Ministry for the Environment
Manatu Mo Te Taiao

Preparing for future flooding

A guide for local government in New Zealand

New Zealand Government

adaptation

Disclaimer

This guide draws on information presented in *Tools for Estimating the Effects of Climate Change on Flood Flow*, a 95-page report prepared for the Ministry for the Environment by NIWA. It also draws on information from other guidance, including the Ministry's technical report *A Methodology to Assess the Impacts of Climate Change on Flood Risk* and draws on work undertaken by SKM for the Ministry.

In preparing this guide, and the report on which this guide is based, the authors have used the best available information, and have interpreted this information exercising all reasonable skill and care. Nevertheless, none of the organisations involved accept any liability, whether direct, indirect or consequential, arising out of the provision of the information within this guide or its source reports.

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Source document

The source document on which this report is partially based is available in full on the Ministry for the Environment website at: www.mfe.govt.nz/publications/climate/climate-change-effects-on-flood-flow/index.html

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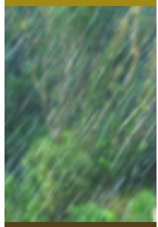

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Introduction

Many of New Zealand's towns and cities are affected by flooding from rivers, lakes, overland flow, the sea and in some cases, a combination of all these. This guide is specifically focused on the effects of climate change on flooding from freshwater systems such as rivers and urban drainage systems.

Climate change is expected to influence flooding in a number of ways through changes in rainfall, temperature, sea level and river channel processes. These changes will exacerbate the existing effects of flooding on infrastructure, including:

- roading
- wastewater and stormwater systems and drainage
- flood mitigation works
- water supply and irrigation
- private and public assets, including houses, businesses, schools and production systems.

Climate change effects on flooding may influence flood risk management priorities, and may even increase the risk from flooding to unacceptable levels in some locations. As a result, you will need to ensure your flood risk assessments incorporate the impacts of climate change on the flood hazard.

The guide comprises four parts:

Part One provides information on the key effects of climate change on flooding.

Part Two presents methods for estimating changes in rainfall, flow rates and inundation.

Part Three provides a method for considering the consequences of future flood risk within a risk management framework.

Part Four highlights principles and options for managing future flood risk.

Parts One and Two of this guide summarise a 95-page report *Tools for Estimating the Effects of Climate Change on Flood Flow* ('the source report'). The report is available from the Ministry for the Environment website at www.mfe.govt.nz/publications/climate/climate-change-effects-on-flood-flow/index.html.

This guide and its source report are not intended to form comprehensive guidance on how to manage flood risk. They aim to provide a picture of the impacts of climate change on river flow and flooding, and provide good practice information and guidance to help local authorities incorporate climate change impacts into flood risk management planning.

Supporting guidance

In addition to this guide and its source report, a range of complementary guidance is available on climate change and hazard management from the Ministry for the Environment. This includes:

- *Preparing for Climate Change: A Guide for Local Government in New Zealand* (2nd edition, 2008), and its source report, *Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand* (2nd edition, 2008)
- *Preparing for Coastal Change: A Guide for Local Government in New Zealand* (2009), and its source report, *Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand* (2nd edition, 2008).

The Ministry for the Environment also provides guidance for local authorities on a range of topics on the Quality Planning (QP) website (www.qp.org.nz), including:

- *Climate Change Guidance Note*
- *Natural Hazards Guidance Note*
- a number of articles relating to flood hazards in the QP library
- a report on natural hazard management in the QP research area.

There are also other resources and guidance on aspects of flood risk management that may be of use such as council reports, good practice guides or international guidelines and methodologies. For example, a comprehensive guide on identifying methods for valuing the costs and impacts of risk management options in monetary terms can be found at the DEFRA[1] website as part of the UK best practice guides on coastal flood defences.

Target audiences

Preparing for Future Flooding is targeted at those of you who are involved in local government decision-making, in particular:

- strategic and policy planners
- asset managers charged with planning future asset needs for communities and resolving existing and emerging problems
- those responsible for natural hazards management, river management, emergency management, 'lifeline' utilities and infrastructure
- staff responsible for council databases, particularly those providing information on hazards and risks to private land owners and other agencies.

Maraekakaho River level (Hawke's Bay floods, 2007). Photo courtesy of Ministry of Civil Defence and Emergency Management

1 www.defra.gov.uk/environment/flooding/policy/guidance/economic-appraisal.htm

Part One

Climate change impacts on flooding

This part covers:

- the causes of flooding in New Zealand
- the climate change scenarios for New Zealand
- the likely impacts of climate change on flooding, such as changes in rainfall, temperature, sea level, storminess and sediment transport processes.

What causes flooding in New Zealand?

The most common weather-related cause of river flooding in New Zealand is heavy rainfall, which can greatly increase water levels in rivers and lakes and cause water to overflow into surrounding areas.

The magnitude of a flood depends on many factors in addition to the intensity and duration of rainfall. Other contributing factors include the land forms and surface features of the land, the vegetation and soil characteristics of the catchment, the wetness of the catchment before the storm (known as the antecedent or initial conditions) and evaporation.

Rainfall-driven floods range in both duration and extent, and may result from:

- brief localised events (eg, thunderstorms in an urban area)
- intense storms lasting a day or two and causing flooding in limited areas
- a repeated sequence of storms over a region, which saturate the soil and fill surface depressions and lakes. The later storms in the sequence produce more run-off because less water is able to be stored, and may lead to widespread flooding.

In some parts of New Zealand such as Otago and Southland, flooding can be exacerbated by the melting of snow. Warm temperatures and rainfall on a deep snowpack can lead to rapid snowmelt, which can sometimes cause or exacerbate a flood. There are also other types of flooding, such as inundation by groundwater or high sea levels, or even dam-break floods, however these are not discussed in this guide.

The impact of flood waters on communities will also depend on non-weather-related factors, including how many people and what assets are at risk, and the effectiveness of flood mitigation and flood warning systems.

Climate change scenarios for New Zealand

To examine the likely impact of climate change on flooding in New Zealand, this guide uses projections of future changes in annual mean temperature and rainfall set out by region. The projections for climate change in New Zealand have been made using six greenhouse gas emission scenarios developed for the Intergovernmental Panel on Climate Change (IPCC). The scenarios consider different combinations of socio-economic profiles, energy use and transport choices into the future. *Preparing for Climate Change* provides more information on how the New Zealand projections were developed.

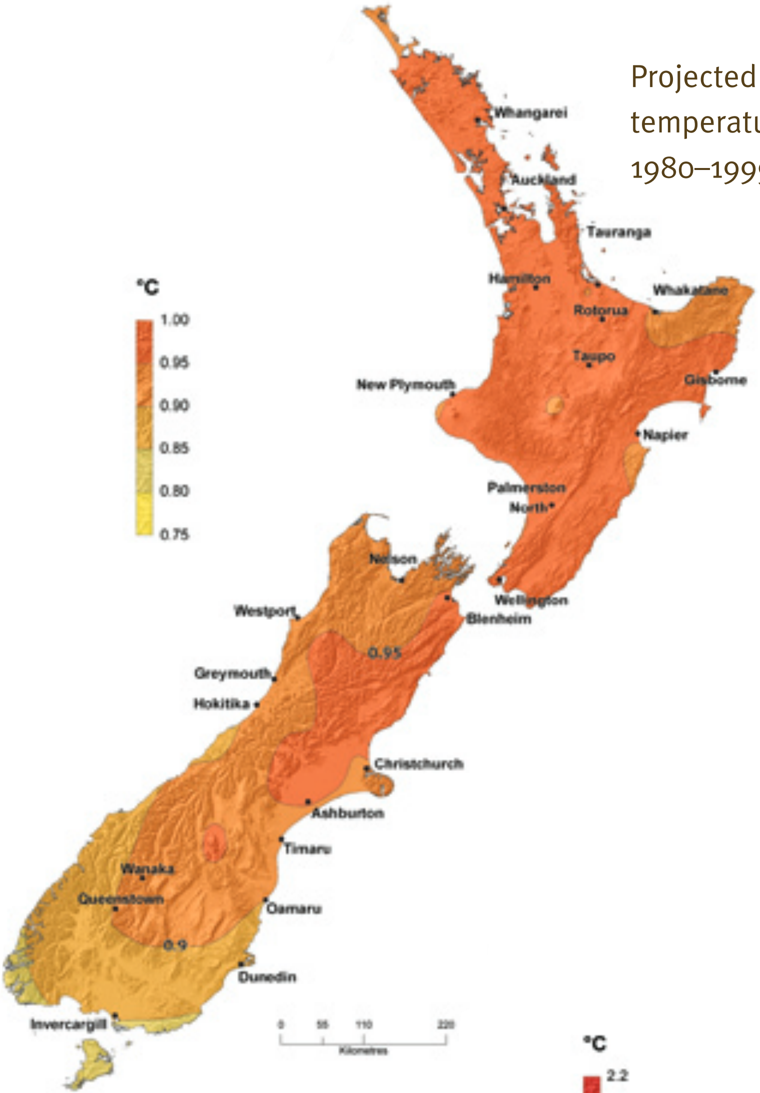
Figure 1 shows projected patterns for temperature change. Because natural effects cause the New Zealand climate to vary from year to year, the changes are specified in terms of the average change for the period 2030–2049 (referred to below as 2040), and for 2080–2099 (referred to as 2090), relative to the climate of 1980–1999 (1990). Tables 2 and 3 in *Preparing for Climate Change* provide the numerical values for the projections of annual mean temperature and rainfall change for each region of New Zealand.

These temperature changes can be used to estimate increases in rainfall to provide a basic screening method for estimating changes in rainfall. A number of more advanced methods for estimating changes in rainfall are also highlighted in Part Two of this guide.

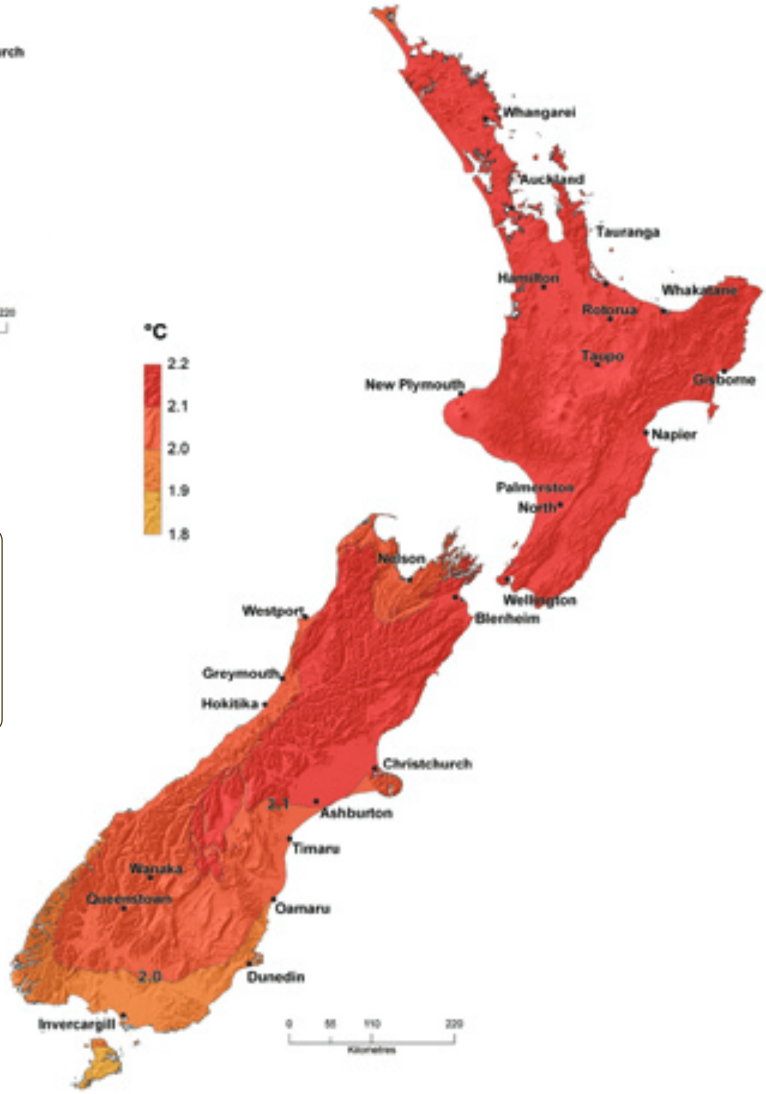
Figure 1: Projected mid-range changes in annual mean temperature (in °C) relative to 1990

Note the different temperature scales for 2040 and 2090. These maps are intended to illustrate broad geographical patterns of climate change within New Zealand. They should not be used as definitive predictions of climate change for specific geographical locations. Projections for specific regions are provided in tables 2 and 3 of *Preparing for Climate Change*.

Projected annual mean temperature change between 1980–1999 and 2030–2049*



Projected annual mean temperature change between 1980–1999 and 2080–2099*



* Based on an average over 12 climate models for a mid-range (A1B) emission scenario.

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Projection: New Zealand Map Grid

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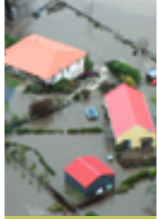
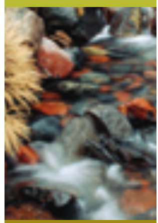




Climate change impacts on flooding

Climate change is expected to lead to increases in the frequency and intensity of extreme rainfall, especially in places where mean annual rainfall is also expected to increase. Therefore, changes in seasonal and annual rainfall patterns, as well as changes in extreme rainfall, will be important factors for understanding future flooding. Generally, wetter conditions in some areas may also change the antecedent or initial conditions, so that floods could occur more often.

Places that currently receive snow are likely to see a shift towards precipitation falling as rainfall instead of snowfall as average temperatures rise and freezing levels climb to higher elevations.

Changes in climate can also affect the magnitude of a flood by indirect means. For example, any change to the balance of sediment transported within a river, storminess, sea levels or even the cycles of natural variability in the climate can all have an effect on river processes and flooding.

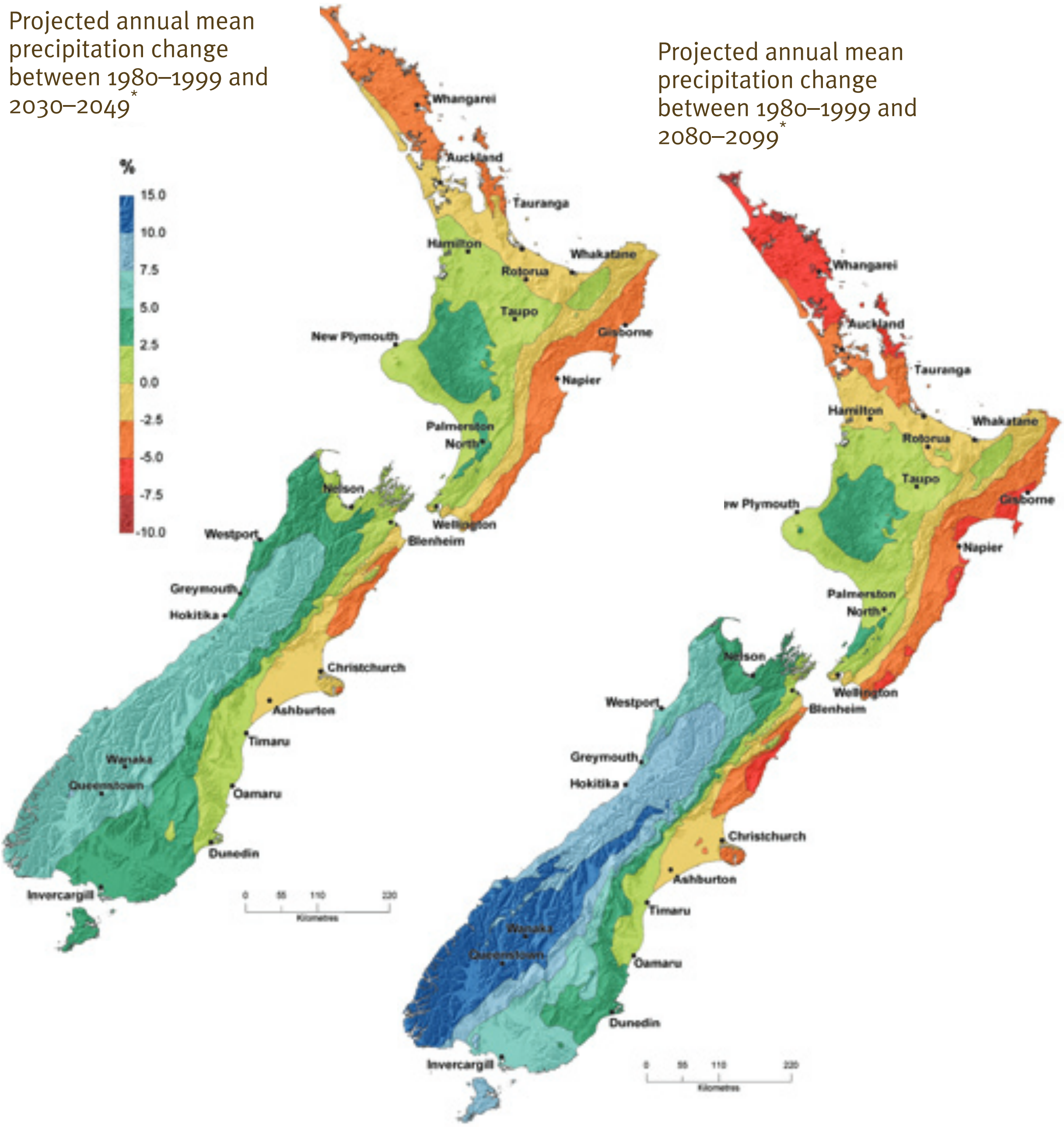
When assessing future flood risk you will need to consider all of these factors to see how they interact to give you a picture of future flood risk in your area. How climate change is likely to affect each of these factors is discussed in more detail below.

Changes in annual rainfall

Figure 2 shows that the projected change in the average annual rainfall has a pattern of increases in the west (up to 5 per cent by 2040 and 10 per cent by 2090) and decreases in the east and north (exceeding 5 per cent in places by 2090). This annual pattern results from the changes in rainfall in the dominant seasons of winter and spring.

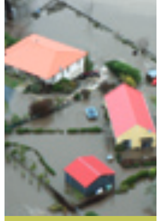
Steve Le Gal gauging Nevis River. Photo courtesy of NIWA.

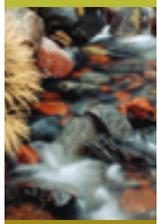
Figure 2: Projected mid-range changes in annual mean rainfall (in %) relative to 1990



*Based on an average over 12 climate models for a mid-range (A1B) emission scenario.

Projection: New Zealand Map Grid

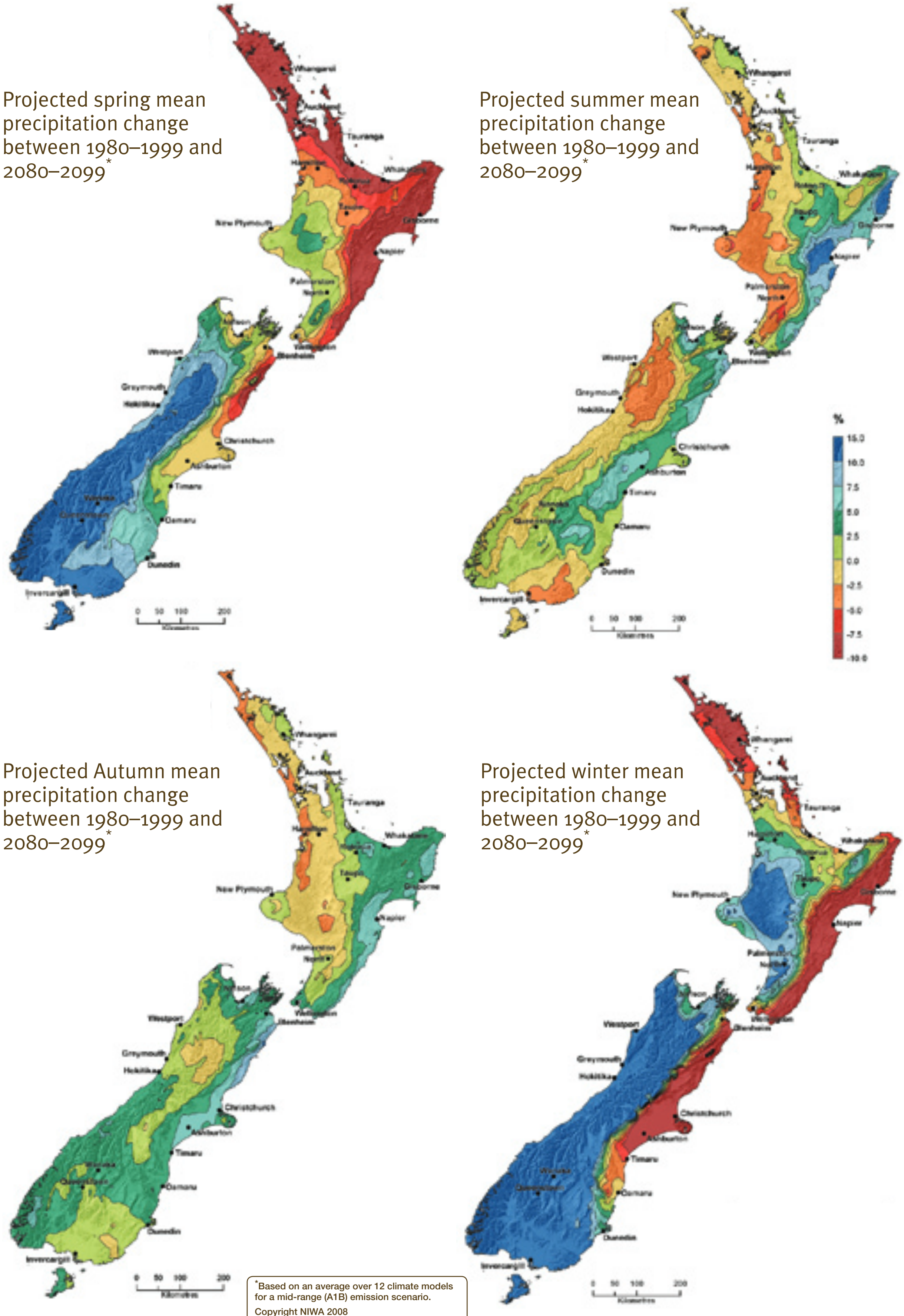




Changes in seasonal rainfall

Projected changes in seasonal rainfall, as shown in figure 3 overleaf, suggest increased westerlies in winter and spring will bring more rainfall in the west of both islands and drier conditions in the east and north. During autumn and summer, drier conditions are expected in the west of the North Island, and rainfall increases are possible in summer for Gisborne and the Hawke's Bay.

Figure 3: Projected mid-range changes in seasonal mean rainfall (in %) for 2090 relative to 1990



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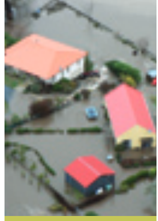
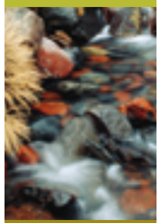
Projection: New Zealand Map Grid





Changes to initial conditions

In regions where seasonal rainfall is expected to increase more than the seasonal evaporation rate, it is likely there will be wetter initial conditions (eg, wetter soils, higher lake levels). Conversely, if seasonal rainfall is projected to decrease, then initial conditions would be expected to be drier. Increases in temperature and wind are also likely to increase evapotranspiration (the amount of water lost to the atmosphere from soil and plants), resulting in drier initial conditions. These factors may also be important for estimating base flows for purposes such as water resource management.

Changes in extreme rainfall

Climate change will have the biggest impact on New Zealand river floods through changes in the frequency and intensity of extreme rainfall. This is because extreme rainfall is the most common trigger for flooding in New Zealand.

A warmer atmosphere increases the water-holding capacity of the air. This means that, assuming other factors remain the same, rainfall is likely to be more intense. The expected percentage increase in extreme rainfall is around 8 per cent per degree Celsius of temperature increase. So if we expect a 1 to 2°C temperature rise by the end of the century, we could estimate that the intensity of extreme rainfall in the future might increase by 8 to 16 per cent.

However, the relationship between rainfall intensity and flood magnitude depends on several factors and is not linear. For example, an 8 per cent increase in rainfall intensity does not lead to an 8 per cent increase in flood peak discharge (when there is the greatest amount of water in the river), and does not lead to an 8 per cent increase in inundation (the area flooded). In many cases, you will need to combine your understanding of the current rainfall/run-off/inundation processes with the expected increases in rainfall to determine the resulting increases in flow and inundation. Methods for determining changes in the rainfall/run-off/inundation processes are discussed further in Part Two.

Table 7 in *Preparing for Climate Change* provides more detail on the recommended percentage adjustments per degree of warming to apply to extreme rainfalls for various average recurrence intervals and for different rainfall durations.

Changes in snowfall

Places at lower altitudes that currently receive snow are likely to see a shift towards more precipitation falling as rainfall instead of snowfall, as freezing levels climb to higher elevations due to rising temperatures. For rivers where the winter precipitation currently falls mainly as snow and is stored until the snowmelt season, there is the possibility of larger winter river flows. These impacts have not yet been quantified, but are in addition to the temperature-driven increases in extreme rainfall that result from a warmer atmosphere.

Sediment transport and erosion

Changes in precipitation will lead to changes in the amount and size of sediment a river can transport, which will then affect riverbed levels and channel width. Increases in rainfall intensity may lead to changes in river channel morphology, leading in turn to changes in the location and likelihood of inundation. For example, extra sediment may be deposited in the bed of a river, raising the level of the bed and thus reducing the flood-carrying capacity of the channel. As a result, for a given river flow rate, less water can be carried in the channel and more water will overflow, causing flooding. The opposite situation may also occur, where an increase in floodwaters in a channel gives greater water velocities, allowing the river to transport more sediment than is being deposited. This can lead to increased erosion and degradation in the channel and subsequent effects further downstream.

Sea-level rise

Projections of future sea-level rise due to climate change (see *Preparing for Coastal Change*) will cause lower freeboard[2] on coastal flood-mitigation structures, increased inland influence of tides and a flattening of river slopes in coastal reaches in some locations. The reduction of a river's slope reduces the energy of the flood flow, increases the depth of flow and reduces the sediment-transporting capacity potentially leading to aggradation in the channel.

A risk-based approach can be used to assess the sensitivity to different amounts of future sea-level rise. *Preparing for Coastal Change* provides guidance on planning for future sea-level rise and recommends assessing the potential consequences of a range of future possible sea-level rise values.

Storminess

Based on our understanding of physical processes in the atmosphere it is likely that climate change will bring increased storminess. 'Storminess' can refer to the number of storms, or to their intensity, which in turn could be judged on the basis of strong winds or heavy rainfall. It is also likely that tropical cyclones will be more intense, and such weather systems can transform into intense sub-tropical lows that bring heavy rainfall, damaging winds, waves and storm surge to New Zealand.

There is also the potential for flooding to be exacerbated in coastal areas by increased frequency and magnitude of wind set-up and storm surge, which result when high winds and decreased barometric pressure during storms raise the local sea level (see *Preparing for Coastal Change*). This may be important for river mouth areas and coastal stormwater systems.

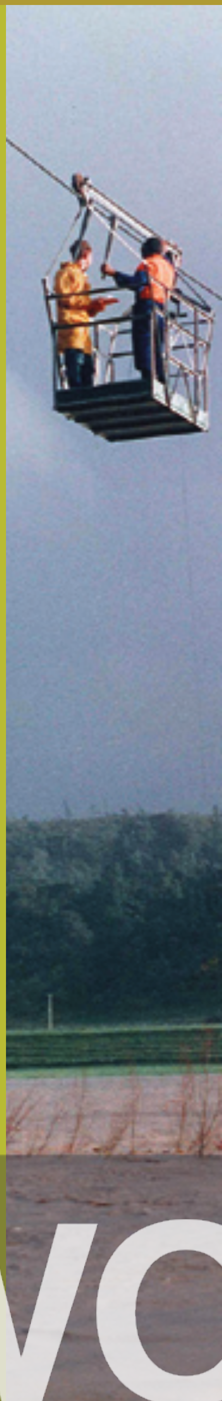
Interdecadal Pacific Oscillation

The climate is naturally variable, and New Zealand's climate is affected by the Interdecadal Pacific Oscillation (IPO). The IPO brings decadal fluctuations in winds and rainfall over New Zealand and this leads to variations in river flow and flooding. Changes in 'climate' over the next 50 years or so are in the same order of magnitude as IPO variability. Therefore, both IPO and climate change effects may need to be considered when calculating flood risk. Section 2.3 in the source report has more discussion on the implications of the IPO for flooding.

Hutt River car park in flood. Photo courtesy of Ministry of Civil Defence and Emergency Management

2 Freeboard is a term used to describe a factor of safety above a design flood level for flood protection or control works. See Part Two for more detail.





Part Two

Estimating the impact of climate change on flooding

This part covers:

- methods you can use to assess the likely change in flooding from climate change
- how to estimate the effects of climate change on rainfall, flood flow and inundation
- some of the implications climate change has for engineering design
- case studies of these methods being used.

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

A range of methods are available to estimate the impact of climate change on flooding. The best method will provide a level of detail that is appropriate to the scale or importance of the decisions which will be based on your assessment of climate change impacts on flooding. The method you choose will depend on a number of factors, such as the size of your community or the value of the assets at risk. The consequences of a potential flood event will dictate the level of detail and resources required.

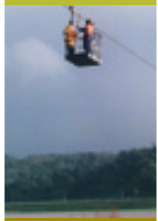
The methods described in this section fall into two main categories: basic screening tools and advanced methods. Screening methods are simpler and can be used to show if there is a potential risk posed by climate change impacts. Advanced methods provide a more detailed assessment of potential risks and are used where the screening suggests there could be an impact. Some examples of screening and advanced methods are presented in the boxes below. However, readers may also want to consult sections 3, 4 and 5 of the source report for a more detailed discussion of the different methods available.

Methods to estimate the impact of climate change on flooding differ in their complexity, data requirements and reliability of results. As the method becomes more complex, so too does the expertise needed to carry out the method. While some methods are intended for all practitioners to apply, the use of the more advanced methods may require expert practitioners.

There may be some situations that require more complex or detailed modelling approaches. For example, if you need to identify which river basins in a region might see a significant change in flood hazard, you could reasonably use a screening method. However, if you are re-evaluating the design flood for a major flood mitigation scheme, using a full risk assessment approach as outlined in *Preparing for Climate Change*, then you would use the advanced methods.

We recommend you consider three questions when deciding how to assess the impact of climate change on flooding and what the most appropriate method is to use:

1. what data does your council have access to?
2. what accuracy and precision do you need?
3. do you have access to the expertise and technology to undertake the analysis and modelling?



Methods for estimating changes in rainfall

The first step in estimating the effects of climate change on river flood flows is to calculate the change in rainfall. The methods that can provide estimates of how climate change may affect extreme rainfall generally convert projections of climate change into a time-series of rainfall (eg, a design storm).

SCREENING METHODS	ADVANCED METHODS
• To calculate changes in extreme rainfall, we recommend adjusting rainfall by a factor of up to 8 per cent for each 1°C of temperature change. See table 7 in *Preparing for Climate Change* for more information.	• One commonly used method is to adjust historical rainfall records for monthly climate change projections. This method can be easy to apply and you can adjust the rainfall distribution (eg, greater extremes) to reflect changes in mean rainfall. • Other advanced methods for estimating changes in rainfall include weather generators, analogue selection from observed data, downscaling of global climate change models, regional climate models, and higher resolution weather models.

Methods for estimating changes in flow

After estimating the change in rainfall, the next step is to convert that rainfall into the amount of water flowing in a river. Historical data and ongoing data collection are vital components of any estimates of future flood flows. While climate change will mean that future flow statistics will be different from past statistics, they are necessary to calibrate or test any model of river flow. Past extreme events may be used as indicators of future trends, and can be invaluable in assessing how climate change has affected river flows.

SCREENING METHODS	ADVANCED METHODS
• Empirical screening methods generally draw on a few basic approaches: the 'rational method', the US Soil Conservation Service (SCS) method, and the unit hydrograph. • The unit hydrograph method reflects how a catchment converts a hyetograph[3] into a hydrograph,[4] while the SCS method relates peak flood flow to rainfall. TP108 is an example of a unit hydrograph method for estimating river flow from rainfall.	• Rainfall/run-off models predict the effects of rainfall on river flow (eg, HEC-1). These models represent the downstream flow of water by way of linked reservoirs, devoting less attention to the physics of the rainfall-run-off processes. • The most advanced approach is to use a fully distributed, physically based catchment hydrology model eg, TopNet or MIKE SHE. These models represent a catchment in great detail, including topography, soil and land use.

Methods for estimating changes in inundation

Climate change affects inundation through the combination of changes on rainfall, river flow and sea level. Coastal and low-lying riverine communities are particularly vulnerable to increased inundation. There is a range of methods to estimate how changes in flood flows may affect inundation levels. Each method converts flood flow data into an estimate of flood height, speed of flow and spatial extent over land.

SCREENING METHODS	ADVANCED METHODS
• The simplest method is to note areas of land that have been inundated in the past. Where inundation has happened, it is clear that increased river flows and sea levels are likely to cause increased inundation of these areas. At this stage, you may consider undertaking a more detailed investigation.	• Advanced methods for assessing the depth and extent of inundation are based on fluid hydraulics. Methods differ in terms of how they represent reality. One-dimensional models approximate river flow as occurring along a single line (eg, the MIKE 11 model). Examples of two-dimensional models include MIKE 21 or MIKE Flood. Three-dimensional models consider flow complexities both across a channel and to depth in a channel (eg, the FLUENT, FLOW-3D or MIKE 3 models). • Climate change effects can be accounted for by altering the flow that enters the modelled area, and in the case of coastal inundation, by altering the hydraulic conditions where water flows out of the modelled area.

3 A hyetograph is a graph showing the distribution of rainfall over a period of time.
4 A hydrograph is a graph showing changes in river flow over a period of time.

Implications for engineering design

Incorporating climate change estimates into flow estimation can reveal various issues pertinent to engineering design. Some of these issues are discussed here.

Using historical records

Gradual shifts in climate and flood risk have important implications for engineering design. An essential element of a 'design flood'[5] study is the prediction of the future risk of extreme floods. As the climate changes, historical observations will be less indicative of future events. In other words, future flood statistics may diverge from historical statistics. Statistical flood data analysis methods, and their applications, will need to change to reflect this.

Historical data is still useful to calibrate hydrological models, to serve as a benchmark to see how flooding is indeed changing, as well as being useful in certain screening and advanced methods discussed in this guide. Also, since flood risk will change as climate changes, it will be necessary to consider the future time horizon that you are planning for and determine flood risk for that specific period. The relevant time horizon will be based on considerations such as the lifetime of the asset you are designing or the legacy or permanency of the decision you are making.

Reporting and providing information

When preparing a report or presenting information on rainfall, flow and inundation estimates, 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

There may be significant uncertainties in the estimates made of rainfall, flow and inundation. These arise through uncertainties in things like rainfall inputs, parameter choices in modelling, errors in modelling and assumptions about antecedent conditions. The combined effects of these uncertainties could be as large as the expected climate change impacts. However, because climate change is likely to have a significant impact on flow, and much of that impact can be calculated, these broader uncertainties should not prevent efforts to include climate change in flow estimation. Where possible you should try to estimate the error bounds of the calculations.

Professional judgement

Your professional or expert judgement will form an important and valuable part of the process of flow and flood estimation. This judgement could be applied to scenario choice, the choice of modelling parameters, the interpretation of past data, and in estimating confidence in the final results. Indeed, this judgement may be most important when considering issues that have yet to be quantified.

Scenario choice

The estimates of rainfall, flow and inundation developed by the procedures outlined here, and further explained in the source report, are likely to be used as the main input in your risk assessment of future flooding. To help in your risk assessment you will need to choose a number of climate change scenarios to span a range of future possibilities. For example, you might examine the consequences of a base level of temperature rise of 2°C by 2100, but also consider the consequences of a greater rise in temperature (for example, at least 3°C rise).

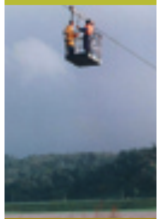
Setting freeboard levels

'Freeboard' is a term used to describe a factor of safety above a design flood level for flood mitigation works. Freeboard allows for the uncertainties in hydrological predictions, wave action, modelling accuracy, topographical accuracy, final flood defence levels and the quality of the digital elevation models. The increase in flood levels associated with climate change is in addition to freeboard, because the uncertainty freeboard incorporates remains in future climate scenarios. Therefore, freeboard should not contain the 'core' component of climate change impacts, but it may be increased to account for climate change uncertainties.

5 Design floods are hypothetical floods of specific storm duration and recurrence interval. They are used for planning and flood plain management investigations.

Research

There is significant climate change research in progress at the time of writing that may aid your flow estimation and engineering design. This includes more detailed information on extremes in temperature, wind and rainfall, changes in offshore waves and storm surge, changes in storm paths and intensity, and changes in snowfall and accumulation. Much of this research is due to provide results within the next few years (2010–2013). Planners, hazard analysts and engineers will need to be alert to the arrival of this 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.



Case Study 1: The Hutt River

In the early 1990s, there was concern that climate change could increase the risk of Lower Hutt being inundated if the stopbanks downstream of the Taita Gorge were overtopped. A study was undertaken to assess the likelihood of this happening and the process followed is discussed below.

Step 1: Obtain catchment rainfall data. Data had to be at hourly time steps to provide enough detail to enable adequate simulation of river flows. The data also needed to realistically reproduce the known spatial variation of rainfall over the catchment.

Step 2: Convert rainfall to flood flows. A rainfall-to-flow model was built for the catchment to convert rainfall into river flow. The model was designed to allow the spatial variation of rainfall to be taken into account. The model was calibrated using data from a 1986 storm to test how well the model simulated the real river flows.

The rainfall amount for each annual flood event was then successively increased by 5 per cent, 10 per cent and 15 per cent. The percentage increases in the rainfalls were chosen in order to bracket the increases likely to occur as a result of climate change and provide a range of potential risk scenarios. The modified rainfalls were then run through the model to form corresponding climate change-affected flows. The peak flows were then extracted from the data to derive the changes in the design flows used for sizing the stopbanks along the Hutt River.

Step 3: Calculate changes in flood inundation. The final step in the investigation was to turn the increased flows into water levels and compare the new levels with the heights of the existing stopbanks to see if the banks would be overtopped.

Conclusions: The Hutt River study concluded that:

- the rainfall-flow model was able to accurately and reliably estimate flows in the Hutt River
- spatial rainfall patterns for each storm give more representative results than a standard pattern based on storage gauges
- rainfall increases of 5, 10 and 15 per cent lead to flow increases of 6.7, 13.4 and 20.3 per cent, respectively
- the present stopbanks are designed to protect against a 1 in 450-year event. It would be unlikely that present stopbanks at Taita would be overtopped for this design event, even if the rainfall increased with climate change to the maximum extent examined. Climate change would reduce that level of service, but not to an unacceptable level in this case.

Case Study 2:

Leith Lindsay flood protection scheme, North Dunedin

The Leith Stream, and its tributary Lindsay Creek, poses a flood hazard in the reaches flowing through the urban area of North Dunedin. A study was undertaken to look at the possible changes in flood risk due to increases in rainfall intensity associated with climate change and to assess the performance of the proposed flood mitigation scheme. The approach was to gather records of storm rainfalls and flood flows for recent events recorded in the Leith catchment. A rainfall-losses/run-off routing model, calibrated for recent storms, was used to assess the expected increase in peak flood flow resulting from expected increases in design storm rainfall intensities. Finally, hydraulic models were used to assess the expected increase in water levels and the increase in flood hazard.

Step 1: Calculate the increase in storm rainfall. The study used expected annual mean temperature changes by 2080 (from 0.4 to 3.1°C), as recommended for the Otago region in the 2004 edition of *Preparing for Climate Change*, to increase design storm rainfall intensities. These changes suggested, for example, that the rainfall intensities for a 12-hour duration, 1 in 100-year event, could increase by between 3 and 21 per cent. The 2008 edition of *Preparing for Climate Change* revised the expected temperature change for Otago by 2090 to 2.0°C average and a range of 0.8 to 4.6°C. Based on these latest projections, the rainfall intensities for a 12-hour duration, 1 in 100-year event, would be expected to increase by between 6 and 37 per cent, with a mid-range value of 16 per cent. This shows the importance of using the latest climate change information available and re-evaluating the impact of climate change from time to time as new information comes to light.

Step 2: Convert rainfall to flow rate. The study used projected percentage increases in storm rainfall with a calibrated rainfall losses/run-off routing model to determine flood flows for the Leith Lindsay catchment. The study found that the 1 in 100-year flood peak for the Leith Stream (above the tidal limits) could increase, on average, from the present day value of 171 m^3/s to 200 m^3/s, a 17 per cent increase in flow. The design flood estimates determined in Step 2 were then used with models to assess the performance of the proposed flood mitigation scheme.

Conclusion: The Otago Regional Council found the flood magnitude for a given standard of protection is expected to increase, but also that there was some uncertainty about the magnitude of the increase. The results showed the proposed scheme would also perform safely under the extreme and long-range climate change scenarios developed using the 2004 edition of *Preparing for Climate Change*.

Photo courtesy of Otago Regional Council

Case Study 3:
The Buller River

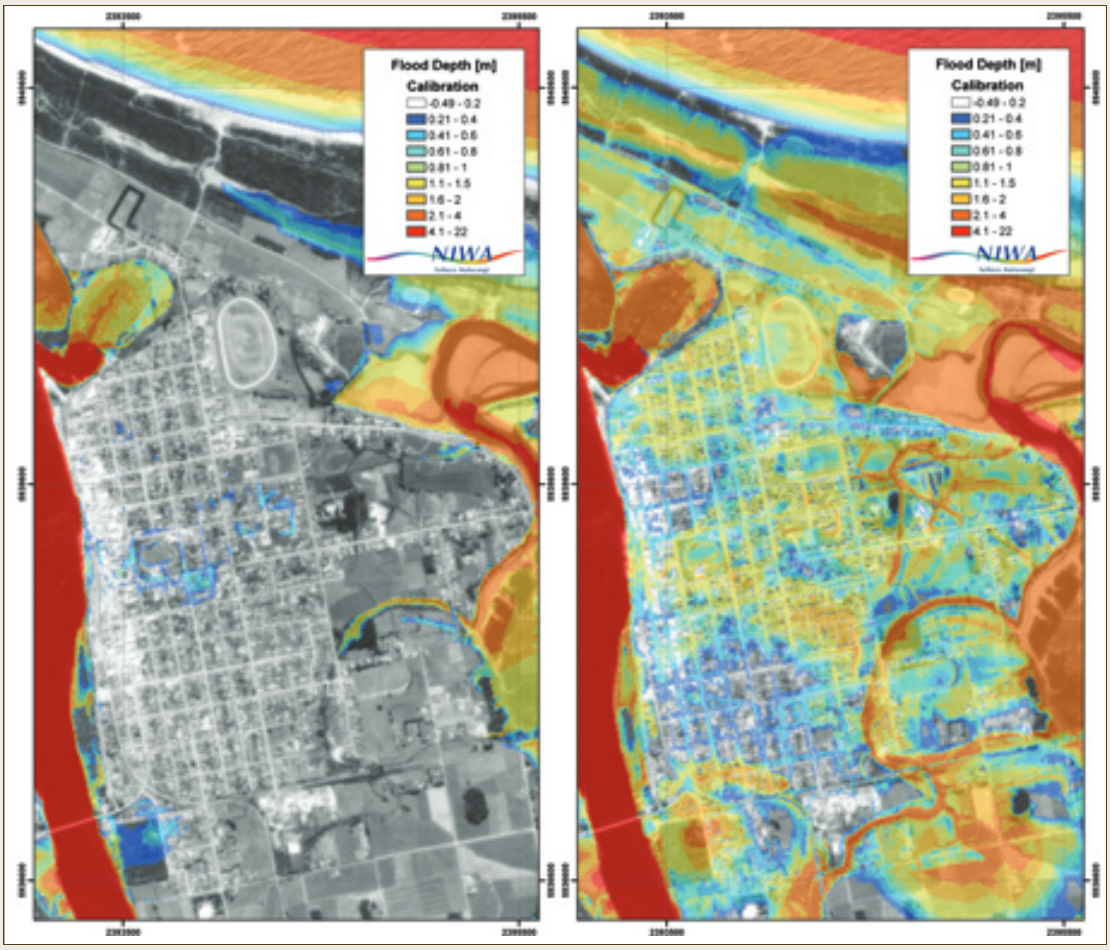
In a report commissioned by the Ministry for the Environment in 2005 a combination of weather, hydrological and inundation modelling was used to look at the impact of three different climate change scenarios on flood inundation for Westport.

Step 1: Choose the climate change scenarios. The three scenarios chosen assumed changes in temperature of 0.5, 1.0 and 2.7°C. It was also assumed that the initial relative humidity remained the same across each scenario.

Step 2: Calculate the changes in rainfall and flow. To determine the impact of temperature on rainfall, weather models were used to replicate the rain from three historical rainfall events. These events were then remodelled, but with the initial conditions based on the three climate change scenarios. The rainfall increased by 3, 5 and 33 per cent on average for the three events, through both an increase in the water-holding capacity of the air as well as through changes in the intensity of the storms. The flow for each of the rainfall events was estimated using the Topnet model. The resulting percentage increases in river flow, averaged over the three events, were 4, 10 and 37 per cent.

cont'd ▶

Figure 4: **1 in 50-year inundation areas in downtown Westport, with the present climate (left) and a mid-high scenario for 2080 (right)**



The average changes in flow were then used to change the rainfall value in a 1 in 50-year design storm. The design storm and its climate-changed versions were used to estimate the flow that would result in the Buller River. No changes were made to the antecedent conditions to allow for other factors, such as a wetter catchment from increases in annual rainfall resulting from climate change. No changes were made to the river flow characteristics either, although changes could be expected as rainfall events are likely to be more intense.

Step 3: Calculate the changes in inundation. The changes in flow were then used to estimate the inundation that may result for the town of Westport. The three scenarios increased the area of inundation from 13, to 30, to 80 per cent.

Conclusions: The results of this study suggest that even with a 1°C change in temperature (which might be regarded as a mid-high projection for 2050 or a mid-low projection for 2100), there could be significant changes in the level of risk of flooding for Westport over the next 50 to 100 years (figure 4). This would have important implications for the level of protection provided by current infrastructure.

Buller River, Murchison, Tasman. Photo courtesy of Rob Suisted (www.naturespic.co.nz)

Part Three

Assessing flood risk

This part covers:

- an overview of the risk assessment process
- how to qualitatively rate risks from future flooding.

The risk assessment process

A sound risk assessment process is fundamental to ensuring climate change is appropriately factored into the planning and decision-making processes. The purpose of risk assessment, in the context of climate change, is to identify risks and hazards caused or exacerbated by climate change and to evaluate their effects and likelihood. Climate change risks and responses can then be prioritised with more confidence and compared equitably with other risks, resource availability and cost issues.

A broad guide to risk management is presented in the international standard *ISO 31000:2009 Risk Management – Principles and Guidelines*.[6] This is the overarching risk management approach recommended by the Ministry for managing risks associated with climate change.

A high-level, decision-making framework for flood risk management is set out in New Zealand standard *NZS 9401:2008 Managing Flood Risk – A Process Standard*. This standard sets out a framework, based on accepted best practice, that users can work through as they seek to address their flood management issues. The standard was developed to give guidance on flood risk management, but it is not a detailed technical document.

There are six steps in the risk assessment process:

1. establish the context
2. identify hazards and describe the risks
3. analyse the risks
4. evaluate the risks
5. assess appropriate responses based on the risks
6. communicate, consult, monitor and evaluate.

An overview of this risk assessment process is described in the companion publication, *Preparing for Climate Change*. More detail on the risk assessment process is contained in sections 4.2.3 and 6.5 of the *Climate Change Effects and Impacts Assessment* manual (available at www.mfe.govt.nz/publications/climate/climate change-effect-impacts-assessments-may08).

This publication does not go into detail on each individual step because this has been covered elsewhere in the documents and guidance described above. However, some aspects of how to determine changes in flood risk resulting from climate change are discussed. In particular, we will show you how to assess flood risk in terms of social, cultural, economic and environmental consequences. This will enable you to determine levels of risk by combining estimates of the consequences and likelihood of an event occurring, so that flood risk can be prioritised alongside other risks.

6 www.iso.org/iso/catalogue_detail.htm?csnumber=43170 (previously known as NZS 4360:2004).

Determining flood risk

The next section describes the parts of the risk assessment process that relate to describing, analysing and evaluating the risks of flooding (steps 2 to 4 on the previous page). It describes how to:

- rate the level of consequences of a flood (from insignificant to catastrophic)
- rate the likelihood of a specific flood event occurring (rare to almost certain)
- assign a risk level, given both the consequences and likelihood (low to extreme)
- analyse the results to compare how your risk profile might change with climate change.

This process then enables you to compare any differences between catchments and ensure the priorities for flood risk management are based on a fair and comparable assessment of risk. In other words, the options used to treat risks may vary across a region or district, but the risk assessment process should not.

Rate the consequences of a flood

Flooding can have a range of different social, cultural, economic and environmental consequences. For each of the impacts that are identified you need to think about how you would rate the severity of those consequences using a five-step range for the expected consequences from 'insignificant' to 'catastrophic'. For instance, 'insignificant' could mean the results have very little or no cost and only some inconvenience, whereas 'catastrophic' could mean financial viability over the long term is compromised, a major disruption in the community or loss of life.

What level of rating you apply to particular consequences should reflect the risks for a specific type of catchment or location. For example, large-scale flooding of rural land may affect relatively few people but can have significant economic consequences at a regional level. Flooding of urban areas is likely to affect more people and could result in serious public health and safety consequences, large business disruptions and significant social upheaval.

An example of consequence ratings is provided in table 1 overleaf. In practice, you are likely to undertake significant consultation and collaboration with stakeholders when establishing your own consequence ratings for an area.

Milton (Clutha floods, 2007). Photo courtesy of Ministry of Civil Defence and Emergency Management

Table 1: An example of consequence ratings

CONSEQUENCE RATING	SOCIAL		CULTURAL	ECONOMIC		ENVIRONMENT
	Public safety	**Community disruption** (eg, displaced people, social disruption, cancelled events, school closures)	(eg, heritage sites, historic structures, archaeological sites, sites of importance to Māori, such as wāhi tapu)	**Local economy and growth**	**Lifelines***	
Catastrophic	Fatalities, or serious near misses, affecting more than 1000 people	Significant disruption; international significance or concern	International significance or concern	Regional decline leading to widespread business failure, loss of employment and hardship; significant long-term impact on the national economy	Systemic failure of lifeline assets, including lost transport connections, water supply and power failure, and failed wastewater systems	Long-term, widespread impacts; slow recovery
Major	Some injuries or serious near misses, affecting more than 100 people	High-level disruption; national significance or concern	National significance or concern	Regional stagnation such that businesses are unable to thrive and employment does not keep pace with population growth	Failure of some lifeline assets (eg, power lines or road access) that require significant recovery investment and long-term temporary lifeline services	Medium- to long-term widespread impacts
Moderate	Minor injuries, or serious near misses, affecting more than 10 people	Moderate disruption; regional significance or concern	Regional significance or concern	Significant but temporary reduction in economic performance relative to current forecasts	Partial failure of some lifeline assets that requires temporary measures to provide lifeline services	Reversible medium-term local impacts
Minor	Serious near misses, affecting fewer than 10 people	Minor disruption; local community significance or concern	Local community significance or concern	Individually significant but isolated areas of reduction in economic performance relative to current forecasts	Some short-term disruption of lifeline assets raising public health concerns	Reversible short-term impacts on local area
Insignificant	Appearance of a threat but no actual harm	Individual significance or concern	Individual or small significance or concern	Minor shortfall relative to current forecasts	Minor disruption to lifeline assets	Limited impacts on minimal area

* Lifeline services include telecommunications, power, gas, water and roading.

Rate the likelihood of a specific event occurring

Likelihood can be expressed either numerically as a percentage chance of an event occurring or described qualitatively from “almost certain” to “rare”. For instance, “almost certain” could mean that something has happened before and is expected to happen again in the next 12 months. “Rare” could mean although something has not happened before in your experience, it is in the realms of possibility.

The numerical likelihood of the probability of a flood occurring within the design life of an asset being considered can be determined using table 2 below. That figure can then be used to determine a qualitative rating to express the likelihood of that flood occurring. Table 3 provides an example of likelihood ranges that you could use, or you may prefer to assign your own categories for describing the likelihoods.

Likelihood should be assessed in terms of the design life of the asset or infrastructure that is at risk from flooding. For example, some buildings might more realistically have a 100-year lifespan,[7] even though they are only required to be designed for a 50-year lifespan. Therefore, the probability that a damaging flood will occur within that longer 100-year time horizon should be considered. The risk to a subdivision should be analysed over a longer period of time, because once land has been developed for residential use it is more than likely to remain occupied for very long periods of time, if not permanently. For temporary assets (eg, a culvert) or temporary land uses (eg, a camping ground), a shorter time horizon may be appropriate.

To illustrate this process in action consider a flood that might occur once in 100 years (a 100-year event) and an asset that has a design life of 100 years. Using the two tables below, the numerical likelihood from table 2 would be 63 per cent and it would be considered as ‘likely’ to occur. Keep in mind that a “1 in 100” year event means there is a 1 per cent chance of the event occurring in a single year, not that the event only occurs once every 100 years.

Table 2: Likelihood of the flood occuring within a given time horizon[8]

AVERAGE RECURRENCE INTERVAL OF FLOOD (YEARS)	DESIGN LIFE – TIME HORIZON (YEARS)								
	2	5	10	20	50	100	200	500	1000
2	75%	97%	100%	100%	100%	100%	100%	100%	100%
5	36%	67%	89%	99%	100%	100%	100%	100%	100%
10	19%	41%	65%	88%	99%	100%	100%	100%	100%
50	4%	10%	18%	33%	64%	87%	98%	100%	100%
100	2%	5%	10%	18%	39%	63%	87%	99%	100%
200	1%	2%	5%	10%	22%	39%	63%	92%	100%
500	0%	1%	2%	4%	10%	18%	33%	63%	100%

Table 3: Flood risk likelihood ratings

RATING	PERCENTAGE CHANCE THAT A FLOOD WITH A GIVEN AVERAGE RETURN INTERVAL WILL OCCUR WITHIN THE DESIGN LIFE
Almost certain	> 85%
Likely	60%–84%
Possible	36%–59%
Unlikely	16%–35 %
Rare	< 15%

7 The Building Act 2004 and Building Code currently require residential buildings and community care facilities to be built at a higher elevation than the flood level of a 1 in 50-year event (ie, they set the minimum height). The Building Code does not yet require a flood protection standard for commercial buildings.

8 The probability P_e that a certain-size flood occurring during any period will exceed the 100-year flood threshold can be calculated using $P_e = 1 - [1-(1/T)]^n$ where **T** is the return period of a given storm threshold (eg, 100-yr, 50-yr, 25-yr, and so forth), and **n** is the number of years.

Assign a risk level, given both the consequences and the likelihood

Finally, a qualitative description of risk can be assigned using the risk assignment matrix in table 4. It enables you to combine the likelihood and consequence ratings for a given return period event as determined in the previous exercises, and assigns a risk value from low to extreme.

Table 4: A risk assignment matrix for setting the level of risk, based on likelihood and consequence

		CONSEQUENCE RANKING				
		Insignificant	Minor	Moderate	Major	Catastrophic
LIKELIHOOD RATING	Almost certain	Moderate	High	Extreme	Extreme	Extreme
	Likely	Moderate	High	High	Extreme	Extreme
	Possible	Low	Moderate	High	Extreme	Extreme
	Unlikely	Low	Low	Moderate	High	Extreme
	Rare	Low	Low	Moderate	High	High

To illustrate this in practice, if we take a hypothetical case of a 100-year event for an asset with a 100-year design life where the consequence rating determined in the previous step using table 1 was 'moderate', and the likelihood rating was considered '63 per cent – likely', then the corresponding risk rating from table 4 would be classed as high.

To take this example further, if climate change were to increase the likelihood of the 100-year event occurring so that it in the future it would be the equivalent to a 50-year event (due to increased rainfall intensity), then the likelihood rating from table 3 would increase from 'likely' to 'almost certain' because there would now be an 87 per cent likelihood of the flood occurring within the asset's design life. Again, if we assume the consequence rating for this level of flood still has a rating of 'moderate', then the risk level assigned to the event in table 4 would change from 'high' to 'extreme'.

Analyse the results of the risk assessment

The next step is to use all of this information to analyse flood risks across a 'quadruple bottom line' that considers social, cultural, economic and environmental consequences. The following examples illustrate how a risk analysis can be undertaken to compare how climate change might alter flood risk over time.

EXAMPLE 1: Current climate –100-year flood event

To illustrate how a risk analysis could be undertaken, and how the risk analysis is altered by the effects of climate change, we have provided an example of a hypothetical flood (table 5). In the current climate this hypothetical flood is assumed to flood homes and affect the performance of some lifeline[9] services, but does not cause injury or long-term economic or environmental consequences. Table 5 (on page 26) provides an example of how, in this hypothetical flood in the existing climate, the likelihood information from table 2 and table 3 and the consequences ratings from table 1 can be combined to determine risk.

To illustrate how climate change might alter the current flood risk, we have reanalysed the flood risk for two climate change scenarios for 2100. These are illustrated in table 6 and table 7 (on page 26).

9 Lifeline services include telecommunications, power, gas, water and roading,

EXAMPLE 2: 100-year flood event in 2100 – higher flow

In the first of the climate change examples (table 6), the hypothetical 100-year climate change flood event has a greater magnitude than in the existing climate. Therefore, the consequences of the climate change flood are greater than the consequences of the current climate flood, although the likelihood of the event occurring is no greater.

In this hypothetical example, under the climate change scenario the consequences for public safety, community concern, economy and the environment remain unchanged, but the cultural risk has shifted from high to extreme, and the lifeline risk has also moved from high to extreme.

In the lifeline case, suppose a bridge is close to the threshold for failure. In the existing climate flood event, flooding may cause temporary closure of the road, but in the larger climate change event the flood may lead to failure of the bridge, causing the road to be closed for a prolonged period. In another example, a marae with nationally significant cultural value may be protected by a stopbank and only prone to local ponding in the existing climate flood event. However, in the larger climate change flood the stopbank could be predicted to overtop, flooding the marae and possibly leading to the destruction of a nationally significant taonga. The increase in risk reflects the increase in flood magnitude with climate change.

EXAMPLE 3: Flood event in 2100 – flooding more frequent

In the third climate change example (table 7) there is an increased likelihood of a flood event occurring in 2100 that has consequences equivalent to the existing flood event. In other words, the 50-year flood event with climate change might have the same consequences as the 100-year flood event in the current climate. The likelihood of these consequences occurring has therefore increased, and hence the risk has increased.

Under the 50-year climate change flood event, public safety and lifelines risk has moved from high to extreme; cultural risk remains at high, because the change from 'likely' to 'almost certain' does not change the risk category when considering a consequence rating of minor. Community concern and economic and environmental risks remain unchanged. The increase in risks reflects the increase in the likelihood of a flood occurring with climate change.

Garty's Road, south of Amberley (Hurunui district floods, 2008). Photo courtesy of Ministry of Civil Defence and Emergency Management

Table 5: Hypothetical risk assessment, current climate – 100-year flood event (Example 1)

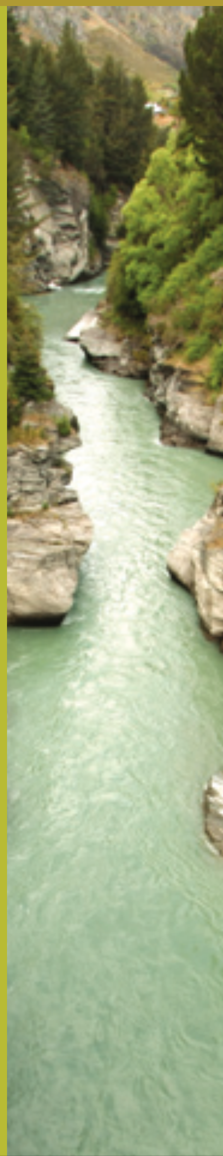
	SOCIAL		CULTURAL	ECONOMIC		ENVIRONMENT
	Public safety	**Community disruption**		**Local economy and growth**	**Lifelines**	
DESIGN LIFETIME HORIZON	100 years	10 years	100 years	10 years	100 years	10 years
CONSEQUENCES RATING	Moderate – minor injuries, or serious near misses affecting more than 10 people	Major – high-level disruption; national significance or concern	Minor – local community significance or concern	Minor – individually significant but isolated areas of reduction in economic performance relative to current forecasts	Moderate – partial failure of some lifeline assets that requires temporary measures to provide lifeline services	Minor – reversible short-term impact on local area
LIKELIHOOD RATING	Likely	Rare	Likely	Rare	Likely	Rare
RISK	High	High	High	Moderate	High	Low

Table 6: Hypothetical risk assessment, 100-year flood event in 2100 – higher flow (Example 2)

	SOCIAL		CULTURAL	ECONOMIC		ENVIRONMENT
	Public safety	**Community disruption**		**Local economy and growth**	**Lifelines**	
DESIGN LIFETIME HORIZON	100 years	10 years	100 years	10 years	100 years	10 years
CONSEQUENCES RATING	Moderate – minor injuries, or serious near misses affecting more than 10 people	Major – high-level disruption; national significance or concern	Minor – local community significance or concern	Minor – individually significant but isolated areas of reduction in economic performance relative to current forecasts	Moderate – partial failure of some lifeline assets that requires temporary measures to provide lifeline services	Minor – reversible short-term impact on local area
LIKELIHOOD RATING	Likely	Rare	Likely	Rare	Likely	Rare
RISK	High	High	Extreme	Moderate	Extreme	Low

Table 7: Hypothetical risk assessment, flood event in 2100 – flooding more frequent (Example 3)

	SOCIAL		CULTURAL	ECONOMIC		ENVIRONMENT
	Public safety	**Community disruption**		**Local economy and growth**	**Lifelines**	
DESIGN LIFETIME HORIZON	100 years	10 years	100 years	10 years	100 years	10 years
CONSEQUENCES RATING	Moderate – minor injuries, or serious near misses affecting more than 10 people	Major – high-level disruption; national significance or concern	Minor – local community significance or concern	Minor – individually significant but isolated areas of reduction in economic performance relative to current forecasts	Moderate – partial failure of some lifeline assets that requires temporary measures to provide lifeline services	Minor – reversible short-term impact on local area
LIKELIHOOD RATING	Almost certain	Unlikely	Almost certain	Unlikely	Almost certain	Unlikely
RISK	Extreme	High	High	Moderate	Extreme	Low



Part Four

Managing flood risk

This part covers:

- the legislation relevant to flood risk management
- principles for managing future flood risk
- options for managing future flood risk
- challenges in managing future flood risk.

Relevant legislation

The two main pieces of legislation relevant to climate change and flood risk management are the Resource Management Act 1991 (RMA) and the Civil Defence Emergency Management Act (CDEM) 2002.

The RMA requires regional authorities to control the use of land for the avoidance or mitigation of natural hazards. Territorial authorities are required to control the actual or potential effects of the use, development or protection of land, including for the purpose of avoiding or remedying natural hazards. The Resource Management (Energy and Climate Change) Amendment Act 2004 further requires local authorities to have particular regard to the effects of climate change.

The CDEM Act is another key piece of legislation for flood risk management. The Act primarily focuses on the sustainable management of hazards, resilient communities and on ensuring the safety of people, property and infrastructure in an emergency. The CDEM Act recommends an approach based on risk reduction, readiness, response and recovery.

Although risk reduction is primarily achieved through proactive planning as required by the RMA and the CDEM Act, other relevant legislation for climate change and flood risk management includes the Building Act 2004, the Local Government Act 2002 and the Soil Conservation and Rivers Control Act 1941.

Principles for managing future flood risk

Local government operates under a range of principles that are set out in the legislation described above or that have evolved through good practice and case law. The following principles should also be incorporated into all aspects of planning and decision-making about managing flood risk exacerbated by climate change.

- **Take a precautionary approach:** a precautionary approach to decision-making means you take into account the level of risk, use existing knowledge and account for uncertainties. The principle implies there is a social responsibility to minimise the exposure of your community to harm as much as possible when scientific investigation has found a plausible risk. A precautionary approach should be used when making planning decisions that relate to new development as well as to changes to existing development. Full information on climate change effects may not be available at the time of decision-making, particularly when there is a high level of uncertainty and where decisions are effectively irreversible. A precautionary approach is particularly relevant where there are effects of low probability but potentially high impact (eg, the effects of infrequent but high flood levels in developed flood plain areas).

- **Use flexible or adaptive management options:** these are options implemented incrementally or as small steps over time, responding to new information and adjusting management gradually, rather than acting in one step. Monitoring is an important part of these approaches and they are good for handling uncertainty, as management is adjusted over time. Being flexible means you do not have to

fully implement an option at a single time. Instead, you implement the option in phases and monitor the situation so you know when each additional phase should be implemented.

- **Use no-regrets options:** these will deliver benefits that exceed their costs whatever the extent of climate change. These should always be implemented where they exist. For instance, if you are already experiencing weather-related problems, then cost-effective actions to deal with them should be no regret options. No regret options are particularly suitable for the near term as they can deliver obvious and immediate benefits, and can provide experience on which to build further actions.
- **Use low-regrets options:** these have relatively low costs and seek to maximise the return on investment when certainty of the associated risks is low. Ensuring that any changing rainfall patterns are taken into account early in the process of maintaining or improving infrastructure is an example of a low regrets option.
- **Avoid making decisions that will make it more difficult for you or others to manage climate change flood risks in the future:** this involves not locking in options that limit further adaptation in the future.
- **Use progressive risk reduction:** new developments should not be exposed to, nor increase, flood risk over their intended lifetime. For existing developments the level of risk should be progressively reduced.
- **Adopt an integrated, sustainable approach to the management of flood risk:** this approach aims to consider a wide range of perspectives to decision-making that contributes to the environmental, cultural, social and economic well-being of people and communities.

Gowan River rapids, tributary of the Buller, Rotoroa, Tasman. Photo courtesy of Rob Suisted (www.naturespic.co.nz)

Options for managing future flood risk

Managing present-day and future risk from flooding through policy development, planning and resource consenting involves a combination of risk-avoidance and risk-reduction activities.

For already developed sites, a wider mix of mechanisms for avoiding, reducing and managing flood risk can be useful. The treatment options could be a combination of avoiding risk where possible, controlling risk through structural or legislative measures, transferring risk through insurance, accepting risk, emergency management planning, warning systems, and communicating risk (including residual risk) to affected parties. When planning new development, infrastructure and services to avoid flood hazards over their intended lifetime, the most effective and sustainable approach is to take a precautionary approach.

While the range of options available to manage flood risk is likely to be the same in the future, the mixture of options you choose to use may be influenced by how climate change will affect flooding in a particular location. For example, climate change could potentially exacerbate your existing flood risk and this may alter your flood management priorities into the future, change your community's acceptability or tolerability of flood risk or mean that you choose different flood risk management options. In practice, you are likely to consider a range of factors to determine the most appropriate treatment options, such as through cost-benefit analysis and community consultation. Some possible options for managing flood risk are outlined below.

- **Take an integrated catchment management approach** to managing flood risk where you consider a range of perspectives across a catchment, in contrast to a piecemeal approach that separates land management from water management.

- **Use planning-based tools** such as regional policy statements, zoning and rules in regional and district plans, resource consent processes and conditions, urban development/growth strategies, asset management and planning, strategic catchment-based management and the development of flood hazard management plans. *Preparing for Climate Change* has a useful checklist for considering climate change in local government plans.

- **Use non-regulatory methods** such as guidelines and codes of practice (eg, that promote appropriate design specifications for stormwater management systems), siting and designing buildings to minimise risk, or risk transference through insurance.

- **Use soft engineering solutions** for more natural flood risk management. This involves maintaining or restoring the natural river and coastal features and processes with the aim of slowing down the flow of water and storing water along catchments. By restoring natural land and water processes, natural flood management techniques can directly contribute to reducing flood risk to people and property, and provide additional benefits such as conservation of biodiversity, habitat protection and improved water quality and amenity. Natural flood management can also be used in combination with hard engineering solutions.

- **If necessary, consider hard engineering solutions or structural treatment options** (eg, stopbanks) which aim to reduce the frequency of occurrence of a hazard by modifying the hazard itself through structural or built measures. Hard engineering solutions should be considered after natural flood management solutions have been looked at. This is because natural solutions can be more sustainable in the long term, are cheaper to maintain and can provide additional benefits to local communities. Examples of structural treatments include upstream storage of floodwaters, stopbanks and floodwalls, erosion protection methods, floodways and deviation channels, and household/business flood protection measures.

- **Increase public awareness** of flood risk through making available, and/or facilitating and supporting, educational material, hazard maps, websites, public talks and meetings. Providing information and raising awareness of flood risk is an approach that can be used to support other methods for managing flood risk. There are also ways of raising public awareness through statutory mechanisms, such as incorporating hazard and risk information in regional and district plans, and in other planning documents (eg, long-term council community plans, strategic plans and possibly annual plans). Providing information on hazard risks alone does not always influence people's decision-making on purchasing property, or their behaviour and choices when living within at-risk areas.

Mangamahu Bridge (Lower North Island floods, 2006). Photo courtesy of Ministry of Civil Defence and Emergency Management

Issues for managing flood risks

In considering the principles and options for managing flooding there are some significant challenges in achieving effective flood risk reduction. Climate change may further complicate some of these challenges including how to deal with residual risk, the acceptability of risk, dealing with uncertainties and providing appropriate levels of service from your infrastructure to your community.

Identifying residual risk

Residual risk is the risk remaining after risk reduction measures have been put in place. Residual risk may be related to failure of the risk reduction measures, parts of the community that do not benefit from the risk reduction measures proposed, or risks from events that exceed the design standards of the structural risk-reduction options. Climate change may increase the amount of residual risk you need to manage over time. Examples of options for managing residual risk include insurance, emergency management planning, warning systems and community education.

Acceptability of risk

It is important not to confuse the cost of flood risk treatment with determining the acceptability or tolerability of flood risk. Just because a community may not want to, or cannot afford to, reduce the flood hazard through the use of an engineering solution does not necessarily make the risk acceptable. Other treatment options should be considered, such as planning controls or risk transference through insurance. In some cases, managed retreat might be appropriate.

Dealing with uncertainty

Flood risk assessments and climate change science will always have a level of uncertainty associated with projections for how climate change will affect natural processes such as sea-level rise and rainfall. Other aspects of the risk assessment also contain uncertainties, including those due to limited data, hydrological flow estimation and fragility of infrastructure. A precautionary approach requires action based on our current understanding of the effect of climate change on flood risk. From time to time you may need to reconfirm that your infrastructure will perform in the future climate as described in the Hutt River case study. In the end you will need to take action and identify adaptable solutions based on a combination of advice from the best expertise and information available at the time balanced with council funding and planning processes and priorities.

Level of service

Another important part of the risk evaluation stage is reaching agreement through community consultation and engagement on the minimum levels of service that you and your community want from your infrastructure. Many local authorities define minimum levels of service for new development, and some define intervention levels for existing development. The flood risk assessment process will enable local authorities to decide whether they will be able to maintain these levels of service under climate change, or whether it will be acceptable to reduce minimum levels of service over time. When considering whether the levels of service should be allowed to be reduced in the future, inter-generational equity should be considered. This will help ensure that decision-making is not unfairly burdening future generations with flood risk that will be unacceptable to them.

Haast River in flood, Westland. Photo courtesy of Rob Suisted (www.naturespic.co.nz)

Looking over Wanganui City and Whanganui River at night. Photo courtesy of Rob Suisted (www.naturespic.co.nz)

Conclusion

Climate change is expected to affect flooding through changes in rainfall, temperature, sea level and river processes. Climate change will exacerbate the existing effects of flooding on infrastructure and community services, including roads, stormwater and wastewater systems and drainage, river flood mitigation works, and private and public assets including houses, businesses and schools.

Climate change may change flood risk management priorities and may even increase the risk from flooding to unacceptable levels in some places. It is therefore important that your flood risk assessments incorporate an understanding of the impacts of climate change on the flood hazard.

Managing present-day and future risk from flooding involves a combination of risk-avoidance and risk-reduction activities. The treatment options could be a combination of avoiding risk where possible, controlling risk through structural or regulatory measures, transferring risk through insurance, accepting risk, emergency management planning, warning systems, and communicating risk (including residual risk) to affected parties. The best combination will consider the needs of future generations and not lock communities into a future of increasing risks from flooding.

Climate change guidance for local government

The Ministry for the Environment provides a range of guidance and information to assist local government and other key stakeholders better understand and take into account climate change effects in their policy and decision-making. Publications in this series include:

Preparing for climate change:
www.mfe.govt.nz/publications/climate/preparing-for-climate-change-guide-for-local-govt/

Climate change effects and impacts assessment:
www.mfe.govt.nz/publications/climate/climate-change-effect-impacts-assessments-may08/index.html

Preparing for coastal change:
www.mfe.govt.nz/publications/climate/preparing-for-coastal-change-guide-for-local-govt/index.html

Coastal hazards and climate change:
www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/

Preparing for future flooding:
www.mfe.govt.nz/publications/climate/preparing-for-future-flooding-guide-for-local-govt/

Tools for estimating the effects of climate change on flood flow:
www.mfe.govt.nz/publications/climate/climate-change-effects-on-flood-flow/index.html