Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Tool 2.4.2: Incorporating climate change into urban stormwater management

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1. Introduction

This tool investigates how climate change guidance [overviewed in Tool 2.4.3] is currently being used by stormwater practitioners in Auckland Councils 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

The tool largely illustrates how stormwater models are being used to determine the possible impacts of climate change on urban stormwater systems. Note that the interviews and literature review were carried out prior to the amalgamation of the ARC and the territorial authorities and therefore describe the situation before November 2010.

2. Stormwater Practitioner interviews

A series of interviews with Auckland stormwater practitioners was conducted between March and May 2010 to determine how climate change guidance is being used by local government to inform stormwater management across the region. The purpose of the interviews was to gain an insight into how key climate change guidance documents are being applied in practice.

Interviewees were identified and selected in discussion with the Auckland Regional Council and included stormwater practitioners across a range of professions (e.g. engineering, policy and planning, GIS, asset management). A total of seven interviews were undertaken with representatives from predominantly urban councils (pre-amalgamation) and the New Zealand Transport Agency. Interviews were conducted by telephone, in person and via email.

Interviewees were asked four questions:

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

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

3. 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.)?

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

The responses were analysed to identify key themes and specific comments. The key points made by interviewees about how climate change guidance has been used to inform urban stormwater management are detailed below. Information has been presented under four themes – use of guidance, outcome of climate change assessments, general comments and recommendations for improving guidance.

2.1 Results - Use of Climate Change Guidance for Stormwater Management

- The key guidance document for climate change and stormwater management used by local councils in the Auckland region is the Ministry for the Environment *'Preparing for Climate Change'* guidance manual (MfE, 2008). This was most commonly used to determine percentage adjustments per degree of warming for extreme rainfalls.

- Most organisations had selected the change in *annual mean temperature* based on a mid-range projection for the Auckland region, relative to 1990, as the parameter used to assess the effect of climate change on extreme rainfall.

- One council had used *mean high water spring* tide (highest level to which spring tides reach on the average) as a downstream boundary condition for modelling the effects of sea level changes on stormwater outfall discharges. This was seen as a more 'conservative' approach to defining sea level (compared with the use of the lower datum of *Mean Sea Level* used by other councils). For this reason, the council did not consider it necessary to include adjustments for sea level rise in stormwater models for the city.

- Technical Publication 108 '*Guidelines for Stormwater Runoff Modelling in the Auckland Region*' (ARC, 1999) provides a recommended method for rainfall-runoff modelling in the Auckland region. At the time of the interviews, TP108 did not include any information on adjustments for climate change. However, this document is under review and it was noted by several practitioners that the revised version is likely to reference climate change guidance provided by MfE as it relates to calculations for extreme rainfall and runoff.

- Most interviewees commented that it was costly to run stormwater models for multiple climate change scenarios, particularly for continuous modelling. The cost of modelling further increased with inclusion of multiple climate change variables or greater model sophistication. Affordability was highlighted as the main reason why only one climate change scenario is commonly used to inform stormwater management.

- One city council had directly engaged NIWA to assess the impacts of climate change on high intensity rainfall in their city and to revise design rainfall intensity duration statistics accordingly.

2.2 Results - Stormwater actions resulting from climate change assessments

The most common actions that local councils have taken following assessments on the impact of climate change on extreme rainfall are:

- Adjustments to city-wide, or catchment- specific, flood hazard maps to illustrate the future extent of flood risk and highlight overland flow paths that require protection (see the literature search for examples);

- Changes to the District Plan to introduce specific controls in areas at risk of future flooding (e.g. activity status and consent assessment criteria, specification of freeboard levels);

- Modifications to engineering design standards to incorporate climate change adjusted rainfall intensity and duration values and guidance on appropriate design solutions.

2.3 Results - General comments about climate change guidance for stormwater management

- The most significant cost to councils in terms of infrastructure investment is the decision to make an investment (i.e. new build or upgrade existing assets). Once this decision has been made, it is relatively inexpensive to marginally increase stormwater pipe diameters to adjust the capacity to accommodate changes in rainfall associated with climate change.

- One interviewee commented that many councils are actively working to meet *current* levels of service for flood control (i.e. they are not meeting specified levels of service for stormwater management). Taking into account effects of climate change that are beyond the 10-20 year planning horizon for flood mitigation and asset management is challenging and not often viewed as a priority.

- One council found that the effects of climate change on flooding were insignificant in comparison to the change in impervious surface associated with urban development and intensification over time.

- There is a need to ensure that asset management plans are flexible and responsive to new information on climate change. It was suggested this would help to integrate the short term planning horizon for asset management and the longer term impacts of climate change.

- One of the interviewees found that political perspectives on climate change have a significant influence on the ability of council officers to integrate the effects of climate change into city-wide planning and decision making for stormwater management.

- Most councils have developed a method for assessing the joint probability and impact of multiple climate change effects (e.g. sea level rise and storm surge with increasing intensity of rainfall) on stormwater assets. Most interviewees commented there is potential to improve methodologies and enhance consistency in approaches across organisations.

2.4 Results - Opportunities for improving climate change guidance for stormwater management

- Regional consistency

  There was an interest in the provision of guidance to improve regional consistency for incorporating the effects of climate change into stormwater modelling, with specific reference to:

  - assessing the effects of sea level rise (SLR) / storm surge (SS)
  - undertaking joint probability assessments for climate change variables (e.g. extreme rainfall coupled with SLR/SS).

- Locally-specific information on climate change effects

Most councils have access to good quality 'high level' information (what scale is this? International / national / regional scale?) on how climate change may impact on stormwater management. There is a real need, however, for locally-specific information at a finer resolution (what scale does this mean?) for detailed analysis which can inform more accurate outcomes.

- Practical guidance materials

There is an interest in the development of 'practical guides' on climate change to translate 'heavy climate science' into useable information specific to practitioners (e.g. stormwater engineers, stormwater modellers, asset managers). Examples suggested by interviewees include:

- Guidance on climate change projections for use in engineering design. It was noted that the use of a mid-range projection is advocated by MfE for undertaking 'risk assessments'; however there is little guidance on how to select appropriate parameters for engineering design. One practitioner provided the example that use of a low projection for engineering design could result in undersized infrastructure that requires costly adaptation or replacement at a later date while a high (precautionary) projection could result in oversized infrastructure at significant expense to the asset owner.

- Guidance on when an impact indicated by preliminary analysis should be considered to be of enough significance, with respect to investment and environmental / social impacts, to require detailed analysis and consideration of adaptation.

- Guidance on how to incorporate climate change considerations (e.g. assessment results) into contingency plans and monitoring regimes for existing stormwater infrastructure. In particular, guidance on how to determine when an adaptation response such as retrofitting or replacement of stormwater infrastructure should be triggered (e.g. what reduction in service level).

- Guidance on integrating climate change adaptation into decision making for activities that have multiple management objectives. An example was given where stormwater management objectives may include delivering a specified level of service, preserving the environment, protecting human health and minimising risk to property. Each may have different implications for stormwater management and may not be compatible with the others. Practitioners are seeking guidance on how to evaluate adaptation options across multiple criteria (e.g. social, cultural, environmental, and financial) to make informed asset management decisions.

- Guidance on the links between the aims for sustainable stormwater management and climate change adaptation. Can adoption of integrated "three-waters" (water supply, waste water and stormwater) management result in a climate change resilient city?

3. Literature search

The literature search was undertaken to identify projects in the Auckland region carried out by local government that have taken climate change into account and to determine the extent to which the available guidance material overviewed in [Tool 2.4.3] informed these projects. For the most part, the literature has been published in national conference proceedings or as internal planning documents. The main areas where climate change has been considered are flood risk mapping at the catchment and regional scales, and assessment of the capacity of drainage infrastructure, notably combined sewers, to accommodate climate change. In both cases, urban drainage modelling is the primary method of assessing the possible impacts of climate change [see Tool 2.4.1 for general modelling advice].

3.1 Wairau Valley Catchment (2004-5)

Modelling of stormwater flows through the flood-prone Wairau Valley was carried out as part of the North Shore City Council's (NSCC) Project Care to evaluate the need for both current and future up-grades to the system (URS, 2004, Shaw *et al.*, 2005). Shaw et al. (2005) is of particular interest here as it follows the first edition of MfE climate change risk assessment guidelines (2004) and is included as a best-practice case-study in the revised guidelines (MfE, 2008). Shaw et al. (2005) go through the following steps in accordance with MfE advice:

1) Establishing the context.

2) Identification of the factors which could influence the response of urban drainage to climate change both with respect to climatic drivers and catchment characteristics.

3) Preliminary screening to evaluate sensitivity.

4) Detailed assessment using continuous modelling forced with stochastically generated rainfall series to determine the range of impacts possible. .

5) Evaluation and decision making.

1) Establishing the context

The context was: identification of urban drainage management as an activity sensitive to climate change.

2) Identification of influencing factors

In the second step, the factors which influence the response of urban drainage to climate change both were identified as xx xx

3) Preliminary screening

Preliminary screening was undertaken using a simplified MOUSE (DHI) representation of surface runoff generation (simulated using the MOUSE RDII module), attenuation in ponds and channel flow. The stormwater drainage system consisted of three sub-catchments drained by open channels, with a number of in-line wet detention ponds and a total catchment imperviousness of 47%.

The preliminary assessment showed that there is a potentially significant impact of climate on drainage in the area which warranted further investigation. It was shown that sub-catchment runoff volumes can increase by between 13-42% depending on the level of imperviousness and the climate scenario simulated. While the impact on stream water levels was fairly low in general, a number of sites were identified where increasing the 10-year rainfall could lead to bank breaches and flooding.

4) Detailed assessment

Continuous model runs were compared with event-based runs to assess determine the potential catchment management and infrastructure design implications of each approach.

The first step of the detailed assessment was to create artificial rainfall series; four series were generated, one for current rainfall and three climate change projections based on NIWA high, medium and low regional climate change scenarios:

- ***Future 1*: A 5% increase in mean monthly rainfall, leaving wet/dry periods unchanged.

- ***Future 2*: An increase in the proportion of dry days by 5% and the mean rainfall by 5%.

- ***Future 3*: An increase in the proportion of dry days by 10% and an increase in the mean rainfall by 5%.

Each series consisted of five 30-year rainfall blocks, i.e., 150 years of data per scenario. The series were created using a stochastic weather generator (Cowpertwait, 2003).

Design storms were created from the stochastic rainfall series to assess the potential impact of extreme events following the same method that was used to derive the design-storms in TP108 (ARC, 1999). It was stated that to properly compare dynamic and design-storm model results, the design storms should be derived from the same rainfall data used in the dynamic modelling. The authors noted that the detailed modelling is likely to have greater uncertainty due to the increased sophistication of the scenario creation.

Results were reported in Shaw et al. (2005) and URS (2004) for the Future 3 scenario. It was found that:

- Both the design storm and dynamic modelling approaches predict increased inundation, the predicted impact was greatest for the design storm modelling and had flows 10 to 15% greater with greater flood extents and depths projected.

- Catchment characteristics and infrastructure can influence the modelled flows and level of inundation. It was speculated that dynamic modelling gives a more realistic picture of long-term catchment response to climate change, this method points to a lower need for future adaptation.

5) Evaluation and decision making

<u>It was noted that the assessment results should be evaluated with respect to cultural, social, environmental and economic values.</u>

The implications of climate change for up-grades and were discussed in the URS report (2004), however, no decisions had been made at the time. The estimated up-grade costs on the basis of both the dynamic and design-storm model results was $28m, this rose to $32m or $44m respectively for the future 3 scenario. At the time the paper was written, the authors planned to consult with the public to evaluate different options to reduce identified risks.

Summaries of both reports can be found at the MfE website;

http://www.mfe.govt.nz/publications/climate/case-study-wairau-catchment-aug04/case-study-wairau-catchment-aug04.pdf

http://www.mfe.govt.nz/publications/climate/effects-impacts-may04/html/page6.html

3.2 Auckland Integrated Catchment Study

As part of the Auckland Integrated Catchment Study (ICS), Auckland City Council and Metrowater (Kinley *et al.*, 2007; Dayananada *et al.*, 2005) reported on a set of flow simulations for future scenarios which included both urbanisation (i.e., population and imperviousness) and climate change (i.e., rainfall and sea level). The simulations were carried out using a simplified MOUSE representation of the city's trunk and principal local wastewater system, called the Global Model, which includes some combined sewers.

The scenarios are outlined below:

- **Population** – the trend in population between the time of the study and the previous census in 2001 was used to determine the population projection for 2051. The increased population was distributed around growth nodes.

- **Imperviousness** was assumed to increase to Maximum Probable Development level (MPD, i.e., the most intense level permitted by the District Plan) by 2051, unless it was already above MPD, in which case it was assumed to remain constant. No zoning changes beyond those proposed as District Plan Changes were included.

- **Extreme rainfall (flood hazard mapping)** – design-storms from both Auckland City and TP108 (ARC, 1999) were used in the flood risk assessment. Both sets of design storms have average recurrence intervals (ARIs) of 10, 50 and 100 years. The Auckland City design storms are derived from historical rainfalls observed at Albert Park and had durations of between 10 minutes to 24 hours. The TP108 rainfalls have a 24-hour duration. The Auckland City design storms have variable temporal distributions whereas the

TP108 design storms assume a Chicago hyetograph. The storms were adjusted for climate change according to Salinger *et al.* (2001). The climate change projection used was for 2050.

- **Rainfall time series (network performance) -** rainfall was stochastically generated for 100-year time-blocks representing current and future rainfall using the same method as for the Wairau Valley (Cowpertwait, 2002). Three sets of 100-years of "2050 rainfall" were generated at 12 locations in the city corresponding to permanent rain gauge sites. These represented three future scenarios: least change from existing; most probable change from existing; and most change from existing. The method was later tested by Cowpertwait *et al.* (2006) by comparing simulated (MOUSE) flows in Auckland's wastewater and combined sewer system. In the later application, historical 5-minute rainfall data from six sites across the Auckland City were aggregated into one-hour blocks which were then disaggregated into artificial 5-minutes rainfall series. The flows simulated with the historical and artificial series were comparable.

The results of the modelling for these different scenarios are described in the following three sections.

3.2.1 Flood risk assessment

Flood risk was simulated in three catchments with different landuses and topography. It was found that the differences in results generated by Auckland City and TP108 design storms were within the range of model error, for this reason, the climate change impact assessment was carried out using only the TP108 design-storms. Simulations were made with and without adjustments to sea level. No changes were made to the drainage parameters for the different runs. Flood risk was assessed with respect to the depth of inundation at outflow points including drains and manholes.

It was found that for a given ARI, the flood depths differed little between the different climate scenarios, generally within the accuracy of the model (i.e. by less than 0.1 m). However, when sea level rise was included in the simulation, the flood depths in coastal areas were generally 0.2 m higher than those simulated with increased rainfall alone, which has implications for water management and flood protection in low-land areas close to the sea.

This study is one of those reported in a recent review of flood risk assessments for climate change by Davis et al. (2010).

3.2.2 Network capacity

Five-year blocks of current and future climate stochastic rainfall were selected from the 100-year series for simulation of the waste water network in five key catchments with differing physical characteristics. The model was run with and without the population and imperviousness scenarios.

The results of the impact assessment were not reported by Kinley *et al.* (2007) and have not been published to date. However, Davis (2008, pers. comm.; formerly Metrowater ICS project director, now at the Auckland Council) states that the relative impact of climate change could not be distinguished above the noise of the model. That is, the difference between "present" and "future" system performance due to climate change was within the accuracy of the flow model. In contrast, the impact of population change and increased imperviousness was evident.

3.2.3 Impact of sea level on urban drainage

The flood hazard simulations showed that sea level has an impact on flows in the catchments simulated. This raised the question of whether there is a historical relationship between sea level, particularly storm surge, and high flow events including back flow in pipes and overflows. Recorded sea levels at Queen's Wharf between 1972 and 1999 were evaluated against number of weather related variables including rainfall depth, air pressure, wind velocity and temperature to determine whether it is possible to predict storm surge. The relationships were tested by hindcasting sea level back to 1910 and subsequently used to project sea level for 2051-2061. The examination of storm surge showed a poor correlation between extreme rainfall events and storm surge for Auckland City. Moreover, there is a threshold below which flooding does not occur. As none of the existing outflow structures for the wastewater and combined sewers are below the maximum height value, even with the predicted climate change induced sea level rise included, overflows may not be affected by sea level..

3.3 North Shore City Stormwater Catchment Management Plans (2008-9)

Adjusting design storms for climate change was standard for the preparation of stormwater catchment management plans (SWCMP) in North Shore City. Plans have been completed for the Lucas Creek and Eskdale catchments (NSCC, 2009a, 2009b). The use of climate change guidance is illustrated here for Lucas Creek. The SWCMP management outcomes sought with respect to flooding are to:

- Reduce the effects of flooding on properties;

- Maintain and enhance the flow capacity of the stream channel; and
- Provide and maintain a public stormwater drainage system to a high standard including flow control for new or re-developments.

The modelling methodology to simulate network capacity and flooding in Lucas Creek is detailed in Appendix D of the SWCMP which was published as a separate document (NSCC, 2008). The TP108 (ARC, 1999) method was used to derive runoff volumes from the design rainfalls. MOUSE was used to simulate flow pathways, including detention basins, and channel hydraulics to determine overflow nodes and flood depth. The model set-up was calibrated against historical flow records. The model set up and results are described in the following sections.

3.3.1 Land use and climate change scenarios

The catchment (626 ha) is currently around 50% urbanised and imperviousness is 17%. There is scope for future urbanisation up to the MPD under the current District Plan which is almost 70%. For this reason, the network capacity modelling was carried out with both current and future levels of imperviousness.

The stormwater network was simulated for the 24-hour, 2-, 5-, 10-, 20-, 50 and 100-year design storms taken from TP108 (ARC, 1999). These design storms were adjusted for a 2°C increase in annual temperature according to MfE (2004) guidelines (see Table 3.1). In all there were 12 model runs, that is, one for each unique combination of current and future projections of land use (imperviousness) and design-storm.

Table 3.1: 24-hour Design rainfall depths for various storm events used in the preparation of the Lucas Creek SWCMP (reproduced from NSCC, 2008)

Design Rainfall Event (ARI)	Existing 24-hour Design Rainfall Depth (mm)	Future 24-hour Design Rainfall Depth (mm)
2-year	80	88.6
5-year	120	134.2
10-year	143	160.7
20-year	160	180.5
50-year	190	215.1
100-year	220	249.5

3.3.2 Network Capacity

The results of the climate change adjusted model runs are not reported, however, it is noted that the system as it stands is undersized in places. Hence it can be surmised that they will also not cope with future increases in rainfalls. It was found that under free full flow conditions, around 15% of the modelled stormwater drainage pipes do not have the capacity to contain the 10-year design flow – this figure rises to 21% at the MPD level of imperviousness. If backwater constraints are also taken into account, 62% of the modelled pipes would be under surcharge conditions during a 10-year storm event under current development levels, this rises to 74% under the MPD. Moreover, it was noted that all the culverts in the stormwater drainage systems are currently inadequately sized and do not meet the NSCC level of surface.

3.3.3 Flood Hazard Mapping

Flood hazard maps were prepared for the results of the 10- and 100-year flow simulations. The results for the 100-year simulations are included in the review by Davis et al. (2010). The flood extent was simulated using a 1D hydraulic surface flow model; channel morphology and topographic information was derived from both channel surveys and LiDAR (Light Detection and Ranging) surface data. The simulation resulted in 77 properties being identified as potentially at risk of extreme floods, of these, 29 are in locations where there is an opportunity for the council to undertake physical flood protection works.

Commenting on this application with respect to climate change, Davis et al., (2010) report that the difference in flood depth and extent for current and future climate were fairly minor along the steep-sided main channels, however, the spread increases somewhat on flat flood plains. It was also found that some drainage infrastructure may not have sufficient capacity for future flood risk. For instance, inundation was simulated for a section of the Oteha Valley Road drained by a 1650 mm diameter culvert.

3.4 Rapid Flood Hazard Mapping (2009-10)

The ARC Rapid Flood Hazard Mapping (RFHM) programme aims to map flood depth and extent in response to extreme rainfalls (100 year ARI) across the Auckland Region (e.g., van Kalken et al., 2009). The simulations have been made using MIKE 21 (2D surface hydrodynamics: DHI) forced with surface runoff generated by the TP108 calculation method using regional design storms (ARC, 1999). Channel flow was not simulated both to simplify model complexity and reduce run-times.

Surface topography has been taken from a range of sources including interpretation of LiDAR data. The spatial resolution of the simulations varies according to land use. Grid cells range from 10 m in urban area, with the exception of North Shore and some parts of Waitakere which had grids of 1 and 2 m respectively, and 20 to 50 m in rural areas. Model results were compared to those obtained by more traditional methods which couple 1D simulations of channel flow with 2D surface flow routing for a number of catchments with different land uses. It was shown that the simplified method gives comparable results.

The ARC has undertaken to simulate the possible impacts of climate change on flood risk in the region. The assessment was carried out using the same model set-up and boundary conditions as the initial RFHM study but with the 100-year design storms adjusted for 2090 using the MfE (2008) methodology assuming a mid-range 3ºC increase in average annual temperature. For eight catchments simulated, including rural and urban land use, increasing the rainfall intensity increased the flood depth and volume (Roberts and van Kalken, 2010). The impact on flood extent was highly dependent on local topography with greater increases in extent mapped for low-land flood plains compared to upper, steeper reaches.

3.5 Papakura Creek (2009-10)

Flood modelling has been carried out in a study for the Papakura Creek which is partially urbanised in the lower reaches. Modelling commissioned by the ARC was carried out by DHI using MIKE FLOOD for a range of design storms, with and without climate change adjustments. Various tidal conditions were also simulated. While the study was included in the review by Davis et al. (2010), the report has not yet been published and is not publically available.

3.6 North Shore wastewater network capacity (2010)

The potential impacts of climate change on flow conditions in the North Shore wastewater trunk network have been assessed by Lockie and Brown (2010). This modelling application is the subject of [Tool 2.4.4]. As synthetic climate data were available for only one climate change projection, the study does not comply with MfE (2008) guidelines for risk assessment. Nonetheless, it can provide an insight into real-world modelling applications.

There 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

- demonstrate use of output from NIWA's Regional Climate Model (RCM) in a real-world application.

- 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 dependent 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.

3.7 Use of guidance material for modelling

The modelling tasks described in the literature cited above can be separated into two groups; a) long-term assessment of network capacity to identify possible points of failure and overflow characteristics including local inundation, and b) catchment scale flood risk assessment and hazard mapping. The tools used and the way in which guidance material was applied varied between studies. The first task requires detailed hydraulic models of the drainage network run ideally with continuous data. The second task requires event-based hydrodynamic modelling of surface and / or channel flows simulated for design-storms with a range of ARIs. The models of choice in the studies cited were MOUSE for the first task and MIKE 11 or MIKE 21 or both coupled for the second task. The studies either followed the TP108 (ARC, 1999) method of generating surface flows from rainfall or used the DHI RDII module for MOUSE. We were unable to find any reports on the incorporation of climate change into design or assessments of possible climate change impact on water quality or the wider implications of climate change on receiving environments.

The Wairau Valley study (URS, 2004; Shaw et al., 2005) follows the MfE risk assessment process. The study goes through the steps given in the guideline first edition (MfE 2004) and is held as an exemplar of how to go about a climate change risk assessment in the 2008 second edition. This is the only study which carried out both a preliminary and detailed assessment.

The Auckland City ICS (Kinley *et al.*, 2007) and North Shore City trunk sewer (Lockie and Brown, 2010a, 2010b) simulations were both carried out to determine the impact of climate change on long-term waste water sewer performance. In each, it was assumed that since there are already unacceptable incidences of sewer overflows requiring network upgrades, continued urbanisation, network deterioration and projected increases in rainfall would all exacerbate the current situation, hence, preliminary screening was not carried out. The Auckland study simulated flows for three climate change projections; high, medium and low. While the North Shore study noted the importance of a range of climate projections, the study was constrained by data availability and only a mid-range climate projection was simulated.

Flood hazard mapping is generally carried out using design storms. The Auckland ICS climate change risk assessment (Kinley *et al.*, 2007; Dayananada *et al.*, 2005) largely pre-dates the MfE guidelines. However, the method used to adjust design-storms (Salinger et al., 2001) was very similar to that later recommended by MfE (2004, 2008). The other flood mapping exercises used the MfE guidelines to adjust TP108 (ARC, 1999) design storms for a range of climate change projections. In each case, the mean annual temperature projection used to adjust the design storms in these studies was a mid-range value; the standard value for flood modelling adopted by North Shore and the ARC is 3.0ºC. The use of a single mid-range climate projection is consistent with MfE guidance for preliminary screening, however, a range of projections should be used for detailed assessment if the screening indicates significant impacts. Davis et al., (2010) reviewed three of the flood risk assessment studies (Auckland City ICS, Lucas Creek and Papakura Stream) and found that the key findings are very similar; i.e., increases in extreme rainfall have less impact on flood extent than changes in land use and water management. The RFHM (Roberts and van Kalken, 2010) preliminary results concur with this conclusion.

The hydrograph simulated by a rainfall-runoff model is highly dependant on the shape of the hyetograph, that is, changing the rainfall distribution will have an impact on water delivery rates and the peak flow volume. This has implications for flood hazard mapping as the choice of hyetograph will change flood depths and extent. The flood risk assessments cited here were based on TP108 design storms which assume a Chicago hyetograph characterised by a steep peaked rainfall distribution. The Auckland assessment, which simulated flooding for a number of extreme rainfalls with different temporal distributions taken from the historical record as well as the TP108 design storm, found that model results were within the range of model error. For this reason, the TP108 distribution was chosen for the climate change assessment.

It was noted that while practitioners cited the need to undertake assessments with multiple climate change projections, models are often run for only one, usually mid-range, projection. Limited access to climate change data and costs associated with modelling are cited as constraints.

4. Conclusion

This purpose of this tool is to determine what climate change guidance material is currently being used to inform stormwater management by local government in the Auckland region.

The results of practitioner interviews and a literature search were presented. Both the interviews and literature review found that the MfE 'Preparing for Climate Change' guidance manual (2008) is the main source of climate change guidance used to inform stormwater management in the Auckland region. MfE guidance for the assessing the impacts of sea level rise (MfE, 2009) and flood risk (MfE, 2010) were also cited as tools used by stormwater practitioners. These three documents are summarised in relation to stormwater management in [Tool 2.4.3].

ARC guidance for constructing design storms and simulating surface flows (TP 108, ARC 1999) and designing treatment devices (TP 10, ARC, 2003) were widely referenced by interviewees and in the literature, it is noted that these document precede MfE guidelines and do not include guidance for climate change. However, both of the ARC documents are currently being updated and revised versions are intended to include climate chance guidance with reference to MfE materials. It is hoped that by including reference to climate change, these documents will provide practitioners with more regionally consistent guidance. However, practitioners are still seeking more detailed guidance than that which is provided nationally, to inform management decisions and engineering design for stormwater management.

Finally, while practitioners cited the need to undertake assessments with multiple climate change projections, models are often run for only one, usually mid-range, projection as was seen in the literature search. Limited access to climate change data and costs associated with modelling are cited as constraints.

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