Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Tool 2.1.1: General guidance on climate change and flood modelling methods used in New Zealand

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1. Introduction

1.1 Background

In May 2010 the Ministry for the Environment (MfE) published a guide that provides advice on preparing for future flooding events with the explicit aim of helping local authority staff manage and minimise the risks posed by increased flood risk due to climate change (MfE, 2010b). The MfE document presents good practice guidance and offers a list of options of varying complexity for carrying out flood modelling and climate change assessments.

1.2 Purpose of Tool

This report [Tool 2.1.1] briefly summarises the MfE (2010b) climate change and flooding guide, as well as drawing from the source document (MfE, 2010a). The following sections of the MfE guide are summarised here: (i) choosing a method to estimate the impact of climate change on flooding; (ii) methods for estimating changes in rainfall; (iii) methods for estimating changes in flow; (iv) methods for estimating changes in inundation; and (v) implications for engineering design.

2. Choosing a method to estimate the impact of climate change on flooding

In order to comprehensively assess the effects of climate change on flooding and the impacts any floods may have the following variables must be determined:

1. Changes in future rainfall

2. Estimated future river flow (taking into account the changes in future rainfall)

3. The extent of any flood inundation

There are a variety of methods available to choose from for estimating the impact of climate change on flooding. According to the local government guidance on estimating the effects of climate change on flood flow (MfE, 2010b) the important factors to consider are:

1. What data are available for the area of interest?

2. What is the required level of precision and accuracy?

3. Is the expertise and technology available in order to undertake the analysis and modelling?

The government guidance divides the methods into two main categories: basic screening tools and advanced methods. The basic screening methods are used to identify if there are any potential risks posed by climate change impacts and the more complicated advanced methods can be utilised where the results of a screening study show that there could be an impact. Both the screening and advanced methods are discussed in the following sections.

3. Methods for estimating changes in rainfall

The initial step in estimating the effects of climate change on river flood flows is to estimate the change in rainfall and the Ministry for the Environment's Climate Change Effects manual (MfE, 2008) provides a range of methods to do this. For worked examples of these methods see [Tool 2.1.2].

3.1 Screening methods

The simplest method presented in the manual recommends the use of a scaling factor by which rainfall is adjusted for each 1°C of temperature change. 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 more detailed description of this method can be found in section 3.2 of the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a)

3.2 Advanced methods

More advanced methods can be used to estimate changes due to 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, 2010a) and these methods are briefly presented below.

Weather generators

Weather generators are used for simulating a daily time-series of 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, 2010a).

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 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). The change in monthly climatological rainfall is then calculated (eg, a 10 per cent increase in a monthly climatology of 100 millimetres means an extra 10 millimetres). The monthly climatological rainfall is estimated by averaging over many years so that the resulting monthly totals represent the current state of the climate. The monthly change in rainfall so obtained (eg, 10 millimetres) is then expressed as a percentage change for the current month. For example, if the current monthly total is 120 millimetres, then the percentage change is 10 millimetres divided by 120 millimetres, which equals 8.3 per cent. This percentage change is then applied to each rain day in the month. This step does not change the number of rain days in the record or alter the inter-annual variance in monthly rainfalls.*

Step 2 *Allow for the changes in frequency of rain days. This reduction in low-rainfall days helps to balance the increased rainfall extremes in step 3. Thus, if:*

NW = number of rain days

NT = total number of days in a year (ie, 365.25)

ΔT = warming

*then the number of rain days will change from NW to (rounded down to the nearest integer) NW – 0.0175 * ΔT * NT. This corresponds to about seven fewer rain days per year per degree of warming. The reduction is applied to days with the lowest rainfall by ranking all rain days in an ascending order* *and setting the calculated number (0.0175 * ΔT * NT) of lowest rainfall days to zero rainfall.*

Step 3 After applying steps 1 and 2, calculate the rainfall percentiles P from the adjusted daily data (all months and years combined). Note that the percentiles are calculated over rain days only (ie, ignoring dry days). The percentile values are then changed according to the formula:

*Change in daily rainfall (in % per °C) = 6.15 * [1. – ln (100–P)/2.3].*

This formula gives zero change at percentile P = 90, + 8 per cent per degree Celsius change at P = 99.5, and about –6 per cent per degree Celsius change at P = 0. For P > 99.5, the change is capped at +8 per cent per degree of local warming (taken as the change in annual-average temperature). This 8 per cent per degree value is widely recognised as the rate at which the water vapour saturation level increases in the atmosphere (the Clausius–Clapeyron relationship), and is the upper limit recommended in the Climate Change Effects manual for adjusting return periods of extreme rainfall. Apply these percentage changes in rainfall to the results of step 2.

Step 4 Recalculate the total rainfall over the whole period (all months and years included) after step 3, and check to see the total rainfall is still consistent with the total in step 1, after the prescribed scenario changes are applied. If it is not consistent, then adjust all daily rainfalls by the factor required for consistency (eg, if the total rainfall is 130 millimetres after step 1, but the total rainfall is 137.2 millimetres after step 3, then multiply all rain days by the factor 130 millimetres divided by 137.2 millimetres). If this adjustment leads to some daily rainfalls dropping below 0.1 millimetres (the threshold for a measurable rainfall), then reset rainfall on these days to the minimum, 0.1 millimetres, and adjust all daily rain days, with rainfall greater or equal to1.0 millimetres, by multiplying them with a consistency factor (less than 1).

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 of 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, 2010a) for more details.

Downscaling of global climate change models

It is possible to obtain estimates of changes in rainfall by downscaling the results from global climate models (GCMs). The suggested approach from the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a) 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."*

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).

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). For worked examples of these methods see [Tool 2.1.2].

4. Methods for estimating changes in flow

Once the estimation of rainfall change has been completed, the next step is to convert the amount of rainfall into the volume of water flowing in a river. To do this, historical data and ongoing data collection are crucial to calibrate and verify any river flow models. In addition, historical extreme event data can be utilized as an indicator of future river flow trends. For more detail, see MfE (2010a and b), and for further worked examples see [Tool 2.1.3].

4.1 Screening methods

The US Soil Conservation Service (SCS) and Unit Hydrograph methods

The unit hydrograph method converts a hyetograph (a graph of the distribution of rainfall over time) into a hydrograph (a graph showing changes in river flow over time) for as chosen catchment. In comparison, the SCS method utilizes land-cover related parameters to relate peak flood flow to rainfall.

The Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a, section 4.2.1) presents the TP108 model (Auckland Regional Council, 1999) as an example of a standard model for computing design flood hydrographs in small catchments.

The Rational Method

The Rational Method is a common technique used in engineering hydrology and it can also be used as a screening tool for predicting changes in flood flow. The Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a) presents the formula for the Rational Method as:

$$Q = C\, i\, A / 3.6$$

where:

- *Q is the estimate of the peak design discharge in cubic metres per second*
- *C is the run-off coefficient*
- *i is rainfall intensity in millimetres per hour, for a duration equal to the time of concentration of the catchment*
- *A is the catchment area in square kilometres.*

4.2 Advanced methods

Storage-routing models

These models can be used for predicting the effects of climate change on river flow. These methods are less concerned with the physics of the rainfall-runoff process and instead represent the downstream flow of water through linked reservoirs. For more detailed information, see section 4.3.1 in the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a).

Catchment hydrology models

This is the most advanced method for investigating the effects of climate change on river flow. They are fully distributed, physically based catchment hydrology models, such as TopNet or MIKE SHE, and they offer highly detailed representations of a catchment including topography, soil and land use. For more detailed information see section 4.3.2 in the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a).

A summary of the advanced methods for estimating river flow can be found Table 6 of the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a). For further worked examples of these methods see [Tool 2.1.3].

5. Methods for estimating changes in inundation

By combining the results from rainfall, river flow and sea level models it is possible to assess how climate change will affect inundation. The most vulnerable communities to inundation are those that are located on low-lying coastal and riverine land. Various methods exist to estimate how changes in flood flows may affect inundation levels. These methods convert flood flow data into an estimate of flood height, velocity and spatial land coverage. It may be as simple as identifying areas of land that historically have suffered from inundation. Where inundation has happened in the past it is likely that any increase to river flow and sea level will result in increased inundation to these areas. Alternatively, if historical data are limited or where the data are inappropriate for future climate scenarios, new hydraulic modeling will be necessary. Refer to section 5.1.1 in the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a) for further information and to [Tool 2.1.4] for further worked examples.

5.1 Screening methods

Non-coastal river reaches

If flood-plain maps are already available for a range of flood sizes and for a particular study area it may be possible to simply reinterpret the return period assigned to each existing map for increased inundation due to increased river flows. If there are river recording stations in the study area any existing rating curves can be used to convert future river flows into corresponding river levels. As an alternative, in uniform stretches of a river, a flow resistance equation (e.g. Manning’s Equation) can be used to estimate river levels from channel size and roughness. GIS tools can then be used to propagate the water levels across a digital representation of the local terrain. For more detailed information see section 5.2.1 in the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a).

Coastal river reaches

GIS techniques can be used to propagate the depth and extent of coast inundation resulting from a raised sea level across a digital terrain dataset. For more information see section 5.2.2 of MfE (2010a) and [Tool 2.2.4] for a further worked example.

5.2 Advanced methods

All advanced methods for assessing the depth and extent of flood inundation are based on fluid hydraulics methods.

One-dimensional numerical models

1D models represent the river and its floodplain as many cross-section slices with each cross section having a flat water surface and constant average velocity. Examples include AULOS, MIKE-11 and HEC_RAS. More detailed information can be found in section 5.3.1 in the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a).

Two-dimensional numerical models

2D models represent the river and its flood plain as three-dimensional representations of the ground roughness and elevation. The variation of water level and velocity can vary in all horizontal directions. Depth has no influence on water velocity in two dimensional flood moddelling. Examples include RiCOM, Hydro-2de, River2d and MIKE21. More detailed information can be found in section 5.3.2 in the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a) and [Tool 2.1.4] for a further worked example.

Three-dimensional numerical models

3D models represent the river and its flood plain in a similar fashion to two-dimensional modeling, but water velocities can vary in all three dimensions. Three-dimensional models consider flow complexities across a channel and to depth in a channel. Examples include FLUENT, CFX and FLOW-3D.

A summary of the advanced methods for estimating inundation can be found Table 7 of the Tools for Estimating the Effects of Climate Change on Flood Flow manual (MfE, 2010a). For worked examples using the two-dimensional model Hydro-2de, see [Tool 2.1.4].

6. Implications for engineering design

The local government guidance (MfE, 2010a) has identified various engineering design issues relating to the effects of climate change on river and flood flow. A summary of the main issues is presented in the following table.

Table 6.1: Implications of future flood estimates on engineering design

Issue	**Implications for engineering design**
Using historical records	As the climate changes, historical observations will be less indicative of future events. In other words, future flood statistics may diverge from historical statistics.
Reporting and providing information	It is important to comment clearly on the parameters used in the assessment, what has been considered and what was beyond the scope of the project. This includes the climate change scenarios chosen, the assumptions made, and the basis for the choices of parameters used in the modelling.
Uncertainties	The combined effects of modelling uncertainties could be as large as the expected climate change impacts. Where possible you should try to estimate the error bounds of the calculations.
Professional judgement	Expert judgement may need to be applied to scenario choice, the choice of modeling parameters, the interpretation of past data, and in estimating confidence in the final results.
Scenario choice	To help in your risk assessment you will need to choose a number of climate change scenarios to span a range of future possibilities. Given current global emissions, these might include a scenario such as A1B to represent a mid-low estimate, and a higher scenario such as A1FI to represent a mid-high estimate.
Setting freeboard levels	Freeboard should not contain the 'core' component of climate change impacts, but it may be increased to account for climate change uncertainties.
Research	Planners, hazard analysts and engineers will need to be alert to the arrival of new information and the implications it has for their work. Decisions need to be made now on the best information available, but you will also need to be flexible enough to take into account further improvements in understanding of climate change. Most importantly, you should not lock in options that minimise your ability to adapt at a later date.

7. References

Auckland Regional Council (1999) Guidelines for Stormwater Runoff Modelling in the Auckland Region. Technical Publication No. 108. Retrieved from http://www.arc.govt.nz/plans/technical-publications/technical-publications-101-150.cfm

Baskaran, B.; Renwick, J. and Mullen, A. B. (2002) On the application of the Unified Model to produce finer scale climate information for New Zealand. Weather and Climate 22, 19-27

Drost, F.; Renwick, J.; Bhaskaran, B.; Oliver, H. and McGregor, J. (2007) Simulation of New Zealand's climate using a high-resolution nested regional climate model. Int. J. Climatol. 27: 1153–1169

Ministry for the Environment (2008) Preparing for climate change: A guide for local government in New Zealand. Publication number: ME 891.

Ministry for the Environment (2010a) *Tools for estimating the effects of climate change on flood flow: A guidance manual for local government in New Zealand.* Woods R, Mullan AB, Smart G, Rouse H, Hollis M, McKerchar A, Ibbitt R, Dean S, and Collins D (NIWA). Prepared for Ministry for the Environment.

Ministry for the Environment (2010b) Preparing for future flooding: A guide for local government in New Zealand. Publication number: ME 1012.