Impacts of Climate Change on urban infrastructure and the built environment

Toolbox Handbook

May 2012

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NIWA Taihoro Nukurangi

BRANZ

MWH® BUILDING A BETTER WORLD

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Contents

Foreword

This handbook has been prepared as a companion to the Urban Impacts Toolbox which has been developed under the MSI funded research programme "Impacts of Climate Change on Urban Infrastructure and the Built Environment". The programme was led by NIWA in collaboration with MWH New Zealand Ltd, BRANZ and GNS. The main objective was to respond to the needs of regional, city and district councils by providing guidance and decision tools that can be used by urban council staff and policy makers to reduce the potential adverse effects of climate change. This handbook provides an overview of the Toolbox structure and gives guidance on its use.

"This unique toolbox is designed to provide guidance and decision tools that can be used by local, regional and central government staff and policy-makers to reduce the potential adverse effects of projected climate changes. Prior to the creation of this toolbox, councils had to adapt or search around for tools to make these evaluations. Now it's all in one place!

We used the toolbox idea because it gives council engineers, managers and planners a logically ordered set of tools, and a consistent approach for incorporating climate change into planning and decision-making in the urban environment.

It's the first time a toolbox approach has been used for climate change assessment in New Zealand.

A council can use the toolbox to go through a full climate change evaluation process. Specific tools in the toolbox can be used to aid and inform decisions on upgrades to flood protection schemes or the size of storm-water pipes, for example.

Climate extremes affect each town or city differently. We are giving councils the ability to assess their specific situation and minimise the risk of climate-related hazards for future generations."

Andrew Tait,
Project Leader

The Toolbox can be accessed at:

http://www.niwa.co.nz/climate/urban-impacts-toolbox

Who should use the Toolbox?

The Toolbox is primarily designed for New Zealand regional and territorial local government staff in urban areas with the following roles and responsibilities:

- Infrastructure management
- Asset management
- Consents
- Transport
- Urban development
- Strategic planning
- Emergency management

Slip in Devon St, Aro Valley, Wellington following heavy rainfall (Erika Mackay, NIWA)

1 Introducing the Toolbox

Around 75% of the $1.5 billion insurance pay-out for damages from natural hazards in New Zealand over the last 40 years (prior to the Canterbury earthquakes) has been for weather-related hazards. These hazards are expected to increase in the future because of climate change. Urban environments are particularly vulnerable to extreme weather and flooding events (including coastal storm surge). New Zealand needs communities that are prepared for climate change and the hazards that come with it.

The Impacts of Climate Change on Urban Infrastructure and the Built Environment Toolbox is the culmination of a four year research programme funded by the Ministry for Science and Innovation (contract CO1X0805). The programme was led by NIWA in collaboration with MWH New Zealand Ltd, BRANZ and GNS Science. The following councils supported the development of the Toolbox: West Coast Regional Council, Buller District Council, Greater Wellington Regional Council, Wellington City Council, Auckland Council, Christchurch City Council and Canterbury Regional Council.

The Toolbox is an online resource (http://www.niwa.co.nz/climate/urban-impacts-toolbox) to help planners, engineers, asset managers and hazard analysts working in councils in New Zealand understand and evaluate the potential impacts of climate change in their cities. The Toolbox demonstrates methods of identifying adaptation options and evaluating their benefits. It consists of a series of 57 reports or 'tools' which are grouped into five sections analogous to trays in a toolbox. Each tray represents a stage in an adaptation evaluation process.

While the tools have been written as stand-alone documents that can be read and understood on their own, they also contain references to other tools that allow users to progress though the evaluation process. The tools demonstrate how to embed climate change information into hazard and risk assessments, and are illustrated using real-world examples from New Zealand drawn from six case studies. Users are able to access tools at different points in the evaluation process by following links to the relevant documents.

The information in the Toolbox is consistent with the Australian and New Zealand Standard for Risk Management, AS/NZS IS0 31000:2009, which is widely used in the public and private sectors to guide strategic, operational and other forms of risk management. The tools build on and frequently reference existing climate change guidance material, particularly the following reports (and their corresponding summary reports) available from the Ministry for the Environment:

- Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand (MfE, 2008a);
- Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand (MfE, 2008b); and
- Tools for Estimating the Effects of Climate Change on Flood Flow: A Guidance Manual for Local Government in New Zealand (MfE, 2010).

Why urban environments?

An urban environment can be described as the spatial area containing an aggregation of buildings, infrastructure and open spaces which provides for the physical interaction of an urban community. Urban environments in New Zealand include settlements which are as small as 1000 people.

The Toolbox has a focus on urban environments for several reasons:

- Urban environments are where the large majority of New Zealanders live for all or most of their lives.
- Urban environments contribute significantly to economic activity and the country's gross domestic and gross national product.

Tidal surge on the North Western Motorway, Auckland (NZTA, 23 Jan, 2011)

- Urban environments contain most of the country's educational, cultural and health facilities, both in number and significance.

- Urban environments contain the large majority of the country's public and community investment, and much of the private investment.

Hazards that are relatively common in New Zealand's urban environments are river flooding, heavy rainfall-induced localised flooding, sustained drought periods, coastal erosion and inundation, and various forms of land instability. Hazards relating to ice, snow and extreme heat are also common, albeit temporary, events in some New Zealand urban environments. All of these hazards have a weather and/or climate-related component; therefore, urban environments are potentially at heightened risk as a consequence of climate change.

Hail disrupts traffic in Tauranga (Weather Watch, 11 May, 2009)

Flood erosion on the banks of the River Leith, Dunedin (A.J. Nancey, 2006)

Waikato rising flood waters in Hamilton (NIWA, R.O. Ovenden, 2008)

2 Toolbox concepts and contents

2.1 Definition of terms

The definitions of hazard, impact, risk and adaptation are central to the Toolbox.

A natural *hazard* is a phenomenon which has an intrinsic ability to cause harm or negative consequences. These consequences are the *impacts* of the hazard and vary depending on location.

Risk refers to the severity of the impacts and the probability of their occurrence. Risk depends not only on the magnitude and frequency of the hazard but also on the nature of the built environment (e.g., land use type and intensity, urban form, infrastructure) and activities (e.g., residential, industrial or commercial) impacted. The Ministry for the Environment (MfE, 2008a) defines *risk* associated with climate change as

> *"the chance of an event being induced or significantly exacerbated by climate change, that event having an impact on something of value to the present and/or future community".*

The primary means of risk reduction explored by the Toolbox is *adaptation*. In the context of climate change, adaptation is defined by the Intergovernmental Panel on Climate Change (IPCC, 2007) as

> *"the adjustment of natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities".*

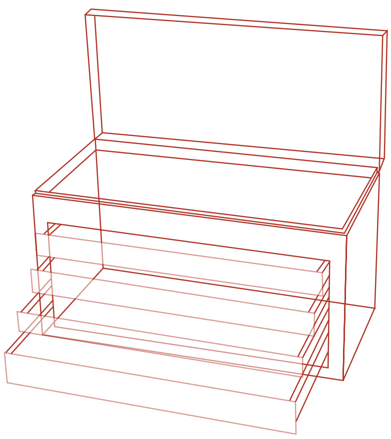
Adaptation can be reactive as a response to impacts as they occur or pro-active to avoid or reduce impacts before they occur. The Toolbox addresses structural adaptation (i.e., adaptations to the design and structure of primarily public infrastructure) and non-structural adaptation (e.g., education and policy to modify behaviour).

2.2 Toolbox trays

The Impacts of Climate Change on Urban Infrastructure and the Built Environment Toolbox is divided into five sections, or trays, representing the key stages of an evaluative process. The process starts with an information gathering phase, followed by a hazard assessment. The next stage is a risk analysis, which considers what the hazard may impact. Stage four involves considering options (and their costs and benefits) to reduce the risk, and stage five is the integration of information into the planning and decision-making process. Users can enter the process at any stage and will find useful tools in any part of the Toolbox.

The toolbox analogy

The toolbox consists of 57 downloadable reports or tools arranged in five trays.



Each tray is a stage in the adaptation evaluation process and contains a set of tools

First Tray: Understand the issues
▼
Second Tray: Assess the likely hazard
▼
Third Tray: Identify the risks
▼
Fourth Tray: Evaluate options and their costs/benefits
▼
Fifth Tray: Using the tools and improving practice

The trays are defined as follows:

First Tray Understand the issues: The tools in this tray provide some general context and background information on climate change impacts and adaptation in urban environments, as well as key steps for beginning the process of evaluation.

Second Tray Assess the likely hazard: This tray contains guidance on how to assess the hazards that are likely to be exacerbated or introduced by climate change. Each urban environment will be exposed to a mixture of different hazards, depending on its location. For this reason, the tools in this tray are divided up into six bins representing different hazards. The tools in each bin are specific to the modelling and assessment of a particular hazard. The bins are.

- Bin 2.1 Flooding
- Bin 2.2 Sea level rise and storm surge
- Bin 2.3 Heavy rainfall induced landslides
- Bin 2.4 Heavy rainfall and urban drainage
- Bin 2.5 Supply and demand of potable water
- Bin 2.6 Other hazards

Third Tray Identify the risks: The tools in this tray give guidance on how to assess the risks associated with a particular hazard or mix of hazard. Risk assessment involves estimating potential damages to buildings and infrastructure and assessing to what extent and how often services or activities sensitive to particular hazards are likely to be impacted. The risks to infrastructure and buildings are of primary interest.

Fourth Tray Evaluate the options and their costs/benefits: The tools in this tray give guidance on the identification and evaluation of adaptation options with respect to their benefits and cost relative to the associated risk. Adaptation options can be assessed using a wide range of methods, including methods that complement each other, and progressive methods that can be changed over time.

Fifth Tray Using the tools and improving practice: The tools in this tray are called 'messages' and are provided to aid the integration of the hazard, risk and adaptation assessments into local government decision making and planning processes. The tools include guidance on how to manage information, keeping up to date and the need to consider a range of adaptation options.

2.3 Tools

There are 57 tools available which are thematically grouped into the Toolbox trays listed above. The tools are stand-alone documents, each designed to help the user with a specific task in the evaluation process and labelled according to its position in the toolbox. Some provide reference information and guidance, while others describe models or approaches for estimating impacts and dealing with uncertainty. Wherever possible, worked examples are provided as well as critical sections on data needs, model assumptions and limitations.

The authors of each tool are identified on the tool and can be contacted directly for more information, particularly regarding the use of models and other analytical methods. A summary list of the tools in each tray is provided in Table 1. A detailed list is given in Appendix A; for each tool, the list gives the title, type, authorship and any associated case studies as well as a brief description of what it contains. Authors and their affiliations are listed in Appendix B alongside the tools to which they have contributed. In the following sections, tools are cited by their tool number only; readers are asked to refer to Table 1 or the appendices for more information.

Table 1: Tools summarised by Toolbox tray.

Tray		Tool	Title
First Tray Understand the issues		1.1	Urban environments and climate change
		1.2	General climate change information and guidance for New Zealand
		1.3	An introduction to risk assessment
		1.4	Urban environments and climate change – Statutory context
		1.5	Council policy and plan auditing tool
		1.6	Sensitivity matrix prioritisation tool
		1.7	Sources of information, help and expertise for climate change impact assessments and glossary
Second Tray Assess the likely hazard	Bin 2.1 Flooding	2.1	Overview of flooding tools
		2.1.1	General guidance on climate change and flood modelling methods used in New Zealand
		2.1.2	Modelling future heavy rainfall
		2.1.3	Hydrological modelling of present-day and future floods
		2.1.4	Inundation modelling of present-day and future floods
		2.1.5	Linkages to risk assessment, adaptation options and decision tools
	Bin 2.2 Sea level rise	2.2	Overview of sea level rise and storm surge tools
		2.2.1	Guidance on assessing sea level rise in New Zealand
		2.2.2	Causes of sea level variation
		2.2.3	Guidance on assessing extreme sea level in New Zealand
		2.2.4	Inundation mapping of future high tides, SLR and storm surge
		2.2.5	Linkages to risk assessment, adaptation options and decision tools
	Bin 2.3 Landslides	2.3	Overview of landslide tools
		2.3.1	General information on the causes of rainfall-induced landslides
		2.3.2	Collection and analysis of historical landslide information and data
		2.3.3	Modelling present-day and future landslide potential
		2.3.4	Mapping the landslide hazard
		2.3.5	Linkages to risk assessment, adaptation options and decision tools
	Bin 2.4 Urban drainage	2.4	Overview of urban drainage tools
		2.4.1	Climate change and urban drainage modelling – data, issues and assumptions
		2.4.2	Incorporating climate change into urban stormwater management
		2.4.3	Climate change guidance material for urban stormwater management
		2.4.4	Modelling the North Shore City Council wastewater network – a case study of potential climate change impacts
		2.4.5	Linkages to risk assessment, adaptation options and decision tools
	Bin 2.5 Potable water	2.5	Overview of potable water tools
		2.5.1	General information on water supply and demand methods and issues
		2.5.2	Bulk water demand trend modelling
		2.5.3	SYM approach to present-day and future potable water supply and demand
		2.5.4	Linkages to risk assessment, adaptation options and decision tools
	2.6 Other hazards	2.6	General information on the assessment of climate change effects on high winds, very high temperatures, snowfall, fog, lightning & hail and drought

Third Tray Identify the risks	3.1	Climate change risk assessment good practice
	3.2	Using RiskScape for risk analysis.
	3.3	Case study example of risk assessment using RiskScape
	3.4	Investigating urban growth and change to inform the risk assessment process
	3.5	Subjective qualified risk analysis tool
	3.6	Linkages to hazard assessment, adaptation options and decision tools.
Fourth Tray Evaluate the options and their costs/ benefits	4.1	Climate change adaptation – key concepts
	4.2	Overview of an option screening tool
	4.3	Rapid cost/benefit evaluation of impacts and adaptation options
	4.4	Individual house flood mitigation measures - benefit/cost tool
	4.5	Overview of a multi-criteria analysis based decision tool
	4.6	Overview of a top-down decision tool
	4.7	Adaptation by design: impact of climate and land use change on the sizing of stormwater management devices
	4.8	Overview of a building flood protection decision framework
	4.9	Linkages to hazard and risk assessment tools
Fifth Tray Using the tools and improving practice	5.1	Managing information (including use of climate change check-lists)
	5.2	Keeping up to date
	5.3	Climate change - the long-term view
	5.4	Adopting a balanced approach
	5.5	Community resilience and sustainable development

2.3.1 Guidance tools

There are two broad kinds of tool available in the Toolbox; guidance and decision tools, these are described below. The guidance tools come in three forms and are classified in Table 2:

- Type I – General information and reference

  These tools provide background knowledge and complement other existing sources of information such as the MfE guidance manuals (2008a, b and 2010).

- Type II – Models and methodology descriptions with examples

  These tools detail the models and methods available that can be used to assess climate change effects. They contain sections on data needs, assumptions and limitations as well as linkages to other tools, including decision tools.

- Type III – Messages for improving practice

  These tools are found in the Fifth Tray and provide information on how to integrate climate change assessments into council planning and operations.

Overview and Linkage tools

Overview and Linkage tools are guidance Type II tools for navigating around the Toolbox. They can be used to find relevant information on a specific issue in other tools.

Overview tools are the first found in each of Bins 1 to 5 in the Second Tray. They give background information about each particular hazard in relation to climate change and contain a summary table of the issues covered and methods presented by other tools in their respective bin.

Linkage tools are the last tools found in each of the Second Tray Bins 1 to 5 and also in the Third and Fourth Trays. These tools give *where to from here* guidance on tools in other trays that may be of relevance to a specific issue.

Table 2: Guidance tools by type.

Type of Tool	Tray		Tool
Guidance I	First		1.1, 1.2, 1.3, 1.4, 1.7
General information and reference	Third		3.4
	Fourth		4.1
Guidance II	Second	Bin 1	2.1, 2.1.1, 2.1.2, 2.1.3, 2.1.4, 2.1.5
Models and methodology		Bin 2	2.2, 2.2.1, 2.2.2, 2.2.3, 2.2.4, 2.2.5
		Bin 3	2.3, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.3.5
		Bin 4	2.4, 2.4.1, 2.4.2, 2.4.3, 2.4.4, 2.4.5
		Bin 5	2.5, 2.5.1, 2.5.2, 2.5.3, 2.5.4
		Bin 6	2.6
	Third		3.1, 3.4, 3.6, 4.9
	Fourth		4.7
Guidance III Messages for improving practice	Fifth		5.1, 5.2, 5.3, 5.4, 5.5

2.3.2 Decision tools and the decision making framework

Decision tools are provided to inform decision making. They present a set of methods and examples for filtering and summarising complex information based on repeatable standardised methodology so that decisions can be rationalised and documented. In many cases, it is suggested that these tools be implemented in a workshop environment to ensure robustness in outcomes.

Decision tools are found in the First, Third and Fourth Trays. Guidance on how to choose and locate decision tools in the Toolbox is summarised below from the *Toolbox Decision making framework* web-page with background information from the *A Toolbox-Based Decision Framework for Climate Change Adaptation* (Oldfield, 2011; available as a PDF download from the web-page). The decision making framework is part of the wider risk adaptation evaluation process which forms the structure of the Toolbox and provides for a balanced and justifiable prioritisation of adaptation to climate change.

In an uncertain future, where climate change effects have the potential to change long- term decisions about the planning and development of the urban environment, councils and other service and utility providers are faced with some fundamental questions:

- Which climate change effects should be of most concern? (Scoping issue)
- Where are the needs for action most pressing? (Prioritisation issue)
- What actions provide the best solution? (Optimising the adaptation response)

There is inherent uncertainty in predicting the timing and location of future effects of climate change, and, in the context of the Toolbox, the effects on the urban and built environment. Geographical and demographic differences mean that the answers to the above questions are very much regionally dependent. In uncertain situations, there is a real danger of over-compensating as well as under-compensating for climate change impacts that are still not well understood at a local scale. For this reason, the framework needs to be risk-based. While there are many ways that priorities for action could be established, it is likely that a staged and risk-centred approach, involving a successive narrowing down and refinement of the issues of concern, will be an important part of setting priorities.

With reference to the key questions listed above, there are three corresponding stages in the Toolbox decision making framework:

1. Assessment of priorities across all the relevant climate change effects for the geographical region of interest - this is to identify priority climate change effects and areas most vulnerable to these effects.
2. Risk mapping of priority (high risk) areas for the selected climate change effects, as identified from Stage 1.
3. Identify preferences among alternative adaptation methods to address the priority climate change effect (identified in Stage 1) and the risk identified in the priority locations (identified in Stage 2). This adaptation optioneering stage has two steps:
    a. Identify and assess risk reduction options; and
    b. Establish a preferred solution, and carry it out.

The tools associated with each stage in the decision making framework are listed in Table 3.

It is not intended, nor it always necessary, to start at Stage 1. In some situations, depending on prior work, it is possible to apply the decision tools without completing earlier steps. However, there could be a danger that later steps may be compromised as a result. For example, inadequate consideration of alternatives may potentially result in delays in achieving the required consents and substantial re-work.

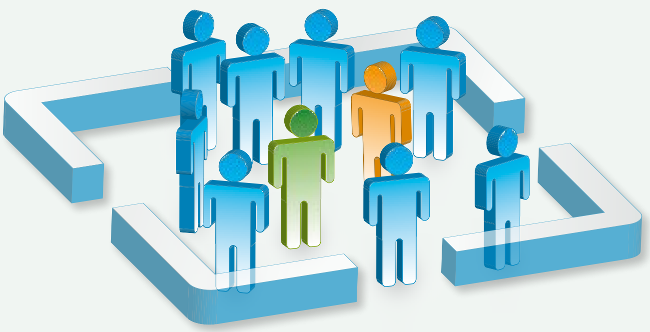
Table 3: Toolbox decision tools in context of the decision making framework.

Decision making framework	Actions	Toolbox tools
Stage 1. Identify vulnerable assets and priority climate change effects. Review relevant policy framework.	Vulnerability assessment and prioritisation	1.5, 1.6
Stage 2. Prioritise geographical locations for attention	Risk prediction Needs analysis	3.2, 3.3, 3.5, 4.5
Stage 3 Adaptation Optioneering		
a. Identify and assess risk reduction options	Options screening and prioritisation	3.5, 4.2, 4.5
b. Establish preferred options	Options evaluation	4.3, 4.4, 4.5, 4.6, 4.8

Workshops, communication and participation

In general, there are three essential elements to decision making:

- The people or stakeholders involved including decision makers, practitioners, consultants and other experts and those affected by the outcome of the decision. Stakeholders can be individuals or organisations.
- Relevant studies and data which inform the decision.
- A process or framework (such as that described above), within which decisions are made.



The Toolbox recommends that many of the decision tools be applied within a workshop setting. This can foster stakeholder engagement, communication and participation and can lead to more robust outcomes than technical analysis alone. A workshop provides a forum for sharing disparate knowledge, including tacit knowledge, from people with different values and fields of expertise. Workshops can allow successive iterations of alternatives to be presented, assessed and modified. Participation in workshops promotes partnerships and supports mutual learning and capacity building. It can improve decision-making by making background information and outcomes transparent and by letting stakeholders have their say. The process leads to more informed, holistic and equitable decision making, promotes consensus and improves the acceptance by stakeholders of the decision.

To be effective, a workshop should be well structured and facilitated by an individual with some knowledge of the topics being discussed, but not necessarily an expert in any one facet of the discussions. The facilitator's role is to provide structure to the discussion, ensure they are open, unbiased and non-confrontational. The facilitator should endeavour to allow for free and inclusive debate but direct the proceeding towards its intended outcome.

Within the Toolbox, stakeholder participation in climate change adaptation planning is outlined in Tool 4.1. The decision tools can be used variously to provide expert information to stakeholders, aid communication between stakeholder or present methods than can be followed to gain stakeholder information for later expert analysis. Workshops are recommended for the implementation of the following decision tools: 1.5, 1.6, 3.5, 4.2 and 4.3. Information from other tools, including guidance tools, can be presented at workshops to aid understanding – hazard risk maps generated by RiskScape (see Tools 3.2 and 3.3), for instance. Likewise, information gained from workshops can be used to provide input data to other tools. Workshops may be held at different stages of the decision making process amongst different sets of stakeholders.

3 Hazard Case studies

Where possible, the tools demonstrate how to work through each stage of the adaptation process using real-world New Zealand examples. The examples are drawn from six case studies chosen by councils and other service providers in Auckland, Wellington, Christchurch and Westport at a series of workshops. The case studies focus on different aspects of urban built environment that are vulnerable to different weather-related hazards. The hazards are river flooding, coastal inundation, landslides and failure of urban water management systems (separated into water supply and drainage). Each hazard is represented by a Bin in the Second Tray; note that there is no specific case study associated with Bin 6 (Other Hazards). The case studies are listed along with tools illustrated by them in Table 4 and are described in the following sections.

Table 4: Tools by case study.

Hazard	Case study	Urban centre	Tools	Second Tray Bin
River flooding	Heavy rainfall and flooding of the Buller River	Westport	1.6, 2.1.2, 2.1.3, 2.1.4, 3.3	Bin 1
	Modelling the Heathcote River	Christchurch	1.6, 2.1.2, 2.1.3, 2.1.4	
Coastal inundation	Sea level rise and storm surge inundation of the Heathcote Estuary	Christchurch	1.6, 2.2.2, 2.2.3, 2.2.4	Bin 2
Landslides	Heavy rainfall induced landslides	Wellington	1.5, 1.6, 2.3.3, 2.3.4	Bin 3
Failure of urban water management systems	Heavy rainfall and urban drainage	Auckland	1.6, 2.4.2, 2.4.3, 2.4.4, 4.7	Bin 4
	Rainfall and potable water supply and demand	Wellington	1.6, 2.5.1, 2.5.3	Bin 5

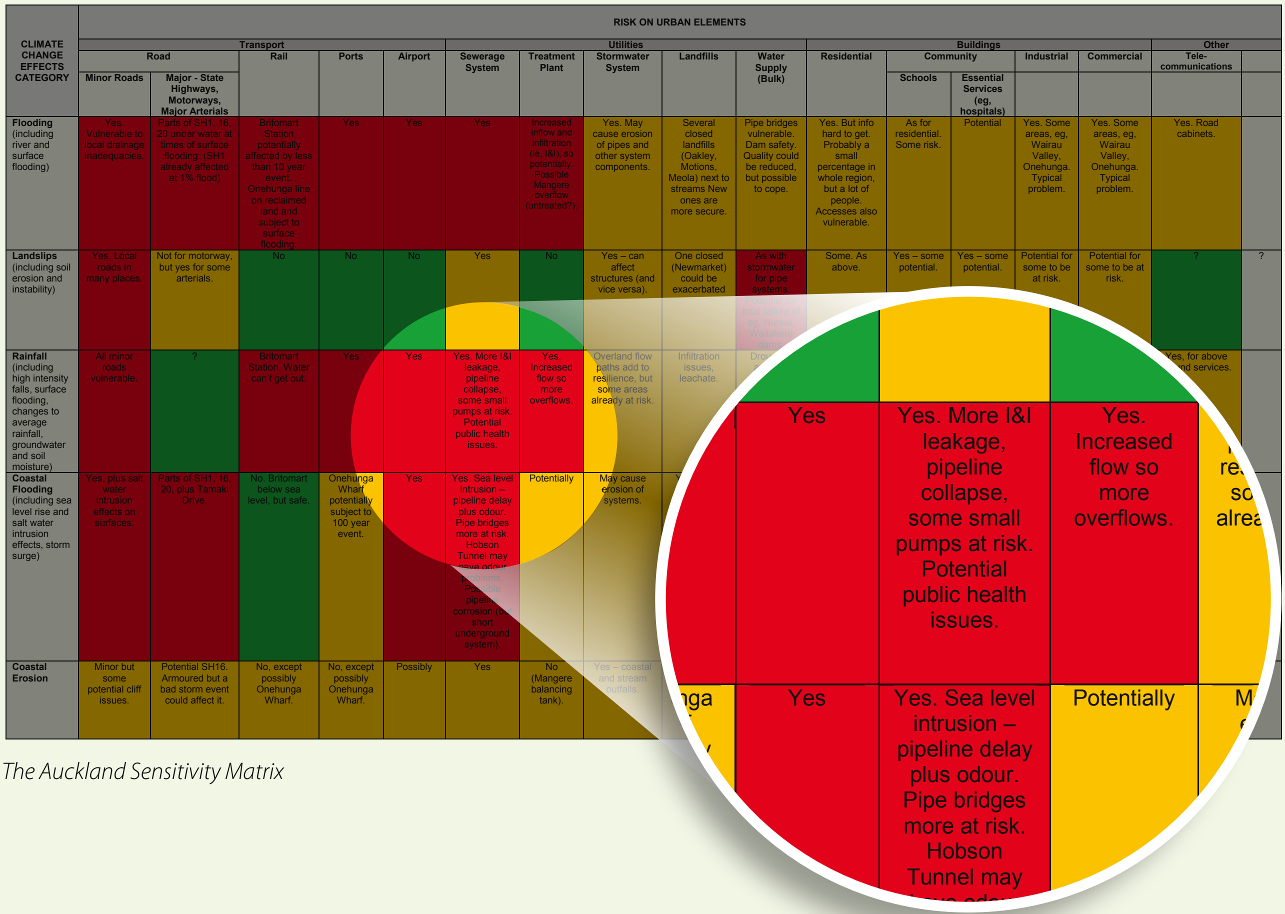
3.1 River flooding

There are two river flooding case studies; the Buller River, Westport and the Heathcote River, Christchurch. The two studies demonstrate different methods recommended by MfE (2010, summarised in Tool 2.2.1) that can be used to assess the impacts of climate change on flood risk. The Westport study demonstrates continuous river modelling techniques whereas the Christchurch study uses event-based modelling techniques. For the former, historical daily rainfall for a particular flood event was adjusted to produce a future rainfall series. For the latter, the MfE (2008a) method of adjusting extreme rainfalls was used to adjust the rainfall intensity of design rainfalls with different return periods. Aspects of both case studies are addressed in Tools 2.1.2, 2.1.3 and 2.1.4. The Westport case study is also addressed in Tool 3.3 with respect to the use of RiskScape, a risk assessment model.

The Sensitivity Matrix applied to case-study selection (Tool 1.6)

The Toolbox hazards and case studies were chosen in consultation with representatives from local and regional councils and other service providers at a series of four workshops facilitated by NIWA and MWH New Zealand Ltd. The workshops were held in Auckland, Wellington, Christchurch and Westport during 2009. At each workshop, attendees were provided with a Sensitivity Matrix on an A1 sheet of paper which was populated during a facilitated session. The completed matrices helped identify the most pressing issues in each area for further investigation. The method followed is presented in Tool 1.6.

The Sensitivity Matrix is a visualisation tool to enable stakeholders to summarise and communicate their current understanding of the sensitivity of a region's urban infrastructure and buildings to the full range of potential climate change effects. The matrix also allows the relevant issues to be scoped and investigated. The matrix consists of a table with urban elements that are potentially vulnerable to climate change heading columns and climate change effects heading rows. Urban elements are public infrastructure, utilities and buildings such as transport and drainage networks, schools and hospitals. Climate change effects include flooding, high intensity and high frequency rainfalls, high winds and extreme temperature. The table cells represent the different combinations of urban elements and climate change effects. Through a workshop process, stakeholders identify the key sensitivities of their town or city in each cell. The climate change effects that have the greatest impact, or multiple significant impacts, on urban elements buildings are then prioritised for further assessment using other tools in the toolbox. In the example below from the Auckland workshop, the matrix cells have been colour coded red, amber and green for high, medium and low expected impacts. The impact of heavy rainfall on the sewage system (inset) was prioritised for Auckland and is presented as a case study.



The Auckland Sensitivity Matrix

3.1.1 Flood modelling of the Buller River, Westport

Westport is particularly vulnerable to flooding because it is on the flood plain between the Buller River and the Orowaiti Estuary, an old channel of the Buller River that carries a substantial flow during large floods. One of the principal reasons the Buller River catchment was chosen as a case study for this project was because there was already a calibrated 2-dimensional hydrodynamic model for the area.

This case study demonstrates a method for adjusting historic daily rainfall data associated with a past (return period approximately 50 years) flood event according to projected future changes to mean rainfall and sea level. The adjusted rainfall data (see Tool 2.1.2) are used in combination with projections of sea level rise to re-model the flood flow in the Buller River (see Tool 2.1.3), and to produce maps of potential flood inundation using a sophisticated hydraulic model (see Tool 2.1.4).

A simplified hydraulic flood model of the Buller River was also produced and calibrated using outputs from the detailed 2-D model. The simplified model was used to generate multiple flood risk maps for a range of different flooding scenarios both for present day and future conditions. Various high-level alternative strategies for mitigating future flood risk were then selected and further flood modelling undertaken to gain an understanding how these strategies may reduce the flood risk (see the Westport flooding case study report).

RiskScape was also used to assess damage estimates to buildings associated with the projected inundation levels for 2090, using mid-range the A1B greenhouse gas emission scenario (see Tool 3.3).

3.1.2 Flood Modelling the Heathcote River, Christchurch

The Heathcote River has a relatively small catchment area of around 103 km^2 at the Ferrymead Bridge where the river discharges into the Avon-Heathcote Estuary. The river is small (mean flow at Buxton Terrace of 1.28 m^3/s) in its non-tidal reaches, but it has a well sustained groundwater-fed base flow. Much of the flood flow originates from the Port Hills, but during extreme events that overwhelm the capacity of the Henderson Basin flood detention area the plains portion of the catchment can add substantially to flood flows.

The Heathcote River was chosen as a case study because it flows through a low lying urban area vulnerable to flooding that was of concern to the Christchurch City Council. The Heathcote River is also tidal within the urban area which makes this part of the catchment vulnerable to sea-level change and so it is suitable for a climate change study that also includes the effects of sea-level rise. The tidal estuary is investigated in relation to sea level rise and storm surge in Tool 2.2.4.

The Christchurch earthquake of 22 February 2011 lifted the tidal portion of the Heathcote catchment by about 0.4 m and lowered the rest by 0.1-0.3 m. Thus, the reported inundation modelling (performed using pre-earthquake topographic and bathymetric data) in this case study should be interpreted with this in mind. Nevertheless, the methods used can be applied to risk assessments in other areas.

For this case study the effect of climate change on rainfall was estimated using the design event approach (see Tool 2.1.2), where extreme rainfall amounts are increased by a percentage per degree of warming. The simple screening approach outlined in MfE (2010) was used to calculate the effect of various climate scenarios on the design event.

RiskScape and Subjective Quantified Risk Analysis

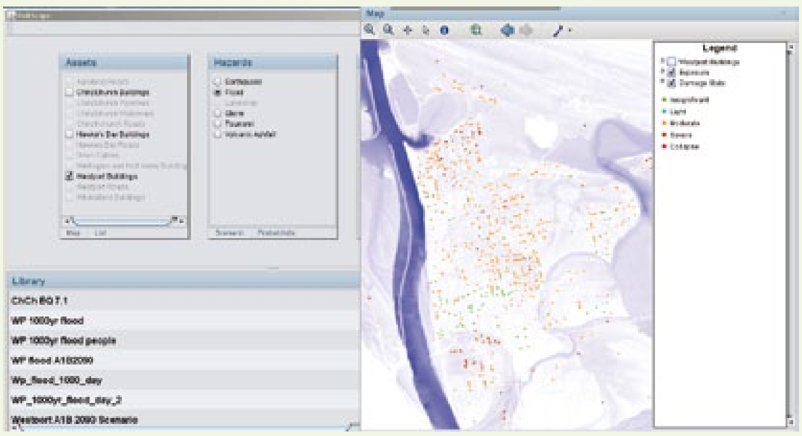
RiskScape and Subjective Quantified Risk Analysis (sQRA) are complementary methods for carrying out different aspects of risk assessments and are documented in the Third Tray. Both methods have been illustrated for flood risk assessments.

RiskScape is a joint venture between NIWA and GNS Science and was developed as an easy-to-use multi-hazard impact model for New Zealand. Its primary purpose is to provide a framework in which the risk of impact to assets due to various hazards can be calculated. This information can be used for a wide range of applications, from planning to hazard management to asset management. Model outputs are provided variously as hazard and impact maps, shape files, pdf reports, summary tables and KML files that can be displayed on Google Earth.

The framework provides a process to quantify risk of impacts from natural hazards by:

1. Identifying the natural hazard event characteristics
2. Determining the exposure of assets to the natural hazard's characteristics
3. Assessing how vulnerable the assets are to impacts from the natural hazard event characteristics
4. Quantifying the consequences of asset impacts arising from the natural hazard event

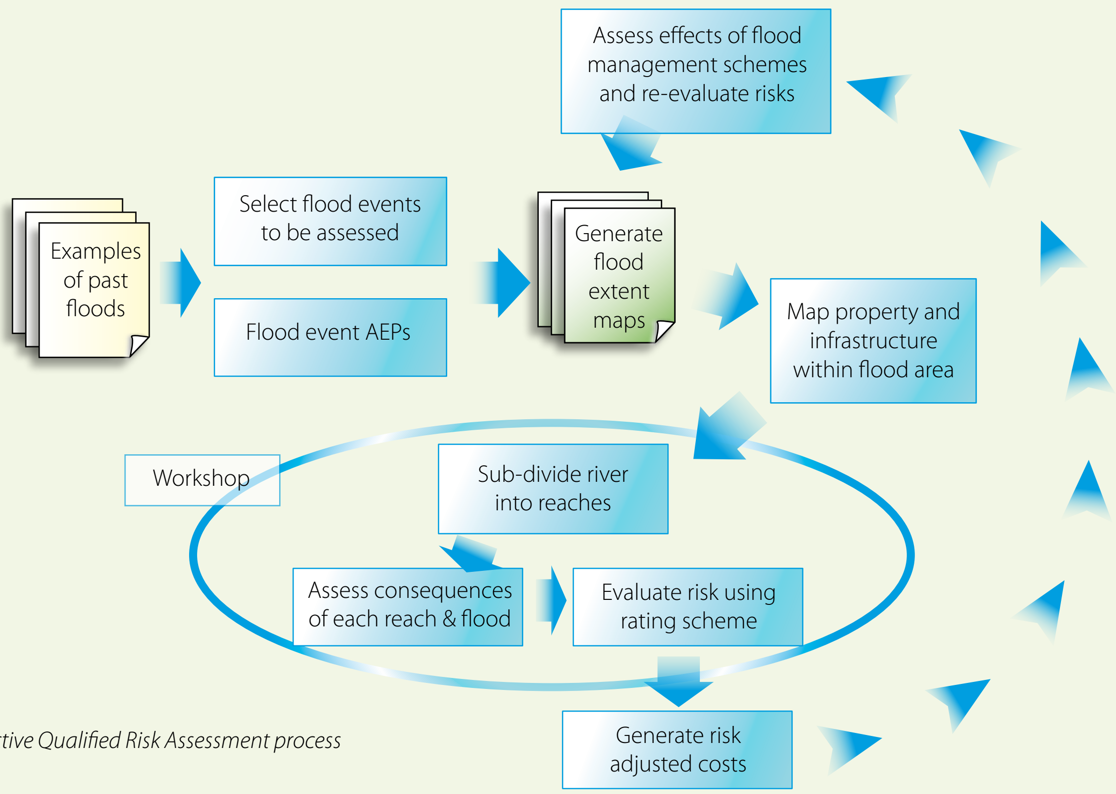
RiskScape features in Tools 3.2 and 3.3 where the model was used to evaluate the extent and impact of future flooding of the Buller River in Westport. The application is documented step-by-step with screen shots of the RiskScape interface in Tool 3.3. Three sets of results are presented: inundation depth for 2090 (A1B emissions scenario); the degree and extent of damage to buildings; and building structural repair cost.



Damage state of buildings in Westport affected by the 2090 A1B 50-year flood

The Subjective QRA Tool (Tool 3.5) provides order-of-magnitude estimates of the consequences and risks of defined events which may be used in preliminary evaluations of high-level strategic options for adapting to climate change, amongst other things. The method is a development of the Risk Matrix method described in Tool 1.3 that uses risk ratings defined in a way that can be translated into annual average risk-adjusted dollar costs. This allows diverse risks to be quantified, aggregated and compared.

Generally, sQRA uses a structured and facilitated workshop approach whereby technical experts and other stakeholders with relevant local knowledge rate the levels of impact of a hazard event guided by mapped information and their expertise. To illustrate, the methodology is applied in the context of flood modelling of a river catchment. Tool 3.5 presents a spread sheet that has been developed for interactive use at a river flooding workshop. It is used to capture pertinent information to inform the rating of flood damage, and to record the flood frequency and consequence scores for each of the river reaches. Flood hazard maps, such as those generated by RiskScape, are the starting point of the assessment and show where impacts are most likely to occur for various flood events with a range of return periods. These impacts are ranked for each river reach with respect to economic, social, environmental and cultural impacts, as well as the number of people and critical assets at risk. The ratings are converted within the sQRA to order-of-magnitude costs which are then multiplied by the probability of the event's occurrence to generate an average annual risk-adjusted cost, or 'cost-risk' for short.



Subjective Qualified Risk Assessment process

RiskScape is available for free evaluation from http://riskscape.org.nz/
The sQRA flood spreadsheet is available from the author of Tool 3.5 on request.

Following this, a hydrological rainfall-runoff model (a TopNet model of the Heathcote calibrated to eight flood events) was used to convert these changes in rainfall to changes in river flow (see Tool 2.1.3). Each design rainfall was used as input to the rainfall-runoff model to produce a different flood hydrograph for each climate change scenario.

A hydraulic model then was employed to assess levels of flood inundation (see Tool 2.1.4). Each flood hydrograph was used as input into the hydraulic model. Lastly, the flood inundation data were used as input into RiskScape to estimate the likely costs of future flooding in the Avon-Heathcote area.

3.2 Coastal Inundation

The sea level rise and storm surge inundation case study of the Avon-Heathcote Estuary complements the Heathcote River flooding study outlined above. The objective was to demonstrate how to carry out inundation mapping to assess effects of sea level rise.

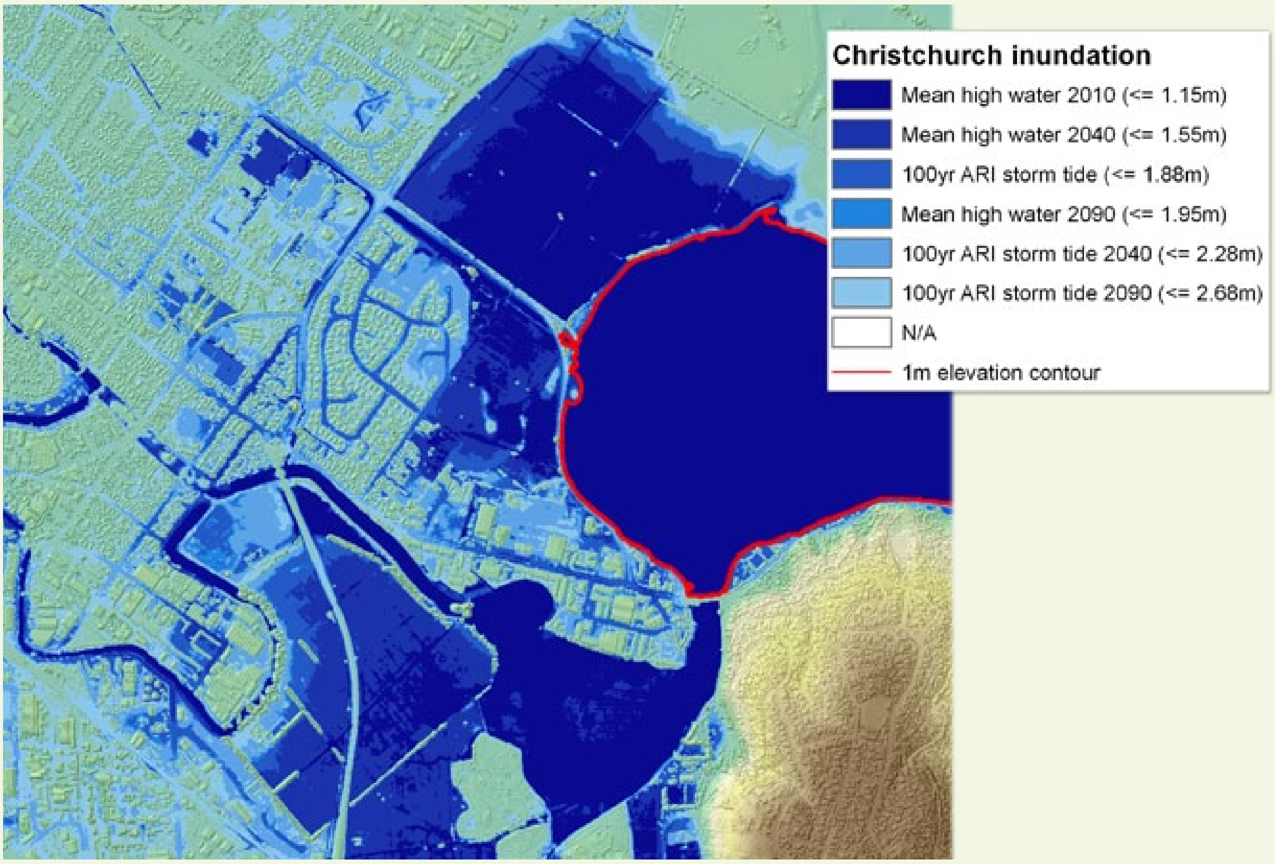
Up until the end of last century, the rate of sea-level rise has been relatively slow. This meant that planning and engineering design focused on extremes due to climate variability. For example, designing for an event with a return period of 50 or 100 years, for parameters such as water level, flood levels or rainfall which remained stationary (i.e., no trend) with time. However as the sea level continues to rise, there is an increasing imperative to consider the effects of climate variability on top of a rising trend when planning for future development. This upwards trend also means the definition of realistic (rather than nominal) planning timeframes becomes much more important than it was in the past. This case study was designed to demonstrate methods for calculating such values as the mean high water spring tide exceeded 10 per cent of the time (MHWS10), which is often used as a practical high tide level for infrastructure design works (see Tool 2.2.2), and also for estimating extreme high storm tides (see Tool 2.2.3).

Estimates of sea level rise can be superimposed on these tide levels and maps of potential future coastal inundation can be produced (see Tool 2.2.4). Using a hazard/risk model, such as RiskScape, estimates can then be made of the potential damage to buildings and repair costs associated with flooding.

Inundation mapping of future high tides, sea level rise and storm surge

Maps are extremely useful for visualising detailed spatial data. Overlaying spatial references such as coastlines, roads, rivers, and place names and including topography and/or semi-transparent hill shading adds to the identification of information and enhances the interpretability of the map. Inclusion of data layers (vector or raster) into a Geographic Information System (GIS) allows analysts to produce maps for specific purposes with multiple levels of information.

Two other tools associated with the Coastal Inundation case study demonstrate methods that can be used to derive present-day and future levels of the sea using tidal harmonic analysis [Tool 2.2.2] and extreme value analysis [Tool 2.2.3]. Tool 2.2.4 shows how data from these statistical analyses can be used in combination with high resolution digital terrain data to produce maps of potential land inundation from the sea.



Sea water inundation around the Christchurch Estuary based on the current (2010) and future (2040 and 2090) mean high water springs tide exceeded 10% of the time, and the 100-year ARI storm tide. Inundation is based solely on (pre earthquake) land elevation above mean sea level and does not take into account hidden flow paths.

3.3 Heavy rainfall induced landslides

Landslides can be divided into four groups for the purposes of determining the probability of a landslide occurring at a site. These are rainfall-induced landslides, earthquake-induced landslides, endogenetic landslides (no external trigger) and pre-existing landslides. Landslides may have a wide range of underlying causes but there are two dominant triggers of movement – rainfall and earthquakes. About 90% of all landslides are triggered by rainfall and different rainfall patterns produce different types of landslides.

This case study demonstrates how to map the risk of rainfall induced landslides resulting from extreme rainfall events using Wellington as an example. Wellington City experiences multiple rainfall-induced landslides every year, resulting in significant damages and clean-up costs. Wellington City Council planning and policy documents were audited for their relevance to landslides in Tool 1.5 and the results are used to illustrate the Planning and Auditing tool supplemental spread sheet.

The case study also shows how two separate landslide datasets were used to assess and calculate the landslide hazard in Wellington using a national probabilistic rainfall-induced landslide hazard model (PRILHM). The landslide data were sourced from the Wellington City Council (WCC) and the Earthquake Commission (EQC). Collectively the datasets provided a picture of rainfall-induced landslides in Wellington City allowing an assessment of landslide hazard to be made. Tool 2.3.3 describes the PRILHM methodology and demonstrated how it can be used to calculate the probability of a rainfall induced landslide occurring for any point in New Zealand with the specific example given of Wellington. Tool 2.3.4 demonstrates how landslide hazard maps can be produced for a range of rainfall events on the basis of the PRILHM results. The change in landslide hazard due to climate change was determined by adjusting current design rainfalls for Wellington for future climate projections using the MfE (2008a) method. Current and future (2090 with emissions scenario A1B) landslide hazard maps were produced for design rainfalls with an ARI ranging from 1.58 years to 100 years.

3.4 Urban water management systems

Urban water management refers to the management of three different systems; water supply, and wastewater and stormwater. Most cities in New Zealand manage these systems independently with separate reticulated pipe networks for each. However, historically, storm and waste water have been managed together and there are some areas still served by combined sewer systems (i.e., waste and stormwater in the same drainage network). There is a current trend internationally towards integrated urban water management with waste and stormwater seen as potential water sources which is gaining ground in New Zealand. While this water is not suitable for potable water use, it can supplement supply for uses such as watering gardens and flushing toilets and reduce demand for treated water. There is also a trend for sustainable stormwater management for water quality and quantity control, the latter to reduce flood risk. These moves are driven in part by the need for water secure resilient cities in the face of climate change.

There are two urban water management case studies in the Toolbox. The first looks at the impact of heavy rainfall on Auckland's urban drainage systems and the second at the future supply of, and demand for, potable water in Wellington.

3.4.1 Heavy rainfall and urban drainage

This case study investigates how climate change is being incorporated into urban drainage planning within a region undergoing rapid population growth and associated urban development. It is expected that the population will double to 2 million by 2050. As the population grows, there will not only be an increase in the area of the urban environment, but also a change towards a more intensively-developed urban form. These changes will have a profound effect on both surface drainage (stormwater) and waste water production putting pressure on existing drainage systems. The possible consequences include surface flooding, sewer overflows of untreated waste water to Auckland's coastal waters and failure of drainage infrastructure. To counter current and expected pressures, there are a number of capital works which have been completed or underway to upgrade drainage networks including replacement and maintenance of pipes, the newly constructed Hobson Bay sewage tunnel and the planned 18 km long Central Interceptor tunnel running from Western Springs to Mangere. Low impact design stormwater management devices for water quality and quantity control are also increasingly common in the city.

Assessing the impact of climate change on waste water networks (Tool 2.4.4)

In Auckland, as with many other coastal urban centres in New Zealand and worldwide, beaches are regularly closed for swimming, and aquatic ecosystems are put at risk due to overflows of untreated sewage, particularly from combined networks, following heavy rainfall events.

Combined sewer overflow in Auckland showing dry weather flow. The side weir is designed to be overtopped during heavy rainfall causing release of untreated wastewater to the receiving environment (P. Pattinson, NIWA, 2003)

In Tool 2.4.4, the former North Shore City Council (now part of the Auckland Council) investigated how adapting proposed capital works to their separate wastewater network for climate change would change the costs associated with those works. While the system is separated, the large volume of stormwater inflow and infiltration following heavy rainfalls results in wastewater overflows. The goal of the capital works is to reduce the number of overflows from over 12 per year to a target of no more than two per year as assessed by network modelling.

The study objectives were to provide an example of how a risk assessment of an urban drainage system can be undertaken using an existing operational model; and to demonstrate use of output from NIWA's Regional Climate Model (RCM) in a real-world application. DHI MOUSE (Danish Hydrological Institute, Model Of Urban SEwers) was used to simulate the network and to investigate what further upgrades would be needed to ensure the target level of service into the future. The model was forced with three rainfall data series – historic rainfall, synthetic current rainfall and synthetic future rainfall. The model was run with a projected increase in population and both with and without network deterioration due to aging.

The estimated cost of the planned capital works is $408 million (2008 currency) with assumed network deterioration. With no assumed network aging the costs drops to $314 million - a difference of $94 million. The costs of adapting the network were examined for both anticipated and unanticipated climate change. With the assumption of network deterioration, anticipated climate change adds a maximum of 13% ($461 million) to the overall costs compared to between 30 and 45% ($531-592 million) for unanticipated climate change. With no assumed network aging, adaptation to anticipated climate change increases the cost to between 2 and 19% ($320-373 million). The costs of adapting to climate change are less than those of accounting for network aging.

A combined sewer overflow outlet on Meola Creek, Auckland, during dry weather. Overflows of raw sewage are common following heavy rainfall and have contributed to the downstream degradation of both the creek and tidal inlet habitats (J. Gadd, NIWA, 2011)

Climate change projections in the region are for decreased annual rainfall but more frequent, higher intensity, rainfall extremes which could exacerbate the pressures noted above. Tool 2.4.2 demonstrates how climate change is being addressed by stormwater managers in the region and summaries the impact assessments which have already been carried out in the region. The goal was to gain an insight into the degree of knowledge held by stakeholders and how that knowledge is being applied, and to identify information gaps which need to be filled. Tool 2.4.3 provides an overview of the regulatory framework for stormwater management in the region and shows how climate change adaptation fits into this framework. Tool 2.4.4 investigates the potential cost of factoring climate change adaptation into proposed capital works in the former North Shore City Council wastewater network. Finally, Tool 4.7 followed MfE (2008a) guidance in carrying out preliminary screening of adaptation needs and options. In this study, the designs of two stormwater management devices (raingardens and wet detention ponds) were adjusted for a range of urban development and climate change scenarios. Adaptation strategies are also discussed.

3.4.2 Rainfall and potable water supply and demand

In some regions of New Zealand, and particularly northern and eastern areas, climate change is expected to increase the frequency and severity of droughts (Hennessy et al. 2007, IPCC 2007). Dry conditions affect both supply and demand for water. In general, an increased frequency and severity of drought will increase the overall variability of water supply and demand that must be 'managed', and the risk of water shortages.

Designing and developing potable water supply infrastructure to be more resilient to climate change effects does not require fundamentally different solutions. Rather, designs need to take into account changing climate-related effects. Climate change effects can influence design through increased 'loading' requirements, and add to other uncertainties because the rate and magnitude of the changes in climate are not known with certainty.

The tools in this case study demonstrate the water supply and demand issues facing Wellington City due to climate change. The methods and statistical models described in the tools are used for demonstration purposes only. It is recognised that other methods and models are available which can be used to perform functions similar to those described here. The tools also recognise that population increase and other societal pressures are also likely over the coming decades, and that these pressures are likely to have a significant effect on water supply and demand. A key finding of the case study is the importance of demand management (along with community engagement, participation and collaboration) in adapting to an increased risk of water shortages.

Tool 2.5.1 acknowledges the complexity and interconnectedness of human and natural resource systems and uses systems-thinking tools to explore the complex dynamics of urban water supply and demand approaches, including relevant social factors, for adapting to the effects of climate change.

Tool 2.5.3 looks at interactions between water supply and demand factors, and climate change trends. This is addressed through the use of scenarios and projections based on water use in Wellington, using Greater Wellington Regional Council's hydrological computer model, the Sustainable Yield Model (SYM).

Te Marua storage lakes (A. Blacklock, NIWA)

4 The Toolbox Online

The Toolbox web-portal is hosted by NIWA under the National Climate Centre, Information and Resources page. The URL to the web-portal is:

http://www.niwa.co.nz/climate/urban-impacts-toolbox

The Toolbox is open-access and all the tools can be downloaded as PDF files. You will need Adobe Reader installed on your PC to read the files, this can be obtained free of charge from:

http://get.adobe.com/reader/

The Toolbox consists of 26 interlinked web-pages. Besides the Urban Impact Toolbox homepage, there are three types of web-page within the toolbox; section main pages and section sub-pages with and without links to tools.

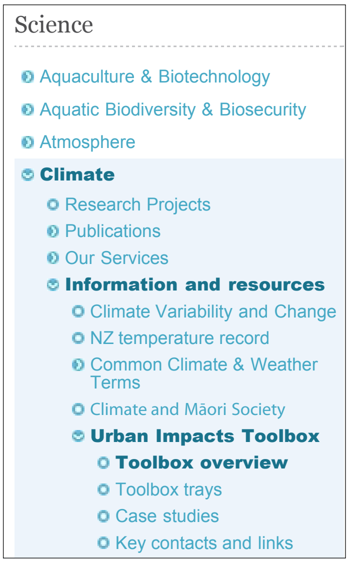
4.1 Toolbox Navigation

The Toolbox has been designed to guide users though the adaptation evaluation process outlined in Section 2. Each page in the toolbox can be accessed via a number of links and links to the tools (PDF files) can be found on multiple pages.

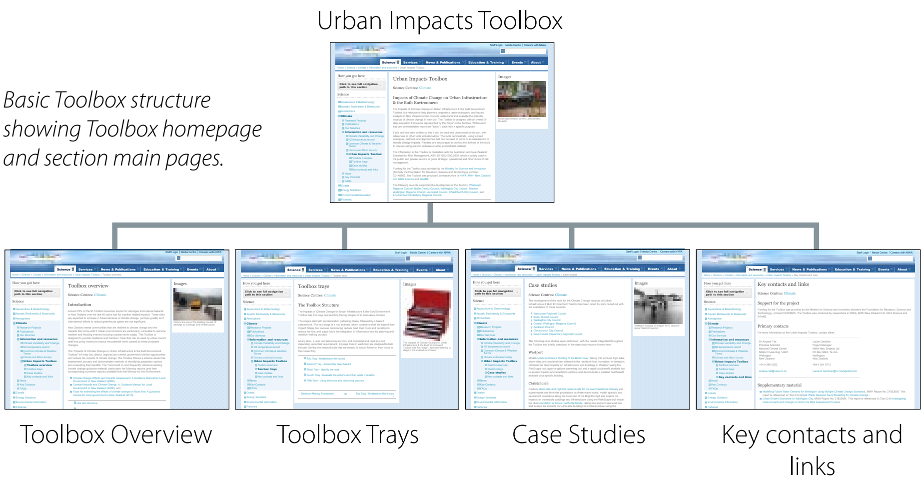
4.1.1 Menu

All the web-pages in the Toolbox can be accessed directly using the side menu located to the left of the Toolbox. The menu is arranged under four headings, which relate to Toolbox sections. With the exception of the *Key contacts and links* page, these sections have a number of sub-pages which are listed in an expanded menu when a section is displayed. The menu and the section main pages showing the basic Toolbox structure are presented here (left). The page currently opened will be highlighted in bold in the menu so that users know their exact location in relation to the Toolbox structure. Clicking on the Urban Impacts Toolbox title will return the user to the site homepage.

The menu does not link directly to tools.



Expanded Toolbox menu showing location under the National Climate Centre. The bold text indicates which page is currently open, in this case, the Toolbox Overview section page, and it's navigation path.

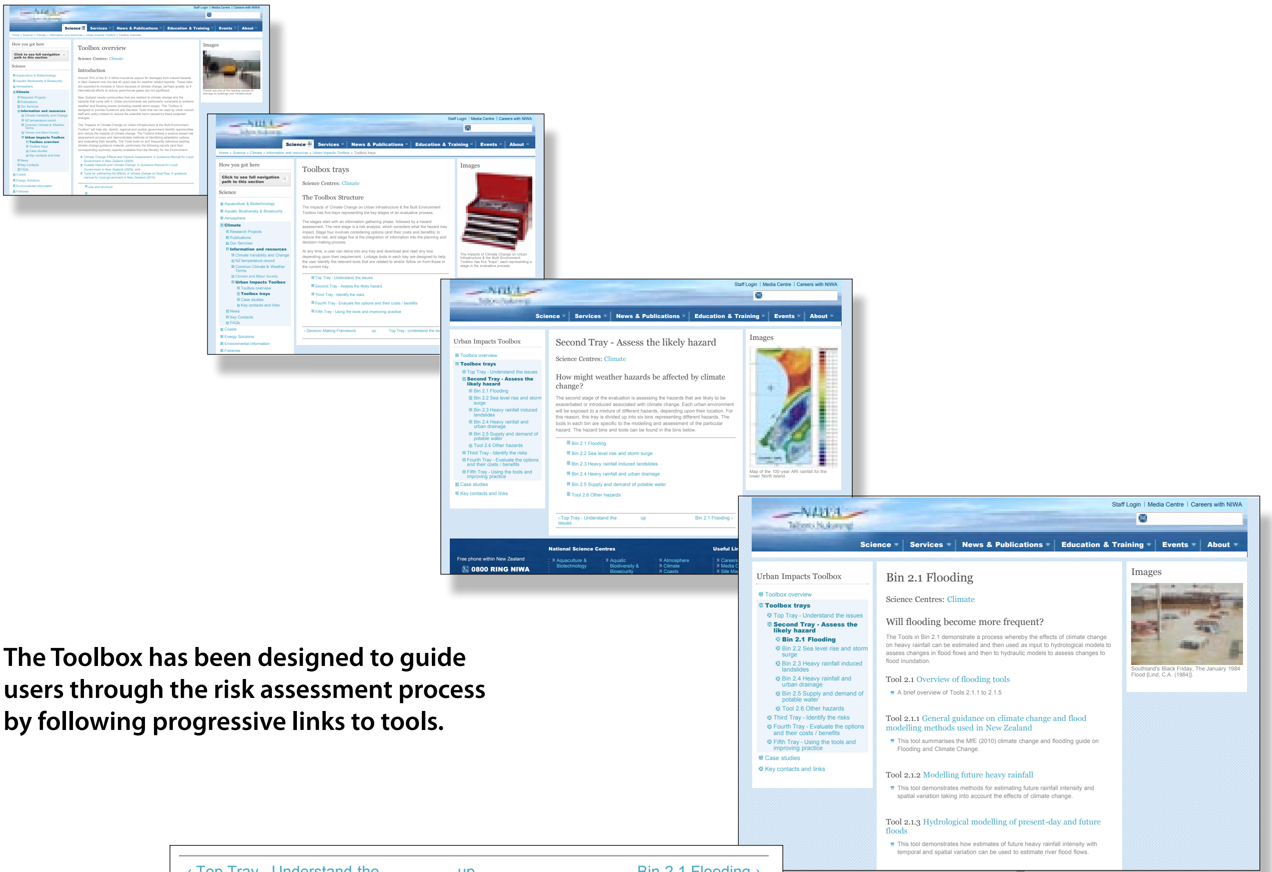


Basic Toolbox structure showing Toolbox homepage and section main pages.

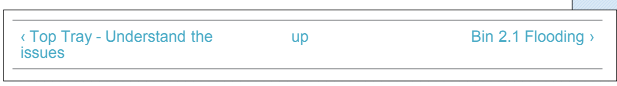
4.1.2 Internal links

In addition to the menu, the Toolbox includes progressive internal links between pages and tools. For example, the *Toolbox trays* page has links to the pages corresponding to each of the five steps in the risk assessment process. These in turn have links to each of the tools associated with that step, with the exception of the Second Tray which links to pages for each of the six hazard bins. Likewise, the case study pages have links to tools associated with each case study. Thus, a link to Tool 2.1.2 (Modelling future heavy rainfall), for instance, can be found on the web-page for Bin 2 (Flooding), as well as the pages for guidance tools (Guidance Type II) and both the Buller River and Heathcote River case-study pages.

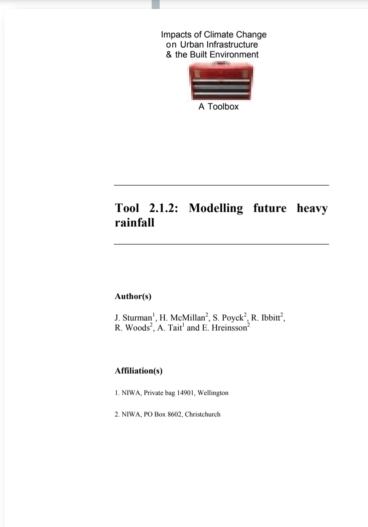
The example below shows the progressive internal links from the Toolbox Homepage to Tool 2.1.2 via the *Toolbox Trays*, *Second Tray* and *Bin 2* pages. Note the expansion of the side menu at each step.



The Toolbox has been designed to guide users through the risk assessment process by following progressive links to tools.



Forward, back and up links are found at the bottom of each page.



PDF file

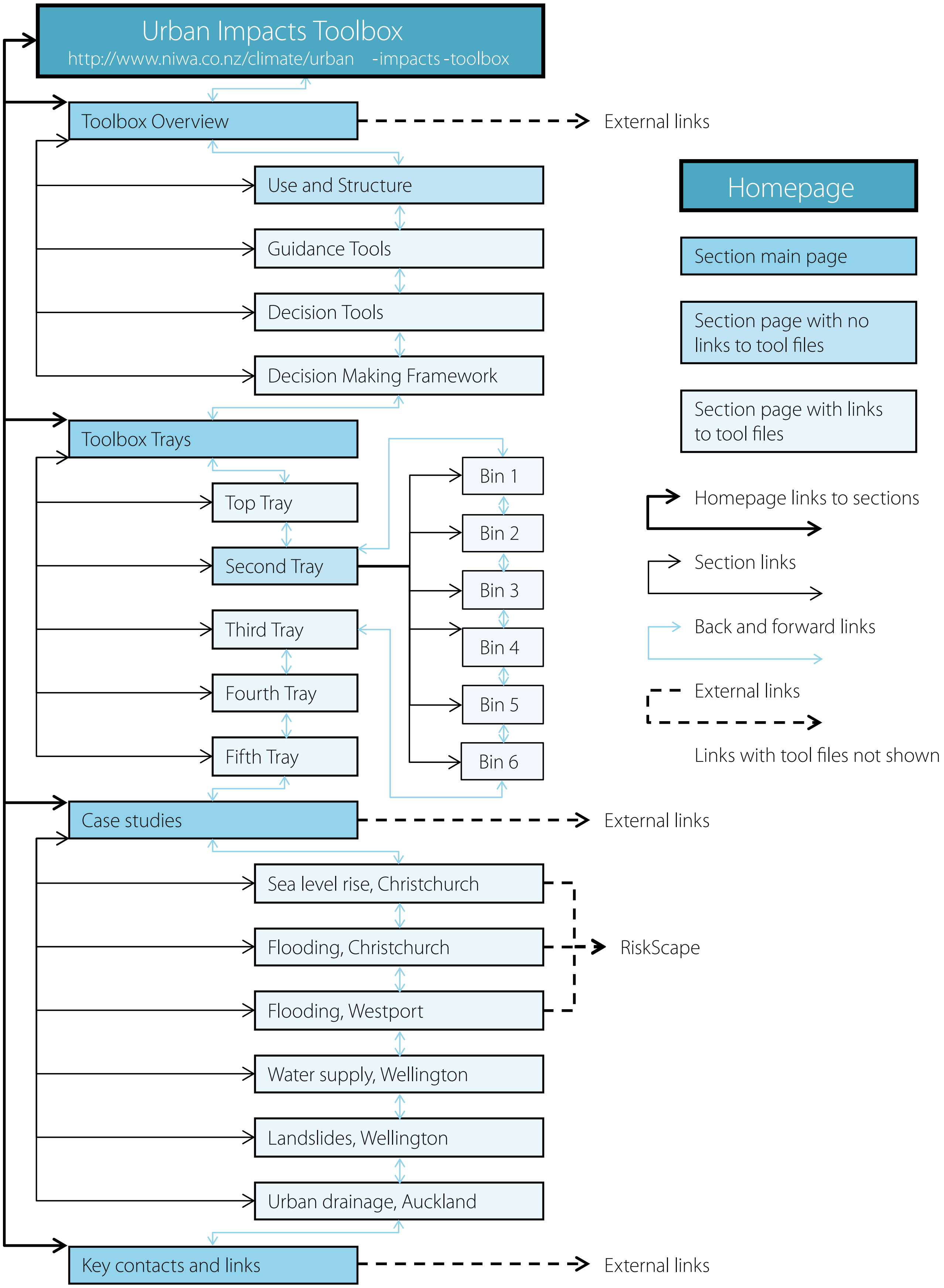
In addition to the progressive internal links, users can also navigate sequentially through every page in the Toolbox by following forward and back links to the previous and subsequent pages respectively. These are found at the bottom of each page along with an up link which returns the user to the level up the hierarchy (e.g., from section sub-pages to the section main page). The order of the Toolbox pages is shown in the Site Map.

4.1.3 External Links

While the Toolbox is self-contained, there are a number of links to external sites such as research partners, supporting organisations and supplementary information throughout the web-pages. The location of external links is shown in the Site Map opposite.

Site map

The Site Map shows the hierarchical structure of the 26 Toolbox pages, the internal links between them and location of external links. Links to tool files are not shown; however, pages which contain tools are noted (refer to Tables 1-4 or Appendix A).



4.2 Citing the Toolbox and tools

Please use the following reference when citing the Toolbox:

> NIWA, MWH, GNS and BRANZ (2012) Impacts of Climate Change on Urban Infrastructure and the Built Environment: A Toolbox. http://www.niwa.co.nz/climate/urban-impacts-toolbox

Individual Tools within the Toolbox can be referenced by the corresponding authors and report titles, for example (note, the publication year for all tools is 2012):

> Duncan, M. and Smart, G. (2012) Inundation modelling of present day and future floods. 13p. Tool 2.1.4 in NIWA, MWH, GNS and BRANZ (2012) Impacts of Climate Change on Urban Infrastructure and the Built Environment: A Toolbox. http://www.niwa.co.nz/climate/urban-impacts-toolbox

5 Concluding Remarks

The Impacts of Climate Change on Urban Infrastructure and the Built Environment Toolbox has been developed to provide guidance primarily to regional and local council staff charged with management of urban infrastructure including buildings, roads, drainage networks and transport networks. The Toolbox is arranged into five trays which represent stages in an adaptation evaluation process. Each tray consists of tools, or downloadable documents, which demonstrate how to embed climate change information in to hazard and risk assessments, and are illustrated using real-world examples from New Zealand drawn from six case studies.

This handbook gives background information on the Toolbox structure and the tools therein. It is intended to showcase the contents of the Toolbox and how the Toolbox can be utilised.

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- West Coast Regional Council
- Buller District Council
- Wellington City Council
- Greater Wellington Regional Council
- Auckland Regional Council and North Shore City Council (now amalgamated in the Auckland Council)
- Christchurch City Council
- Canterbury Regional Council.

7 References

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Oldfield, S.G. (2012) A Toolbox-Based Decision Framework for Climate Change Adaptation. 12p. in NIWA, MWH, GNS and BRANZ (2012) Impacts of Climate Change on Urban Infrastructure and the Built Environment: A Toolbox. http://www.niwa.co.nz/climate/urban-impacts-toolbox/toolbox-overview/decision-making-framework

Appendix A List of tools

The following tables list all of the tools grouped by Toolbox tray (see Section 2.2). The type of tool and authors are provided along with a brief description for each tool. Where applicable, the tables also note which case studies a tool is associated with (see Section 2.3.2).

A list of authors and their affiliations is given in Appendix B.

First Tray: Understand the issues

Tool	Title	Case study	Type of Tool	Authors	Description
1.1	Urban environments and climate change	-	Guidance I (reference)	S. Allan A. Tait	Provides context for the toolbox by answering some frequently asked questions
1.2	General climate change information and guidance for New Zealand	-	Guidance I (reference)	R. Nottage	Provides basic climate change guidance for New Zealand and information on the Intergovern-mental Panel on Climate Change (IPCC)
1.3	An introduction to risk assessment	-	Guidance I (reference)	S. Oldfield	Provides introductory guidance on basic risk as-sessment methods appropriate for use in setting priorities in terms of climate change issues of concern and the vulnerability of assets.
1.4	Urban environments and climate change – Statutory context	-	Guidance I (reference)	S. Allan	Outlines key legislation that influences planning and infrastructure for urban environments, and where to obtain update information.
1.5	Council policy and plan auditing tool	-	Decision	S. Allan S. Oldfield	Provides the basis for undertaking a 'health-check' audit of existing planning provisions to take account of climate change effects and to identify gaps and needs for additional planning instruments.
	Supplemental				A spreadsheet example of the policy and plan audit tool.
1.6	Sensitivity matrix prioritisa-tion tool	All	Decision	S. Oldfield S. Allan	Provides the basis for structured subjective assessment of the vulnerability of an entity (e.g. a Council) to climate change effects across its assets and service responsibilities.
1.7	Sources of information, help and expertise for climate change impact assessments & glossary	-	Guidance I (reference)	R. Nottage	Lists key sources of existing climate change information for NZ and overseas (reports and web-pages); includes a detailed glossary of terms used throughout the Toolbox.

Second Tray: Assess the likely hazard

Bin 1. Flooding

Tool	Title	Case study	Type of Tool	Authors	Description
2.1	Overview of flooding tools	-	Guidance II (method)	A. Tait	Summary of Tools 2.1.1 to 2.1.5
2.1.1	General guidance on climate change and flood modelling methods used in New Zealand	-	Guidance II (method)	J. Sturman H. McMillan S. Poyck R. Woods A. Tait E. Hreinsson	Summary of the MfE (2010) guidance on flooding and climate change.
2.1.2	Modelling future heavy rainfall	Chch. Heathcote River & Westport	Guidance II (method)	J. Sturman H. McMillan S. Poyck R. Ibbitt R. Woods A. Tait E. Hreinsson	Demonstrates methods for estimating future rainfall intensity and spatial variation taking into account the effects of climate change.
2.1.3	Hydrological model-ling of present-day and future floods	Chch. Heathcote River & Westport	Guidance II (method)	J. Sturman H. McMillan S. Poyck R. Ibbitt J. Walsh R. Woods A. Tait E. Hreinsson	Demonstrates how estimates of future heavy rainfall intensity with temporal and spatial variation can be used to estimate river flood flows.
2.1.4	Inundation modelling of present-day and future floods	Chch. Heathcote River & Westport	Guidance II (method)	M. Duncan G. Smart	Demonstrate how estimates of river flood flows corre-sponding to future scenarios of heavy rainfall can be used to estimate the corresponding flood inundations.
2.1.5	Linkages to risk as-sessment, adaptation options and decision tools	-	Guidance II (method)	A. Tait	Identifies the next stages in an assessment of flooding impacts due to climate change.

Second Tray: Assess the likely hazard

Bin 2. Sea level rise and inundation

Tool	Title	Case study	Type of Tool	Authors	Description
2.2	Overview of sea level rise and storm surge tools	-	Guidance II (method)	A. Tait	Summary of Tools 2.2.1 to 2.2.5
2.2.1	Guidance on assessing sea level rise in New Zealand	-	Guidance II (method)	R. Bell S. Stephens	Summarises the MfE (2009) guidance on coastal hazards and climate change.
2.2.2	Causes of sea level variation	Chch. Heathcote Estuary	Guidance II (method)	S. Stephens R. Bell	Describes the "drivers" of sea-level variability, including waves, climate (e.g. El Niño Southern Oscillation), astro-nomical effects (e.g. tides), and storm surge.
2.2.3	Guidance on assessing extreme sea level in New Zealand	Chch. Heathcote Estuary	Guidance II (method)	R. Bell S. Stephens	Provides a background to extreme sea-level analysis so that a reader can: 1) Understand how an extreme sea-level analysis works; 2) Select an appropriate method to analyse available data; 3) Understand the advantages and disadvantages of various extreme sea-level analysis methods; and 4) Interpret the output of an extreme sea-level analysis.
2.2.4	Inundation mapping of future high tides, SLR and storm surge	Chch. Heathcote Esturary	Guidance II (method)	A. Tait J. Sturman G. Smart	Demonstrates a simple GIS-based method for the spatial mapping of coastal inundation.
2.2.5	Linkages to risk as-sessment, adaptation options and decision tools	-	Guidance II (method)	A. Tait	Identifies the next stages in an assessment of coastal inundation impacts due to climate change.

Second Tray: Assess the likely hazard

Bin 3. Heavy Rainfall Induced landslides

Tool	Title	Case study	Type of Tool	Authors	Description
2.3	Overview of landslide tools	-	Guidance II (method)	A. Tait	Summary of Tools 2.3.1 to 2.3.5
2.3.1	General information on the causes of rainfall-induced landslides	-	Guidance II (method)	G. Dellow	A general introduction to the causes of rainfall induced landslides
2.3.2	Collection and analysis of historical landslide information and data	-	Guidance II (method)	G. Dellow	Describes in generic terms the data sets needed to calculate the probability of a rainstorm-induced landslide occurring at any point in New Zealand and the specific datasets used for a study in Wellington to assess the rainfall-induced landslide hazard.
2.3.3	Modelling present-day and future landslide potential	Wellington landslides	Guidance II (method)	G. Dellow	Describes a generic methodology, the Probabilistic Rainfall-Induced Landslide Hazard Model (PRILHM), that can be used to calculate the probability of a rainstorm-induced landslide occurring at any point in New Zealand.
2.3.4	Mapping the landslide hazard	Wellington landslides	Guidance II (method)	G. Dellow	Presents the results of applying the methodology described in [Tool 2.3.3] to produce hazard maps for a range of rainfall conditions
2.3.5	Linkages to risk assessment, adaptation options and decision tools	-	Guidance II (method)	A. Tait	Identifies the next stages in an assessment of rainfall-induced landslide impacts due to climate change

Second Tray: Assess the likely hazard

Bin 4 Heavy rainfall and urban drainage

Tool	Title	Case study	Type of Tool	Authors	Description
2.4	Overview of urban drainage tools	-	Guidance II (method)	A. Semadeni-Davies A. Tait	Summary of Tools 2.4.1 to 2.4.5
2.4.1	Climate change and urban drainage modelling – data, issues and assumptions	-	Guidance II (method)	A. Semadeni-Davies	Reviews the issues and assumptions involved in urban drainage modelling to determine the possible impacts of climate change.
2.4.2	Incorporating climate change into urban stormwater management	Auckland	Guidance II (method)	A. Semadeni-Davies J. Puddephatt	Investigates how climate change guidance is currently being used by stormwater practitioners and how they apply this guidance with respect to stormwater quantity control.
2.4.3	Climate change guidance material for urban stormwater management	Auckland	Guidance II (method)	A. Semadeni-Davies	Provides a stocktake of guidance material available to urban stormwater managers in the Auckland region, including a summary of the regulatory framework relevant to stormwater management and a review of national and Auckland regional technical guidance material that can be used by practitioners to plan for possible adaption to the impacts of climate change on stormwater management.
2.4.4	Modelling the North Shore City Council wastewater network – a case study of potential climate change impacts	Auckland	Guidance II (method)	A. Semadeni-Davies	Provides an example of a climate change risk assessment for an urban wastewater network.
2.4.5	Linkages to risk assessment, adaptation options and decision tools	-	Guidance II (method)	A. Tait	Identifies the next stages in an assessment of urban drainage impacts due to climate change.

Second Tray: Assess the likely hazard

Bin 5 Supply and demand of potable water

Tool	Title	Case study	Type of Tool	Authors	Description
2.5	Overview of potable water tools	-	Guidance II (method)	A. Tait	Summary of Tools 2.5.1 to 2.4.4
2.5.1	General information on water supply and demand methods and issues	Wellington potable water	Guidance II (method)	N Taptiklis	Demonstrates use of systems-thinking tools to explore the complex dynamics of urban water supply and demand approaches, including relevant social factors, with particular regard to communities adapting to the effects of climate change.
2.5.2	Bulk water demand trend modelling	-	Guidance II (method)	C. McCormack A. Joyner	Two modelling tools are presented here: The WaterTrac climate correction modelling tool, which is designed to monitor trends in bulk water production and to provide water utilities with information about climate influences on water demands; and the ClimateTrac modelling tool, which was developed for annual and monthly forecasting of the impacts of climate change on water demands.
2.5.3	SYM approach to present-day and future potable water supply and demand	Wellington potable water	Guidance II (method)	N. Taptiklis	Provides an overview of a case study using the Greater Wellington Regional Council's Sustainable Yield Model (SYM). One of the objectives of this case study looked at interactions between water supply and demand factors, and climate change trends.
2.5.4	Linkages to risk assessment, adaptation options and decision tools	-	Guidance II (method)	A. Tait	Identifies the next stages in an assessment of water supply and demand impacts due to climate change.

Second Tray: Assess the likely hazard

Bin 6 Other Hazards

Tool	Title	Case study	Type of Tool	Authors	Description
2.6	General information on the assessment of climate change effects on high winds, very high temperatures, snowfall, fog, lightning & hail and drought	-	Guidance II (method)	R. Nottage	A key lesson from many climate studies is that even small changes in average climate can lead to a disproportionate increase in the incidence of damaging extremes. This tool investigates what is currently known about potential future changes to these 'other' hazards.

Third Tray: Identify the risks

Tool	Title	Case study	Type of Tool	Authors	Description
3.1	Climate change risk assessment and good practice	-	Guidance II (method)	S. Oldfield	Provides guidance on quantifying climate change risks, the treatment of uncertainty and how to make judgements about the tolerability of risk, to support decisions about the levels of protection that would be considered sufficient and appropriate.
3.2	Using RiskScape for risk analysis.	-	Decision	S. Reese	Description of RiskScape, a regional risk and impact assessment tool. Its primary purpose is to provide a framework in which the risk of impact to assets due to various hazards can be calculated. This information can be used for a wide range of applications, from planning to hazard management to asset management.
3.3	Case study example of risk assessment using RiskScape	Westport	Decision	S. Reese	Demonstrates how RiskScape can be used to evaluate the impact of future flooding.
3.4	Investigating urban growth and change to inform the risk assessment process	-	Guidance I (reference)	C. van Halderen S. Oldfield S. Allan	Provides an outline of where to obtain relevant information, including uncertainties, for predicting urban growth and change to inform the risk assessment process in the context of managing climate change effects in the urban environment.
3.5	Subjective quantified risk analysis tool	-	Decision	S. Oldfield	Provides order-of-magnitude estimates of the consequences and risks of defined events which may be used in preliminary evaluations of high-level strategic options for adapting to climate change, amongst other things.
3.6	Linkages to hazard assessment, adaptation options and decision tools.	-	Guidance II (method)	A. Tait	This tool identifies the linkages from the risk tools in this tray back to hazard assessment tools and forward to decision tools.

Fourth Tray: Evaluate the options and their costs / benefits

Tool	Title	Case study	Type of Tool	Authors	Description
4.1	Climate change adaptation – key concepts	-	Guidance I (method)	A. Tait	Provides some climate change adaptation key concepts based on a literature review of primarily urban-based climate change studies and identifies the many issues associated with preparing for and adapting to present-day and future weather and climate hazards in urban settings.
4.2	Overview of an option screening tool	-	Decision	N. Keenan S. Oldfield	This tool is designed to be used in a brainstorming context, the tool provides a means of exploring a wide range of generic options and short-listing the most promising for the local context.
4.3	Rapid cost/benefit evaluation of impacts and adaptation options	-	Decision	S. Oldfield	Demonstrates the classical Cost Effectiveness process embodied within a subjective order of magnitude approach to quantifying the costs and benefits of alternative adaptation scenarios.
4.4	Individual house flood mitigation measures - benefit/cost tool	-	Decision	I. Page	Aids in the screening and short-listing of flood damage reduction measures for existing housing at the small scale level. The Tool is equally applicable to current flood scenarios as well as to future climate change effects on flooding scenarios.
4.5	Overview of a multi-criteria analysis based decision tool	-	Decision	S. Oldfield	This MCA-based tool is specifically designed to allow prioritisation of actions to prevent or mitigate the impact of landslides based on the level of risk they present, taking account of climate change.
4.6	Overview of a top-down decision tool	-	Decision	S. Allan	This is a tool to assist decision-making in a "real-world" context, where statutory and policy provisions must be included along with other considerations.
4.7	Adaptation by design: impact of climate and land use change on the sizing of stormwater management devices	-	Guidance II (method)	A. Semadeni-Davies	Gives information on how the design of stormwater retention devices could change based on scenarios of future heavy rainfall events.
4.8	Overview of a building flood protection decision framework	-	Decision	J. Roberti	Provides a linked set of tools for adaption of individual buildings that are prone to enhanced flood risk due to climate change.
4.9	Linkages to hazard and risk assessment tools	-	Guidance II (method)	A. Tait	Provides quick links between the decision tools in this tray and the hazard and risk assessment tools in trays 2 and 3.

Fifth Tray: Using the tools and improving practice

Tool	Title	Case study	Type of Tool	Authors	Description
5.1	Managing information (including use of climate change check-lists)	-	Guidance III (message)	S. Allan	Explains the range of information that the practitioner needs to be aware of.
5.2	Keeping up to date	-	Guidance III (message)	S. Allan	Outlines the fast-moving nature of climate change information.
5.3	Climate change - the long-term view	-	Guidance III (message)	S. Allan	Outlines guidance on timeframes for planning and decisions.
5.4	Adopting a balanced approach	-	Guidance III (message)	S. Allan	Discusses adaptation approaches and the basis for decisions on community responses.
5.5	Community resilience and sustainable development	-	Guidance III (message)	S. Allan	Describes some concepts and techniques used to assist in transforming communities towards greater resilience.

Appendix B Author affiliations

The following table lists the tool authors and their affiliations alphabetically. Tools for which the author was the main contributor are in **bold**.

Author	Affiliation	Contact Address	Website	Tools
Allan, S.	Allan Planning and Research Ltd	26 Patrick St Petone, Lower Hutt	-	**1.1**, **1.4**, **1.5**, 1.6, 3.4, **4.6**, **5.1**, **5.2**, **5.3**, **5.4**, **5.5**
Bell, R.	NIWA Ltd.	PO Box 11-115 Hamilton	www.niwa.co.nz	**2.2.1**, **2.2.2**
Dellow, G.	GNS Science	PO Box 30-368 Lower Hutt 5040	http://gns.cri.nz/	**2.3.1**, **2.3.2**, **2.3.3**, **2.3.4**
Duncan, M.	NIWA Ltd	PO Box 8602 Christchurch	www.niwa.co.nz	**2.1.4**
Hreinsson, E.	NIWA Ltd	PO Box 8602 Christchurch	www.niwa.co.nz	2.1.1, 2.1.2, 2.1.3
Ibbitt, R.	NIWA Ltd	PO Box 8602 Christchurch	www.niwa.co.nz	2.1.2, 2.1.3
Joyner, A.	MWH New Zealand Ltd	PO Box 13 249 Christchurch 8141	www.mwhglobal.com	2.5.2
Keenan, N.	MWH New Zealand Ltd	PO Box 9624 Te Aro, Wellington	www.mwhglobal.com	**4.2**
McCormack, C.	MWH New Zealand Ltd	PO Box 13 249 Christchurch 8141	www.mwhglobal.com	**2.5.2**
McMillan, H.	NIWA Ltd	PO Box 8602 Christchurch	www.niwa.co.nz	2.1.1, 2.1.2, 2.1.3
Nottage, R.	NIWA Ltd	Private Bag 14901 Wellington 6021	www.niwa.co.nz	**1.2**, **1.7**, **2.6**
Oldfield, S.	MWH New Zealand Ltd	PO Box 9624 Te Aro, Wellington	www.mwhglobal.com	**1.3**, 1.5, **1.6**, **3.1**, 3.4, **3.5**, 4.2, **4.3**, **4.5**
Page, I.	BRANZ	Private Bag 50 908 Porirua	www.branz.co.nz	**4.4**
Poyck, S.	NIWA Ltd	PO Box 8602 Christchurch	www.niwa.co.nz	2.1.1, 2.1.2, 2.1.3
Puddephatt, J.	MWH New Zealand Ltd	PO Box 12-941 Auckland	www.mwhglobal.com	2.4.2
Reese, S.	NIWA Ltd	Private Bag 14901 Wellington 6021	www.niwa.co.nz	**3.2**, **3.3**
Roberti, J.	BRANZ	Private Bag 50 908 Porirua	www.branz.co.nz	**4.8**
Semadeni-Davies, A.	NIWA Ltd	Private Bag 99940 Auckland	www.niwa.co.nz	**2.4**, **2.4.1**, **2.4.2**, **2.4.3**, **2.4.4**, **4.7**
Smart, G.	NIWA Ltd	PO Box 8602 Christchurch	www.niwa.co.nz	2.1.4, 2.2.4
Stephens, S.	NIWA Ltd.	PO Box 11-115	www.niwa.co.nz	2.2.1, 2.2.2, **2.2.3**
Sturnam, J.	NIWA Ltd	Hamilton	www.niwa.co.nz	**2.1.1**, **2.1.2**, **2.1.3**, 2.2.4
Tait, A.	NIWA Ltd	Private Bag 14901 Wellington 6021	www.niwa.co.nz	1.1, **2.1**, 2.1.1, 2.1.2, 2.1.3, **2.1.5**, **2.2**, **2.2.4**, **2.2.5**, **2.3**, **2.3.5**, 2.4, **2.4.5**, **2.5**, **2.5.4**, **3.6**, **4.1**, **4.9**
Taptiklis, N.	NZ Climate Change Research Institute, Victoria University	Private Bag 14901 Wellington 6021	www.victoria.ac.nz/sgees/research-centres/ccri	**2.5.1**, **2.5.3**
van Halderen, C.	MWH New Zealand Ltd	Wellington P.O.Box 600 Wellington	www.mwhglobal.com	**3.4**
Walsh, J.	NIWA Ltd	PO Box 9624 Te Aro, Wellington	www.niwa.co.nz	2.1.3
Woods, R.	NIWA Ltd	PO Box 8602 Christchurch	www.niwa.co.nz	2.1.1, 2.1.2, 2.1.3