran *et al*., 2002).

### 2.2.6 Mesoscale weather models

A mesoscale weather model can be used to firstly simulate an event that could or has occurred under the current climate, and secondly to run the same simulation under a climate with increased air temperature consistent with the warming from a climate change scenario. These types of models can provide specific information on the location, structure and timing of rainfall across a study area or region of interest (MfE, 2010a). A summary of the advanced methods for estimating rainfall can be found Table 5 of the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a).

## 2.3 Choosing the right method

The process diagram below (Figure 2.1) provides basic guidance on selecting the most appropriate method based on simple questions relating to the particular study. It shows only the most common methods. For more detailed guidance with advantages, disadvantages and data requirements for all possible methods, refer to Table 5 of MfE (2010).

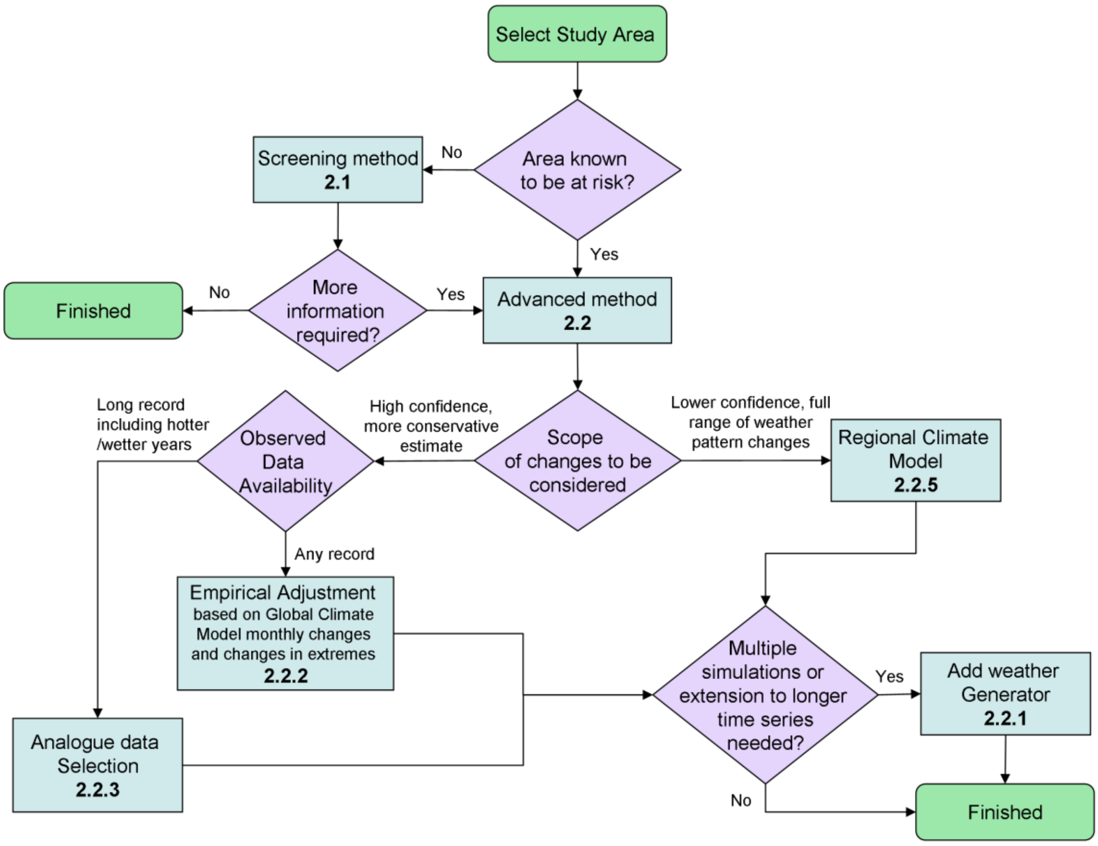



**Figure 2.1: Process diagram providing guidance on choice between the most commonly used methods for modelling future heavy rainfall**

# 3. Case study examples

## 3.1 Impacts of climate change on floods for the Heathcote River

The method demonstrated here to estimate the effect of climate change on the Heathcote River (Christchurch) flood risk, follows the general simple screening approach outlined in Section 2.1 above and in Section 3.2 of MfE (2010). To estimate the effect of climate change on rainfall a range of warming scenarios from Tables 2.2 and 2.3 of MfE (2008) were used, together with the percentage increases per degree of warming from Table 5.2 of MfE (2008).

For background information on the Heathcote River and catchment, refer to [Toolbox Overview and Case Study Examples]. The rainfall estimation described in this tool is used as input into the following [Tool 2.1.3] and [Tool 2.1.4] to estimate future flood flows and inundation. The design event approach can be summarised as follows:

(1) A design rainfall total for the current climate was calculated based on Griffiths et al. (2009) rainfall statistics [See this section].

(2) Design rainfall totals for the required climate change scenarios were calculated by scaling the current rainfall total [as described in Section 2.1; example given this Section].

(3) The temporal pattern of rainfall (for both current and future scenarios) was taken from an observed severe rainfall event. [See this section].

(4) A rainfall-runoff model was developed for the Heathcote using the Topnet model (Clark et al., 2008). [See Tool 2.1.3]

(5) Each future design rainfall was used as input to the rainfall-runoff model to produce a different flood hydrograph for each climate change scenario [see Tool 2.1.3].

(6) These flood hydrographs were provided as input for a hydraulic model used to estimate flood inundation [see Tool 2.1.4].

**Design Rainfall**

To create a design rainfall event, the first step was to select a rainfall duration that was appropriate for the Heathcote catchment size. The duration chosen was 24 hours (J. Walsh and G. Smart, *pers. comm.*). Information was then obtained on the frequency of extreme 24-hour rainfall totals at Christchurch Gardens, and finally a method for distributing the rainfall within the 24-hour duration was used.

<u>(1) Rainfall Totals: Current Climate</u>

The source of extreme rainfall information used in this case for the current climate was Griffiths et al. (2009). This report provides a detailed assessment of extreme rainfall in Christchurch. If it had not been available then we would have used HIRDS.

According to Griffiths et al. (2009), the median annual maximum daily rainfall at Christchurch Gardens is 50.5 mm, and rainfall totals for more extreme events can be estimated as a proportion of this median annual maximum. The resulting daily rainfall estimates are shown in Table 3.1.

**Table 3.1: Extreme daily rainfall estimates at Christchurch Gardens, using Griffiths et al. (2009)**

| ARI (years) | Daily Rainfall (mm) |
|---|---|
| 10 | 85 |
| 20 | 99 |
| 50 | 121 |
| 100 | 138 |
| 200 | 156 |
| 500 | 183 |
| 1000 | 205 |

(2) Rainfall Totals: Effect of Climate Change

These extreme daily rainfall totals are expected to increase if the climate warms. Temperature change scenarios were taken from MfE (2008). We used the Low, Medium and High annual temperature increases for 2040 and 2090 in Canterbury, given in MfE (2008) Tables 2.2 and 2.3 (and reproduced here as Table 3.2).

**Table 3.2: Temperature increases in Canterbury for 2040 and 2090 (MfE, 2008, Tables 2.2 and 2.3)**

| Scenario | 2040-Low | 2040-Med | 2040-High | 2090-Low | 2090-Med | 2090-High |
|---|---|---|---|---|---|---|
| Increase in Temperature ($^{o}$C) | 0.2 | 0.9 | 1.9 | 0.7 | 2.0 | 5.0 |

The daily rainfall for each climate scenario was determined by applying percentage increases to the daily total for the current climate, according to MfE (2008) Table 5.2 (see Table 3.3 below).

**Table 3.3: Increases in daily rainfall per degree of warming (MfE, 2008) Table 5.2**

| ARI | Increase in daily rain for 1°C T rise (%) |
|---|---|
| 10 | 6.3 |
| 20 | 7.2 |
| 50 | 8.0 |
| 100 | 8.0 |
| 200 | 8.0 |
| 500 | 8.0 |
| 1000 | 8.0 |

The rainfall totals for various ARIs under the future climate scenarios are obtained by taking the rainfall totals from the current climate (Table 3.1), the temperature increases in Table 3.2, and the rainfall increases per degree from Table 3.3. The resulting daily rainfall totals are shown in Table 3.4.

**Table 3.4: Daily rainfall totals at Christchurch Gardens for a range of ARIs and climate scenarios**

| | Daily Rainfall totals (mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| ARI (years) | Current Climate | 2040-Low | 2040-Med | 2040-High | 2090-Low | 2090-Med | 2090-High |
| 10 | 85 | 86 | 90 | 95 | 89 | 96 | 112 |
| 20 | 99 | 101 | 106 | 113 | 104 | 114 | 135 |
| 50 | 121 | 123 | 129 | 139 | 127 | 140 | 169 |
| 100 | 138 | 140 | 148 | 159 | 146 | 160 | 193 |
| 200 | 156 | 159 | 167 | 180 | 165 | 181 | 218 |
| 500 | 183 | 186 | 196 | 211 | 193 | 212 | 256 |
| 1000 | 205 | 208 | 219 | 236 | 216 | 237 | 286 |

### (3) Distributing rainfall within the design event

The current climate was simulated using a specific event (from January 1980) that was selected to be representative of the type of event that can produce severe floods (see Figure 3.1). Climate scenarios were simulated by increasing or decreasing all hourly rainfall amounts in the storm by the same scale factor. The scale factor was chosen to produce the daily rainfall total for the desired ARI average recurrence interval and climate scenario.

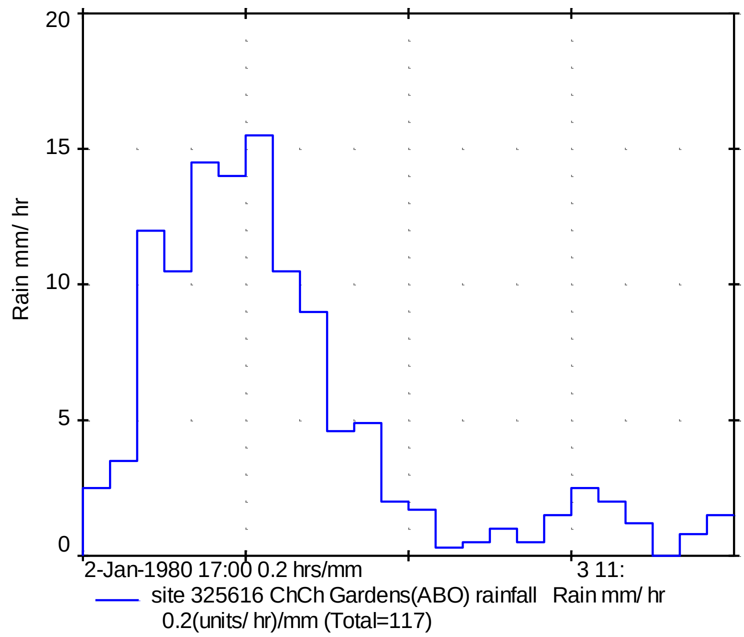
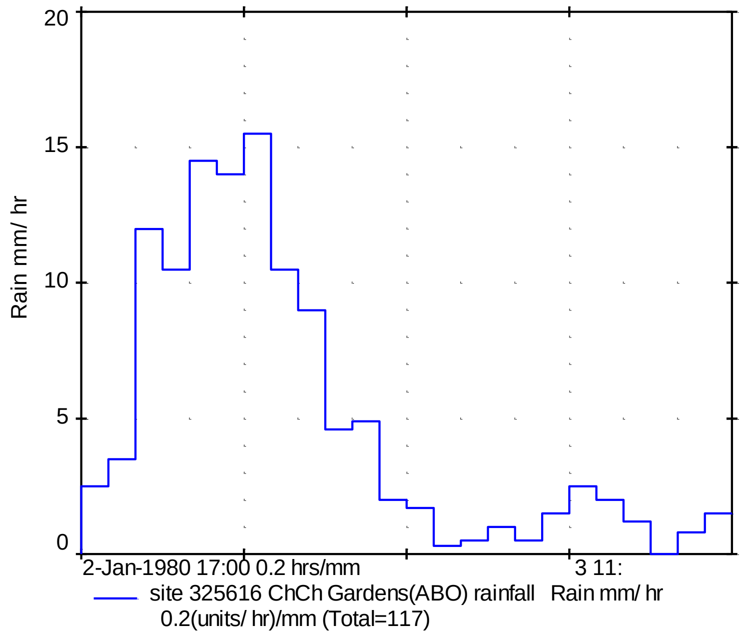



**Figure 3.1: Hourly rainfall at Christchurch Gardens on 2 January 1980**

For example, to simulate the flood with 1000-year ARI under the 2090-High climate scenario, we multiplied all the hourly rainfalls from the January 1980 event by 286/127.8, where 286 is the rainfall total for this event (Table 3.4), and 127.8 is the rainfall total from the January 1980 event




(

Figure 3.1), and rainfall totals over the rest of the catchment continued to be distributed within the catchment according to the pattern of average annual rainfall (Tait et al., 2006). The rainfall data was then incorporated into a hydrological modelling methodology to determine river flow. This process will be covered in detail in [Tool 2.1.3].

## 3.2 Heathcote experimental case study: Estimating future heavy rainfall using a weather generator and Regional Climate Model

The advanced method demonstrated here used for estimating the effect of climate change on the Heathcote River (Christchurch) flood risk, uses output from a Regional Climate Model (RCM) linked to a weather generator, as briefly outlined in Section 2.2.1 above and in Section 3.3.1 of MfE (2010). This approach is at the leading edge of methods to assess climate change impacts, due to the ability of the physics-based RCM to directly simulate climate processes such as changes in storm tracks. Regional-scale modelling has previously been shown to improve climate simulations for New Zealand (Renwick *et* al., 1998). Previous research created a framework for the use of RCM output linked to hydrological modelling via a weather generator (McMillan et al., 2010). However, as will be discussed here and in the following [Tool 2.1.3], application of this method in the Heathcote catchment showed that there is a need for substantial further research to make this approach universally applicable.

The RCM and weather generator approach can be summarised as follows:

(1) Climate scenarios for current and future climates were extracted from the RCM [see this section].

(2) Rainfall totals from the RCM were corrected for bias [see this section].

(3) A stochastic weather generator was used to extrapolate from the 30 years of predicted climate data, to more extreme rainfall events [see this section].

(4) A rainfall-runoff model was developed for the Heathcote using the Topnet model (Clark et al., 2008). [See Tool 2.1.3]

(5) Each future design rainfall was used as input to the rainfall-runoff model to produce a different flood hydrograph for each climate change scenario [see Tool 2.1.3].

Note that due to the experimental nature of this approach, the flood hydrographs were not found to be reliable at this stage and hence were not routed through a hydraulic model to extend the method to estimation of flood inundation. See [Tool 2.1.3] for further information.

## Climate Scenarios

The climate scenarios are derived from the UK Met Office HadCM3 Global Climate Model. This model has been coupled to the HadRM3 Regional Climate Model, also from the UK Met Office in order to provide dynamically downscaled climate predictions for the New Zealand region at a grid scale of 30km. Three simulations are used, a control run is available for the years 1970-2000 and two future runs are available for the B2 (low to moderate) and A2 (moderate to high) emissions scenarios for the years 2070-2100. RCM output for the grid points surrounding the Heathcote catchment was extracted for all three scenarios.

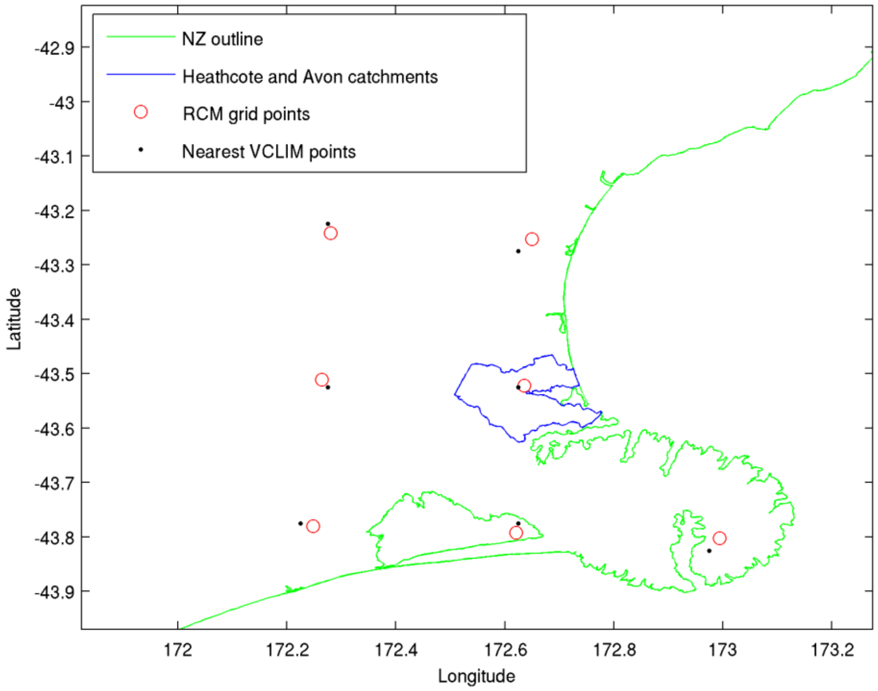



**Figure 3.2: Regional Climate Model and Virtual Climate Station Network grid point location in relation to the Heathcote catchment.**

## Bias Correction

Quantile-mapping bias correction is used to correct any persistent bias in regional climate model rainfall volumes when compared to observed rainfall data. The climate data is extracted from the RCM as described in the previous section. Observed rainfall series for the same locations (one per grid point) is extracted from the Virtual Climate Station Network (VCSN; refer to Section 4. Data Needs). The VCSN is on a high resolution grid of 0.05° Lat/Lon and hence locations can be matched very closely (see Figure 3.2).

For each location, the distribution of daily rainfall amount was calculated for both the observed (VCSN) and modelled 'current climate' data. The mapping between the two distributions was then used to correct both the percentage of days where rain was observed, and the rainfall depths. To correct the modelled 'future climate' data in the same way, although there is no 'observed future climate' data for comparison, we assume that the same biases are present as those in the current climate. The RCM temperature series are similarly corrected for bias, by comparison with minimum and maximum daily temperature data taken from the VCSN. The only difference is that the temperature biases are treated as additive rather than multiplicative, as is standard in climate change applications.

**Weather Generator**

A multisite weather generator of the 'Hidden Markov Model' type has been developed for New Zealand under the FRST 'Climpacts' programme (Thompson *et al.*, 2007). The model is used to understand rainfall variation over space and time, within a localised area affected by regional-scale weather patterns. The rainfall generator uses input rainfall series for multiple locations and fits statistical distributions of daily rainfall volume. It can then generate further rainfall series as required which have the same rainfall volume and pattern characteristics. It is possible for the generator to simulate rainfall heavier than that occurring in the original series, consistent with the possibility of more extreme events occurring when a longer rainfall series is modelled.

To set up the weather generator, the bias-corrected 30-year rainfall series from the seven RCM output grid points and for each scenario (current climate, A2, B2) were used as input, together with the location of each point. The weather generator was then run to produce 1000-year rainfall series for each scenario. Simulated temperature minimum and maximum daily values for the same 1000-year series were also generated using a first-order auto-regressive moving average model (Mullan *et al.* 2003): these are needed for the hydrological model.

**Weather Generator Results**

The output of the weather generator can be analysed directly to give maximum rainfall totals for particular durations and/or return periods, for example see Figure 3.3. However for estimation of flood flows under climate change, the complete rainfall series is fed directly into a hydrological model. Flood return periods are calculated from the hydrological model output. The strength of this method is that it gives implicit consideration of antecedent wetness conditions in the catchment, e.g. allowing for floods caused by extended periods of high rainfall such as a wet winter following a wet autumn. This is a significant advantage over the simpler method of event-based simulation where rainfall events are considered in isolation.

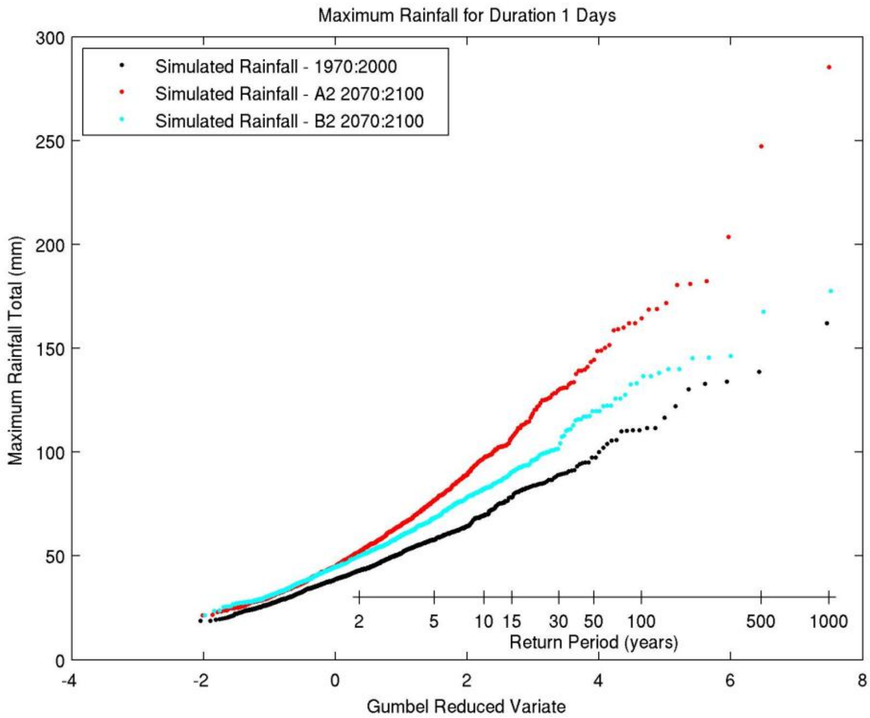



**Figure 3.3: Maximum daily rainfall in the Heathcote catchment for return periods up to 1000 years, for simulations of current and future climate, as predicted by the weather generator.**

**Limitations of the Method**

During the study, some current limitations of the RCM and weather generator approach were identified which need to be addressed in future research.

1) RCM predictions are dependent on occurrence and exact locations of a few large storm events during the 30-year time series. Due to the limited number of RCM runs (as each run is highly computationally intensive) the uncertainty due to these factors cannot be properly assessed. In the future more runs

incorporating multiple GCMs to drive the RCM will enable this uncertainty assessment.

2) The weather generator used in this study performed reasonably well for producing daily rainfall simulations over long time series. However the types of statistical distributions fitted by the weather generator are currently limited and should be increased to include heavy-tailed statistical distribution types which may increase the number of heavy rainfall events predicted.

### 3.3 Estimating future flood flows at Te Kuha, Buller catchment

The advanced method demonstrated here used for estimating the effect of climate change on the Buller River (Westport) flood risk, follows the *empirical adjustment of daily rainfall data* method outlined in Section 2.2.2 above and in Section 3.3.2 of MfE (2010).

For background information on the Buller River and catchment, refer to [Toolbox Overview and Case Study Examples]. The rainfall estimation described in this tool is used as input into the following [Tool 2.1.3] and [Tool 2.1.4] to estimate future flood flows and inundation. The approach can be summarised as follows:

(1) An historical flood event was chosen as the baseline flood scenario for the current climate. Rainfall and temperature data relating to this event were taken from NIWA's Virtual Climate Station Network [See this section].

(2) Rainfall and temperature data for the required climate change scenarios were calculated using the *Empirical Adjustment of Daily Rainfall Data* method [as described in Section 2.2.2; example given this Section].

(3) A rainfall-runoff model was developed and calibrated for the Buller using the Topnet model (Clark et al., 2008). [See Tool 2.1.3]

(4) The future rainfall/temperature data were used as input to the Buller rainfall-runoff model to produce a different flood hydrograph for each climate change scenario [see Tool 2.1.3].

(5) These flood hydrographs were provided as input for a hydraulic model used to estimate flood inundation [see Tool 2.1.4].

**(1) Rainfall and temperature data from historical flood event**

An historical flood event was chosen to represent the type of extreme flood event of interest for the Buller catchment. The flood occurred on 31 August 1970 when the peak flow at Te Kuha was measured at 8483 $m^3s^{-1}$.

Rainfall and temperature data for this event were extracted from NIWA's virtual climate station network (VCSN). These data are interpolated from climate station records onto a 0.05° lat/long (~5x5 km) grid over the whole of New Zealand (Tait et al., 2006; Tait, 2008). Daily values of rainfall and minimum and maximum temperature from all the VCSN grid points within the Buller catchment were used. A bias correction was applied to the rainfall grid based on a previous study which compared total volumes of rainfall and river flow on a multi-year basis, and gave percentage corrections required to the VCSN rainfall data required to ensure water balance was maintained in the catchment (Woods *et al.*, 2006). Finally, the daily rainfall values were disaggregated from daily to hourly time steps using hourly data from the Greymouth Airport climate station to distribute the rainfall within the 24-hour period.

**(2) Rainfall and temperature data for Climate Change Scenarios**

In this study, 3 emissions scenarios and 2 different time periods were chosen to cover a wide range of possible futures. They were as follows:

1) Medium emission scenario A1B, 2030-2049 (2040-Med)

2) Medium emission scenario A1B, 2080-2099 (2090-Med)

3) High emission scenario A2, 2030-2049 (2040-High)

4) High emission scenario A2, 2080-2099 (2090-High)

5) Low emission scenario B1, 2030-2049 (2040-Low)

6) Low emission scenario B1, 2080-2099 (2040-Low)

Rainfall and temperature data (again on a daily time scale) were produced for each of these scenarios using transformations of the current climate rainfall and temperature data. The *empirical adjustment of daily rainfall data* method was used, as outlined in Section 2.2.2 above, however two variations were made to the approach such that conservative estimates of the climate change impacts were obtained.

First, in Step 1 [refer to Section 2.2.2], the monthly rainfall changes for 2040 and 2090 were smoothed using six-month averaging. Two averaging periods were chosen: June–November and December–May. Each month within the two periods was assigned the corresponding six-month average temperature and rainfall changes. This smoothing was performed because some of the projected monthly rainfall changes from MfE (2008) for this region are quite large, hence a more conservative approach was chosen. The same six-month averaging was applied to the projected monthly temperature changes for 2040 and 2090 for this region.

The second variation that was used for this case study was not to do Steps 2–4 [refer to Section 2.2.2]. Thus, there was no change made to the number of rain days in the record or to the inter-annual variance in monthly rainfalls. Again, this was regarded as a conservative variation.

The current and projected rainfall and temperature data described above were then incorporated into the hydrological model TopNet to determine stream flow [see Tool 2.1.3]. Table 3.5 shows the peak 24-hour (9am-9am) rainfalls and the resultant runoff as modelled by Topnet.

**Table 3.5: Projected changes to the peak 24-hour (9am-9am) rainfall in the Buller catchment for each future scenario, and the resulting changes to catchment runoff modeled by Topnet.**

| Climate Scenario | Period | Peak rainfall (mm/day) | Increase compared to current (%) | Runoff (m) | Increase compared to current (%) | Runoff: rainfall ratio |
|---|---|---|---|---|---|---|
| Base | Current | 350 | | 0.257 | | 0.733 |
| B1 (Low) | 2030-2049 | 362 | 3.4 | 0.265 | 3.4 | 0.733 |
| A1B (Med) | 2030-2049 | 368 | 5.2 | 0.270 | 5.2 | 0.734 |
| A2 (High) | 2030-2049 | 371 | 6.0 | 0.276 | 7.6 | 0.735 |
| B1 (Low) | 2080-2099 | 370 | 5.7 | 0.270 | 5.4 | 0.731 |
| A1B (Med) | 2080-2099 | 381 | 8.9 | 0.279 | 8.6 | 0.731 |
| A2 (High) | 2080-2099 | 387 | 10.6 | 0.290 | 13.1 | 0.734 |

# 4. Data Needs

Design rainfalls have been estimated for many locations in New Zealand, for example see Griffiths et al. (2009) for an analysis based on Christchurch Gardens rainfall observations. For locations without specific site analyses, the High Intensity Design Rainfall System (HIRDS) can be used (http://hirds.niwa.co.nz).

Climate data for New Zealand can be downloaded for free using NIWA's online access to the National Climate Database, http://cliflo.niwa.co.nz.

NIWA's Virtual Climate Station Network (VCSN) is a regular grid (0.05 degrees lat/long, or ~5km x 5km) covering all of New Zealand.  At each of the 11491 gridpoints there are daily estimates of 11 climate variables including rainfall and maximum and minimum temperature.  These data can also be accessed from http://cliflo.niwa.co.nz (choose the "Special Datasets" option).

# 5. Assumptions and Limitations

Global Climate Models (GCMs) are designed to simulate long-term changes to the Earth's climate based on scenarios of future greenhouse gas emissions and concentrations in the atmosphere. The physical processes that result in extreme rainfalls that can lead to flooding are still not modelled well by most GCMs, as many of these processes occur on very small spatial scales. Thus, at present, "adjustment" methods like those described and worked through above are still required to estimate how flood-producing rainfalls may change in the future. Choices based on expert judgement, such as those described in Section 3.3 to use conservative variations of the empirical adjustment method for daily rainfall data for the Buller, will affect (in this case reduce) the final flood flow predictions and must be taken into account during an impact assessment.

Much research is ongoing on developing Regional Climate Models, which are able to directly simulate many of these small scale processes. However, as demonstrated in Section 3.2 above, there is still a lot of work to be done in this field.

Thus, it is suggested that "High, Medium, and Low" scenarios be worked through, as shown in the examples above, to provide an envelope within which the future heavy rainfalls are expected to lie. Depending upon what is at risk from heavy rainfall and potentially flooding, adaptation strategies can then be tailored to a particular part of this envelope (e.g. to the middle-road, or to a medium-high projection) [see Tool 2.1.5].

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