TOOLS FOR ASSESSING CLIMATE CHANGE ADAPTATION OPTIONS FOR URBAN DRAINAGE: AUCKLAND CASE STUDY

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ABSTRACT

NIWA is leading a collaborative FRST-funded programme to assist local government to assess risks associated with climate change in the urban environment and identify opportunities for reducing those risks. The aim is to create an *Urban Impacts of Climate Change* "tool-box" of methods and processes to assess the risk of climate change impacts and responses to them across different aspects of urban resource and hazard management. An Auckland case-study forms part of this research and investigates how climate change is being incorporated into urban drainage planning within a region undergoing growth. While the focus is stormwater management, surface water inflows and sewer infiltration into wastewater networks are also addressed. The case-study has resulted in six tools consisting of separate reports on:

- Tool 2.4.1 Climate change and urban drainage modelling;
- Tool 2.4.2 Incorporation of climate change guidance into current stormwater management practices;
- Tool 2.4.3 National and local climate change guidance material for urban drainage management;
- Tool 2.4.4 Modelling wastewater in North Shore City;
- Tool 2.4.5 Linkages to adaptation options, urban growth strategies and sustainable development policy; and
- Tool 4.7 Design of stormwater treatment devices for adaptation.

KEYWORDS

heavy rainfall, modelling, design, drainage networks, city growth

PRESENTER PROFILE

Annette Semadeni-Davies has been a stormwater engineer at NIWA since 2006. She has an interest in the use of sustainable urban drainage systems for water management and as potential adaptations for climate change. She gained her PhD at Lund University in Sweden and is known for her work on urban drainage in cold regions. She has published several papers in international journals on the potential impacts of climate change on urban water management.

1 INTRODUCTION

NIWA is leading a collaborative FRST-funded programme with partners MWH New Zealand Ltd, BRANZ and GNS. The aim is to create an *Urban Impacts of Climate Change* "tool-box" to help central and local government reduce the risks associated with climate change to the urban environment and its infrastructure, through development of a science-based risk assessment process and identification of opportunities for adaptation. The programme was initiated in 2008 is in its final year. The tool-box is due to be published in September this year and will be made freely available to all local governments.

The definitions of hazard, impact, risk and adaptation are central to the programme. 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 change depending on location. 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*". Risk refers to the severity of the impacts and the probability of their occurrence and depends not only on the magnitude and frequency of the hazard but also on the nature of the built-environment (e.g., land use intensity, urban form, infrastructure present) and activities (e.g., residential vs. commercial land use) impacted. The primary means of risk reduction explored in the programme 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 impacts before they occur.

To date, local governments in New Zealand have largely focused their attention on identifying the potential risks of climate change according to guidance material prepared by central government. That is, the impacts of climate change have been or are being assessed according to the increase in the risk associated with natural hazards that are affected by climate change. The primary sources of guidance for risk assessment are the manuals for local government by MfE '*Preparing for Climate Change*' (MfE, 2008b); '*Preparing for Coastal Change*' (MfE. 2009); and '*Preparing for Future Flooding*' (MfE, 2010), known as the Red, Blue and Green books respectively. Each of these documents is a summary of more detailed documents also available from MfE (including MfE, 2008a). The intention of the tool box is to provide guidance on how to reduce the identified risk.

The tool-box consists of five trays; each tray represents a stage in the adaptation evaluation process and contains a number of tools. The tools demonstrate how to deal with the specific needs of each stage of the process and are illustrated using real-world New Zealand examples. The examples are drawn from five case-studies which focus on different aspects of urban built environment that are vulnerable to a different weather-related hazard. The case-studies are listed below:

- Westport – heavy rainfall and river flooding
- Christchurch –sea level rise and storm surge inundation
- Wellington – heavy rainfall and landslides
- Wellington – rainfall and potable water supply and demand
- Auckland – heavy rainfall and urban drainage

The trays are as follows:

Tray 1	*Understand the issues:* General information including climate change projections for New Zealand and an overview of urban planning legislation in relation to climate change. There are six tools in this tray.
Tray 2	*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. Hazard assessment requires the identification of impacts and qualitative and qualitative descriptions of those impacts on services and activities. The 30 tools in this tray are divided into six bins, one for each case-study topic and a sixth with guidance for other hazards such as strong winds, fog and snow.
Tray 3	*Identify the risks:* the six tools in this tray give guidance on how to assess the risks associated with a particular hazard. Risk assessment involves 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. Tools include guidance on how to use existing software or methods to both analyse and communicate risk. The use of the tools is demonstrated for the landslide, and coastal and river flooding case-studies.
Tray 4	*Evaluate the options and their costs / benefits:* the seven tools in this tray give guidance on the evaluation of adaptation options with respect to their efficiency and cost relative to the cost associated with the risk. Adaptation can be engineering- or policy-based and should involve no- or low-regrets options that can be changed over time. The tools include generic methods for evaluating adaptation options and tools specific to the case-studies including stormwater management.
Tray 5	*Using the tools and improving practice:* the six tools in this tray have been provided to enable the hazard, risk and adaptation assessments to be integrated into the local government decision making and planning process. The tools contain messages gained from the previous trays and include guidance on how to manage information, keeping up to date and the economics of adaptation.

This paper overviews the context for the Auckland case-study and presents a summary of the six tools specific to urban drainage. The study was included in the programme as management of the three urban waters (water supply, wastewater and stormwater) are key services provided by local authorities. These services were identified by MfE (2008a) as being sensitive to weather-related hazards and therefore at increased risk due to climate change. It is noted that as Auckland is experiencing other challenges driven by population growth and continued urban development, any consideration of future risk must also take these challenges into account. While the focus is on stormwater management, rain dependant flows in wastewater networks due to inflow and infiltration are also addressed. Water supply was the subject of one of the two Wellington case-studies and is addressed in other tools (notably Tray 2, bin 5). More information about the research programme can be found on the NIWA website[1].

2 CHALLENGES TO URBAN DRAINAGE IN AUCKLAND

Auckland is the largest city in New Zealand and is undergoing rapid population growth and associated urban development. The population of the region rose by 12.4% between 2001

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[1] http://www.niwa.co.nz/our-science/climate/research-projects/all/climate-change-and-urban-impacts (date last accessed, 28/2/2011)

and 2006 which led to an increase in occupied housing of 11.2% (ARC, 2007). It is expected that the population will double to 2 million by 2050 – this will be met by further development. As the city grows, it is anticipated that in accordance with the Regional Growth Strategy (ARC, 1999 a), there will be not only a change in city extent, at least to the Metropolitan Urban Limits, but also a change in urban form towards more compact land use. The reduction in land available for green-field development means that brown-field development and infilling are expected to continue so that existing urban areas become more intense (Gamble, 2010). Certainly, there has been an increase in inner city apartments and suburban terrace housing over the past decade.

Using the European Environment Agency (Smeets and Weterings, 1999) 'Drivers-Pressures-State-Impact-Response' (DPSIR) framework for reporting on environmental issues, population growth and development are key drivers which exert pressures on drainage networks by increasing both waste-water production and stormwater generation from impervious surfaces. This pressure changes the state of the built and natural environments with increased hydraulic and contaminant loads, to cause an impact on local resources (Figure 2). These impacts may elicit a response by water managers to avoid or mitigate their occurrence or severity. This response can feedback to all stages in the system.

In Auckland, green-field developments will result in the need for new or extended waste and stormwater drainage networks. Infilling and brown-field development could stress existing networks requiring retrofitting and replacement. Moreover, as networks age and deteriorate, they will require ongoing maintenance and rehabilitation. Overflows from sanitary sewers are already a problem in some areas and regularly close beaches to swimmers. A number of major projects over recent years are testament to the need for capital works on drainage networks including ongoing separation of combined sewers in the inner city suburbs; North Shore sewer rehabilitation as part of Project CARE; and the construction of the 3km-long Hobson Bay tunnel.

Flooding, in part driven or exacerbated by increased imperviousness, is a concern in parts of the city and has been the subject of several studies over recent years (e.g. Arthur et al., 2008, Miselis and Captain, 2009; Parkinson et al, 2009). These studied have variously investigated flood risk and alternatives for managing urban stormwater to avoid this risk.

The quality of stormwater and sediments transported by stormwater are of major concern in the region. Erosion of exposed soils, stream sediments and at coastal stormwater outfalls has lead to degradation of water ways and receiving environments (e.g., Elliott et al., 2004) including changing stream morphology and down-stream deposition of eroded sediments in Auckland's many tidal rivers and estuarine mudflats. Many contaminants in Auckland stormwater, especially metals, tend to be in particulate form (Timperley *et al.*, 2005; Bibby and Webster-Brown, 2005, 2006). The deposition of these contaminated sediments is known to be a major hazard to the ecological health of Auckland's harbours (Kelly, 2010). Williamson and Morrisey (2000) found an increase in the metal content of sediments in Auckland estuaries with urbanisation.

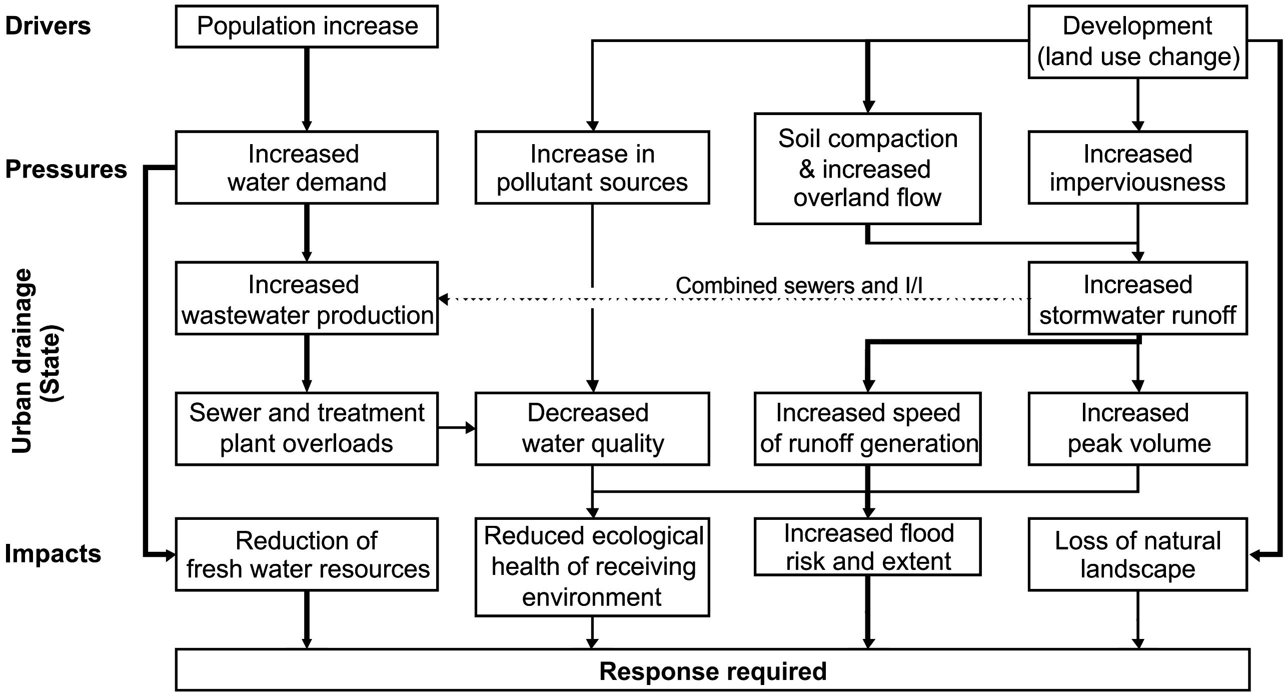

Figure 1: Effects of population growth and urbanisation on urban drainage

2.1 POTENTIAL CLIMATE IMPACTS ON URBAN DRAINAGE

The magnitude and timing of the impacts of urban drainage on receiving environments discussed above are closely linked to the frequency and intensity of heavy rainfall, both of which are projected to increase over the coming century, potentially exacerbating these impacts. In addition to changes in the frequency and intensity of extreme rainfalls, the seasonality of rainfall delivery can also have an effect on urban drainage hitherto not discussed by changing antecedent conditions. Wetter winters could mean that soil is unable to dry between events so that catchments respond more rapidly and with greater peak flows to rainfall. In contrast, drier summers could lead to increased soil moisture deficits decreasing recharge and base-flow. Summer heating of runoff both by direct warming of shallow water bodies (i.e., streams, ponds and wetlands) and by heating of surface flow paths (i.e., roads, roofs and paving), could also lower water quality by increasing the temperature of natural water bodies and reducing their dissolved oxygen levels. Changed rainfall dynamics could also see a change in the timing of contaminant deliveries to receiving environments by changing patterns of accumulation and wash-off. That is, while the total load in the long-term may remain stable, the load and concentration transported by individual events may change. In coastal zones, sea level rise due to climate change could result in inundation of drainage infrastructure such as sewer outfalls and pumping stations. This could cause changes in the sewer energy line resulting in lowered drainage efficiency and back flow, especially during storm surge events.

Clearly, urban drainage is an activity which is sensitive to climate change. That is, climate change can be added as a third driver in the DPSIR framework above. In accordance with the IPCC definition cited above, adaptation is then a system response to climate change. In the context of urban water management, the similarity in the impacts associated with population growth, urbanisation and climate change, along with the fact that these drivers are concurrent means that the notion of adaptation could be extended to include the combined response to all three drivers.

2.2 PROJECTED CLIMATE CHANGE FOR AUCKLAND

Regional climate change projections for New Zealand have been published in a range of documents over recent years including in MfE guidance (MfE, 2008a) and are also available online from NIWA[2]. Climate change projections are available for two future periods - 2030-2049 and 2080-2099, referred to as 2040 and 2090 respectively - and six greenhouse gas emission scenarios; B1, A1T, B2, A1B, A2 and A1FI (IPCC, 2000). These projections were obtained from an ensemble of 12 global circulation models (GCMs). Projected seasonal and annual changes in temperature and rainfall are reproduced for the region from MfE (2008a) in Tables 1 and 2.

Table 1: Projected changes in seasonal and annual mean temperature (in °C) from 1990 to 2040 and to 2090, for the Auckland region. The average change, and the lower and upper limits (in brackets) over the 6 gas emission scenarios are given (Source: MfE, 2008a).

Period	Summer	Autumn	Winter	Spring	Annual
1990-2040	1.1 [0.3, 2.6]	1.0 [0.2, 2.8]	0.9 [0.2, 2.4]	0.8 [0.1, 2.2]	0.9 [0.2, 2.5]
1990-2090	2.3 [0.8, 6.5]	2.1 [0.6, 5.9]	2.0 [0.5, 5.5]	1.9 [0.4, 5.4]	2.1 [0.6, 5.8]

Note: This table covers the period from 1990 (1980-1999) to 2040 (2030–2049) and to 2090 (2080–2099), based on downscaled temperature changes for 12 global climate models, re-scaled to match the IPCC global warming range for 6 illustrative emission scenarios (B1, A1T, B2, A1B, A2, and A1FI).

Table 2: Projected changes for selected stations within the Auckland Region in seasonal and annual precipitation (%) from 1990 to 2040 and to 2090. The average change, and the lower and upper limits (in brackets) over the 6 gas emission scenarios are given (Source: MfE, 2008a)

Period	Location	Summer	Autumn	Winter	Spring	Annual
1990 - 2040	Warkworth	1 [-16, 20]	1 [-13, 22]	-4 [-22, 2]	-6 [-18, 6]	-3 [-13, 5]
	Mangere	1 [-17, 20]	1 [-14, 17]	-1 [-10, 5]	-5 [-15, 10]	-1 [-10, 6]
1990 2090	Warkworth	-2 [-31, 20]	-1 [-20, 12]	-4 [-24, 5]	-12 [-33, 6]	-5 [-19, 6]
	Mangere	-1 [-33, 20]	-2 [-21, 12]	-1 [-12, 9]	-9 [-30, 11]	-3 [-13, 9]

Note: This table covers the period from 1990 (1980-1999) to 2090 (2080–2099), based on downscaled precipitation changes for 12 global climate models, re-scaled to match the IPCC global warming range for 6 indicative emission scenarios.

The main features of climate projections within the Auckland Region are:

- Increased mean temperature;

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[2] http://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios (date last accessed 28/2/2011)

- Fewer cold temperature episodes and increase in number and intensity of high temperature episodes;
- Decreased mean rainfall, notably in spring which could result in increased drought risk; and
- Increased frequency and intensity of extreme rainfall events.

3 CASE-STUDY TOOLS

As stated above, the *Urban Impacts of Climate Change* tool-box consists of five trays, each relating to a different stage in the adaptation evaluation process and containing a range of tools that demonstrate this process for a range of weather-related natural hazards. The Auckland case-study resulted in six interlinked tools. The position of these tools in relation to the tool-box is shown in Figure 2. The objectives and contents of each of the tools are summarised in the sections below.

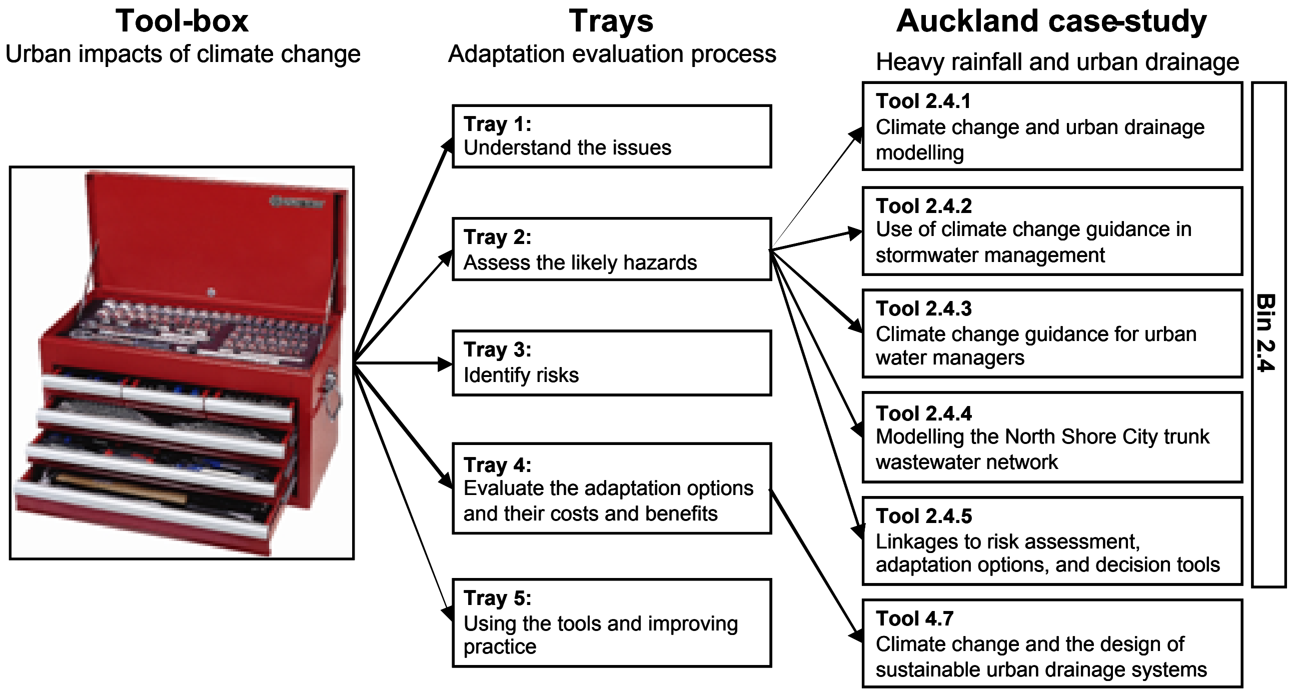

Figure 2 Urban impacts tool-box showing trays and the tools developed for the Auckland case-study.

Tool 2.4.1 Climate change and urban drainage modelling – data, issues and assumptions

According to MfE guidance material (2008a and b, 2009, 2010), modelling is a key component of hazard and risk assessment and is used to both identify and quantify potential impacts of hazards sensitive to climate change. This tool overviews the issues and assumptions involved in urban drainage modelling.

The key points made are:

- Models chosen should be robust with a demonstrable ability to simulate flow over the range of projected climatic and hydrological conditions. Model choice should reflect the purpose of the assessment, the scale of the relevant processes and data availability.

- Typical model applications in urban areas include flood hazard mapping and evaluations of waste- and stormwater network capacity. The former application generally uses event-based simulation of extreme events with simplified flow assumptions whereas the latter requires continuous simulation with detailed representations of the drainage network.

- Rainfall is the main climatic driver of urban flows. There are a number of methods that can be used to simulate changes in rainfall according to climate change projections including:

    - Adjustment of extreme rainfalls for event based simulations.

    - Adjustment of historical rainfall records for continuous simulation.

    - Direct input of synthetic rainfall records for continuous simulation.

- Each of these choices has associated uncertainties relating to amongst others, discordant scales between atmospheric and drainage processes, methods of downscaling, disaggregation and aggregation and the assumptions of the underlying climate projection. For this reason, models should be run for more than one climate projection to ascertain the level of model sensitivity.

- Changes in population, urban form and land use intensity, drainage networks and management practices can be simulated by changing the parameters which govern flow such as imperviousness, pipe roughness and internal storage capacity. Sea level rise can be simulated by changing the model boundary conditions.

- No published examples of urban water quality modelling for climate change impact assessment were found.

Tool 2.4.2 Incorporating climate change into urban stormwater management: current practices

This tool investigates how climate change guidance available in the region is being used by stormwater practitioners in Auckland and how they apply this guidance with respect to stormwater quantity control. The results are presented in two parts:

1. Stormwater Practitioner Interviews

2. Regional Literature Review

A total of seven interviews were undertaken with representatives from predominantly urban councils (pre-amalgamation) and the New Zealand Transport Agency (NZTA). Each practitioner was asked the following questions:

- What climate change guidance material does the organisation use to inform stormwater management?

- How is this guidance material applied to plan for and manage urban stormwater?

- What has been prepared or implemented for stormwater management as a result of climate change assessments (e.g. adjustments to stormwater models, updated flood hazard maps, plan/policy changes, etc.)?

- Are there any gaps in current climate change guidance material for stormwater management? If so, do you have any suggestions for guidance improvement?

The literature cited was largely concerned with modelling urban drainage systems for either flood risk assessment or to assess whether sewer networks have the capacity necessary to maintain current target levels of service. The studies overviewed were:

- Modelling of stormwater flows through the Wairau Valley by the North Shore City Council (NSCC; URS, 2004, Shaw *et al.*, 2005)

- Auckland Integrated Catchment Study (ICS), Auckland City Council and Metrowater (Kinley *et al.*, 2007; Dayananada *et al.,* 2005)

- NSCC Stormwater Catchment Management Plans (2009 a and b)

- Regional Rapid Flood Hazard Mapping (RFHM) carried out by DHI for ARC (Roberts and van Kalken, 2010)

- Impact assessment of the NSCC wastewater trunk network (Lockie and Brown; 2010 a)

The tool largely illustrates how stormwater models are being used to determine the possible impacts of climate change on urban stormwater systems. Note that while the focus is on stormwater, wastewater was included in the literature review. This is because wastewater overflows following heavy rainfalls are a major issue in the city and much of the work to date has been to assess the possible impacts of climate change on the hydraulic loads in sanitary sewers.

Both the interviews and literature search found that the primary source of guidance material used by local authorities is the MfE publication Red book (MfE 2008b) or its first edition (MfE, 2004). Auckland Regional Council (ARC) guidance for constructing design storms and simulating surface flows (TP 108, ARC 1999 b) is widely referenced by interviewees and in the literature. It was noted that this document precedes both the RMA 2004 Climate Change Amendment and the MfE guidelines and therefore does not include guidance for climate change. However, TP 108 is currently under review and the revised document is likely to include climate chance guidance with reference to MfE guidance. It is hoped that by including reference to climate change, the document will provide practitioners with more regionally consistent guidance. Practitioners are still seeking more detailed guidance than that which is provided nationally, to inform management decisions and engineering design for stormwater management at the local level.

Tool 2.4.3 Climate Change Guidance Material for Urban Stormwater Management

The purpose of this tool is to provide a stock-take of guidance material available to urban stormwater managers in the Auckland region. The tool is split into two sections. The first is a summary of the regulatory framework relevant to stormwater management noting where climate change is addressed in relation to stormwater. The second and main section is 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.

Many of the planning documents in the Auckland region pre-date the RMA 2004 amendment which requires the impacts of climate change to be taken into account as part of resource management. Hence, there are relatively few mentions of climate change in relation to stormwater management. The newly amalgamated Auckland Council is preparing a new plan which will supersede the current regional and district plans (i.e., the Unitary Plan).

The technical guidance material can be split into two groups. In the first group are the Ministry for the Environment documents cited above (MfE, 2008 a and b, 2009, 2010). The second group consists of national and regional design criteria for drainage infrastructure including those for low impact design.

The MfE documents have a strong emphasis on natural hazard risk identification and management including evaluation of adaptation strategies. These documents follow a risk assessment process to help plan for adaptation where needed to reduce the identified risks associated with climate change. While there was little specific mention of stormwater in the guidance, it was pointed out in both the Coastal Hazards (MfE, 2009) and Flooding (MfE, 2010) guidance that the way in which stormwater is managed could have an impact on the risks of natural hazards in urban areas and their receiving environments. For instance, failure of stormwater systems during peak flows could exacerbate the risks of river and coastal flooding. While the links may not be explicitly addressed in the guidance, they are assumed to be part of the tacit knowledge of stormwater practitioners.

The national design criteria reviewed were NZS4404:2010 (Land Development and Subdivision Infrastructure) and the Stormwater Treatment Standard for State Highway Infrastructure (NZTA, 2010). These documents incorporate the guidance from MfE into the design process, largely by adjusting design-storms for a mid-range temperature projection according to the MfE method of adjusting extreme rainfalls. The regional guidance documents were TP 10 (ARC, 2003) and TP 108 (ARC, 1999 b). While they do not mention climate change, they are under review and the updated versions are likely to refer to MfE for climate change guidance.

Tool 2.4.4 Modelling the North Shore City Council wastewater network: a case-study of potential climate change impacts

This tool provides an example of a risk assessment using an existing urban drainage model of the NSCC wastewater trunk network. It presents work commissioned by NIWA that was carried out by NSCC (Lockie and Brown, 2010a). Aspects of this work have previously been presented at the Water New Zealand Annual conference (Lockie and Brown, 2010b). As synthetic climate data were available for only one climate change projection, the study is not fully consistent with MfE (2008a) guidelines for risk assessment. None-the-less, it can provide an insight into real-world modelling applications.

There were two sets of objectives. The objectives for NIWA were to:

- provide an example of how a risk assessment of an urban drainage system can be undertaken using an existing operational model; and
- demonstrate use of output from NIWA's Regional Climate Model (RCM) in a real-world application.

The objectives for NSCC were to:

- assess the possible effect of climate change on the NSCC trunk wastewater network; and

- assess the impact of accounting for climate change (i.e., adaptation) to maintain the target level of service on the costs of the proposed capital works programme.

The impact of climate change was assessed using a MOUSE model of the trunk network which was developed by NSCC as part of Project CARE to aid the planning of a capital works programme to upgrade the network. Overflows from the network following high intensity rainfall events have been identified as a major source of contamination to coastal receiving environments. Rain dependant flows enter the separated sewer network as sewer infiltration or inflow. At present, there are around 12 overflow events per year. The planned capital works are needed to limit the number of city-wide overflows to a target of no more than two events per year.

The model was forced using synthetic rainfall data generated by the RCM. Two 30-year synthetic series were supplied representing current (1970-2000) and future (2070-2100) climate. These series were split and the model run for the first and last decade of each. The model was also forced using the same historical rainfall record which was used by NSCC to evaluate present network performance. An analysis of extreme rainfalls found that the historical rainfall series has higher intensity rainfalls for all event durations investigated than both the current and future synthetic rainfall series. This is an ongoing research issue, and an identified limitation of the use of these synthetic data.

All the model runs assume city growth to 2060 and network deterioration due to development driven by growth. Model runs were made both with and without network deterioration due to aging.

The implications of climate change to the estimated cost of the capital works programme were evaluated by scaling the costs estimated using the historical record by the relative change in costs estimated for the two synthetic rainfall records. Costs due to climate change were estimated assuming adaptation as part of the capital works (i.e., anticipated climate change) and delayed adaptation carried out 10 years after the capital works (i.e., unanticipated climate change). It was found that the former is more cost effective than the latter.

With the assumption of network deterioration due to aging, anticipated climate change adds a maximum of 14% to the overall costs compared to between 30 and 45% for unanticipated climate change. If no network aging is assumed, the costs of the planned capital works estimated with the historical rainfall record drops to $314 million. Adaptation for anticipated climate change increases this estimate to between $320 and $373 million. Thus, the cost implications of adapting to climate change are less than that of accounting for network aging.

Tool 2.4.5 Linkages to risk assessment, adaptation options and decision tools

Each of the Tray 2 bins for the five case-studies has a *Linkages* tool. The purpose of these tools is to cross-reference the information specific to each case-study to other tools located elsewhere in the tool-box. For instance, readers wanting basic information on how to carry out a risk assessment would be directed to Tool 1.3 (Understand the issues: An introduction to risk assessment). Similarly, readers will be directed to Tray 3 for more detail and examples of asset management, risk identification and planning aspects such as urban growth; and to Tray 4 for more detail for a range of methods for adaptation options and decision. The intention is to enable people to work out what information and methods are going to be most useful for them, depending on where they are in the evaluation processes and what their primary risks or concerns are.

Tool 4.7 Stormwater management devices as climate change adaptation options

The ability of stormwater management devices to both treat stormwater and modify flows has led to their being an increasingly common sight in Auckland's urban landscape. The city's receiving environments face increased risk of degradation due to urbanisation and use of management devices has been encouraged in the region as a means of responding to those risks. Internationally, it has been suggested that these may also be a means of adapting to the risks posed by increased rainfall and rainfall intensity (e.g., Scholz and Yang, 2010; Semadeni-Davies et al., 2008 a and b; Ashley et al., 2008; Shaw et al., 2007; Watt et al., 2003). This tool investigates the implications of incorporating climate change into the design of management devices with respect to sizing. Possible adaptation strategies using these devices are also discussed. The devices investigated are ponds and raingardens. These differ in their location in the drainage network, function, level of capital expenditure and their scale of operation

This tool uses locally available guidance on climate change adaptation (MfE, 2008a) and stormwater design (ARC, 2003) to investigate how device design may change over the coming decades. Design rainfalls were adjusted for incremental increases in annual temperature over the range of projected climate change (up to 6ºC) and imperviousness was increased to simulate land use intensification (from 30 to 90% for ponds and 100% for raingardens). The goal was to develop a method which can be used to display the range of possible changes in the size of devices in the context of both climate change and increasing imperviousness. Such a method could be used to communicate uncertainty in design to stakeholders and to aid in their understanding of the varying needs for adaptation. The resulting response-curves are intended to aid stakeholders engaged in decision making as part of preliminary screening for planning adaptation strategies. Response-curves can display outputs for multiple scenarios allowing easy comparisons to be made.

Volume and surface area response-curves were created for ponds and raingardens which are stormwater management devices that have different functions and operate at different spatial scales. The example below shows the change in pond surface area that would be required to detain the flow generated by a 10-year, 24-hour rainfall (taken from NIWA's High Intensity Rainfall Design System, HIRDS, online at www.hirds.niwa.co.nz). It is assumed that the pond has a depth of 2m at the water quality volume level (WQV) and a trapezoid bathymetry with side slopes of 1:3. The pond has a length-to-with ratio at the WQV of 1:3. Peak runoff was calculated using the method given in TP 108 (ARC, 1999 b). The initial abstraction was 0 and 0.5 mm for impervious and permeable surfaces respectively and the curve number for permeable surfaces was set to 70. The catchment area is 4 ha. Marked on the response-curve are MfE (2008a) minimum, mean and maximum temperature change projections for both 2040 and 2090. The maximum increase represents an extreme and NIWA suggest a risk-averse projection of 4°C by 2090 be used as an outer boundary, this projection is also marked. It can be seen that the size of the pond required varies greatly depending on the climate projection and the level of imperviousness. It is also apparent that the 2040 and 2090 projections overlap.

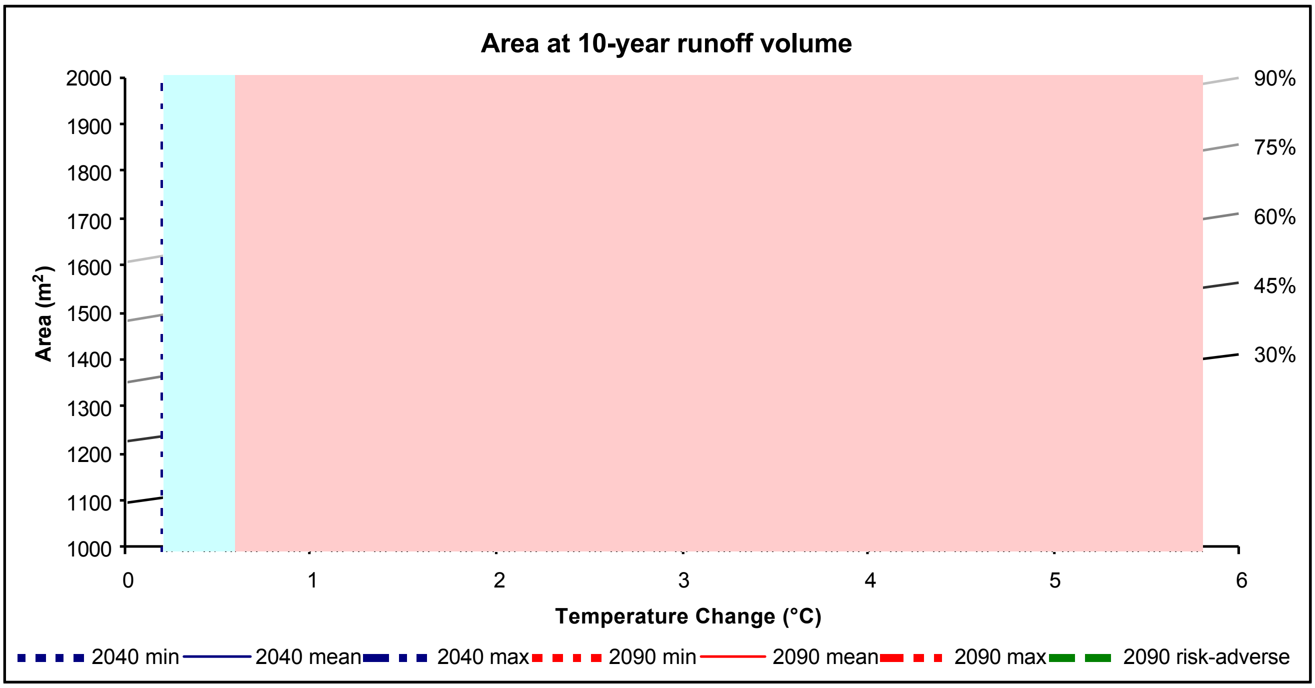

Figure 3 Pond area at the 10-year design-storm runoff level calculated for design-storms adjusted by incremental changes in temperature. Catchment area is 4 ha. Curves are shown for five different levels of imperviousness in the range 30 to 90%. MfE (2008a) temperature projection bands for 2040 and 2090 are overlaid.

The potential use of response-curves to aid adaptation planning was demonstrated for hypothetical climate and land use change scenarios. It was suggested that an incremental adaptation strategy, whereby adaptation traces changes in risk over time, is appropriate for ponds. Increasing imperviousness and rainfall both increase the storage demand of ponds. Pond design is at least as sensitive to imperviousness as to changes in design rainfall. It was postulated that sizing ponds for future conditions today could lead to ponds which are either undersized or oversized tomorrow if the land use / climate change scenario chosen does not match actual change. Additionally, even if ponds are correctly sized for a future 70 years hence, they may be incorrectly sized for current conditions leading to poor performance in the interim.

In contrast to ponds, raingardens generally serve solely impervious surfaces so any increase in imperviousness would be met with an increase in the number of raingardens during development rather than resizing. Moreover, the relative size of raingardens and the fact that climate change is likely to have a minor impact on sizing means that it may be more appropriate to design them for climate change adaptation from the outset.

4 CONCLUSIONS

This paper has presented and overviewed the six tools specific to urban stormwater management prepared for inclusion in the *Urban Impacts of Climate Change* tool-box. The tool-box is being developed as part of a FRST-funded programme by NIWA and partners MWH New Zealand Limited, BRANZ and GNS. The tool-box is intended to aid central and local government to reduce the risks associated with climate change to the urban environment and its infrastructure, through development of a science-based risk assessment process and identification of opportunities for adaptation.

The urban stormwater management tools draw on the Auckland 'heavy rainfall and urban drainage' case-study undertaken as part of the research programme. Five of the tools are grouped together in Tray 2 (Assess the hazards) and variously address the nature of guidance material available to stormwater managers and the way this material has been utilised by them in the Auckland region. Much of the work to date has been using models to assess the possible impacts of climate change on flood risk and network capacity. The sixth report is in Tray 4 and investigates the implications of climate change on the design of treatment devices. It was noted the devices are a possible option for adaptation which requires them to be designed either for future conditions at the time of construction or with the ability to adapt them if and when the need arises.

ACKNOWLEDGEMENTS

This paper has been prepared with funding from the NZ Foundation for Research Science and Technology: Climate Change and Urban Impacts (FRST contract number C01X0805) project.

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