Impacts of Climate Change
on Urban Infrastructure
& the Built Environment

A Toolbox

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

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Contents

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1. Introduction

This tool provides an example of a climate change risk assessment for an urban wastewater network that was carried out as part of the Auckland case-study. The tool builds on from the discussion of modelling for climate change impact assessments provided in [Tool 2.4.1] and the overview of modelling applications carried out in the Auckland region given in [Tool 2.4.2]. It presents work commissioned by NIWA that was carried out by the North Shore City Council (NSCC). Full documentation can be found in:

Lockie, T. and Brown, N (2010) Potential impact of climate change on NSCC's wastewater capital works programme. North Shore City Council Report.

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.

At the time of modelling, RCM rainfall data were available for the Auckland region for only a single global circulation model (HadAM3P) and gas emission scenario (A2). Hence, while this tool can serve as an example of how climate change and socio-economic scenarios can be incorporated into urban drainage models for impact assessment, it is not consistent with the Ministry of Environment (2008) requirements for detailed analysis as part of their recommended risk assessment process.

2. Project CARE

In 1998, the North Shore City Council (NSCC) established Project CARE (Council Action in Respect of the Environment) to reduce the impacts of urbanisation on beach receiving environments (see Heijs et al., 2002). Although the NSCC wastewater network is separated from stormwater, overflows of untreated wastewater do occur following high intensity rainfalls, and are a major source of contamination (i.e., nutrients, micro-organisms) to North Shore beaches. Major network upgrades are required to limit the occurrence of overflows.

The Wastewater Network Strategic Improvement Programme (WNSIP) was initiated to assess the wastewater sewer network to plan the capital works programme. The network was evaluated in 2001 using a MOUSE model of the trunk wastewater network which included all pipes with a diameter ≥300mm. The model was used to identify overflow locations in need of upgrades. At that time, the estimated cost of the planned capital works was $231 million.

A revision of the WNSIP was undertaken in 2008 (see Lockie, 2010) using an updated version of the trunk model (Model Build 2006, see Lockie et al., 2010) which expanded the modelled network to include all key network components. The length of the modelled network was almost doubled. The review was carried out to evaluate the potential performance of the planned upgrades assuming future city growth and eventual network deterioration, and to advise on the possible need for further upgrades. The estimated cost of the capital works as determined from the 2008 WNSIP review comes to a total of $408 million (2008$).

2.1 Catchment description

The wastewater catchment covers an area of 12000 ha; of this, 7500 ha is serviced by the trunk sewer network which is 112 km in length (Figure 2.1). In addition, there are 1200 km of local sewer lines which connect to the trunk network. The NSCC assumed per capita foul water production rate to the network is 225 l/day. Wastewater is conveyed via gravity sewers to 18 pumping stations which pump the collected water over ridges within the catchment to the Rosedale Wastewater Treatment Plant.

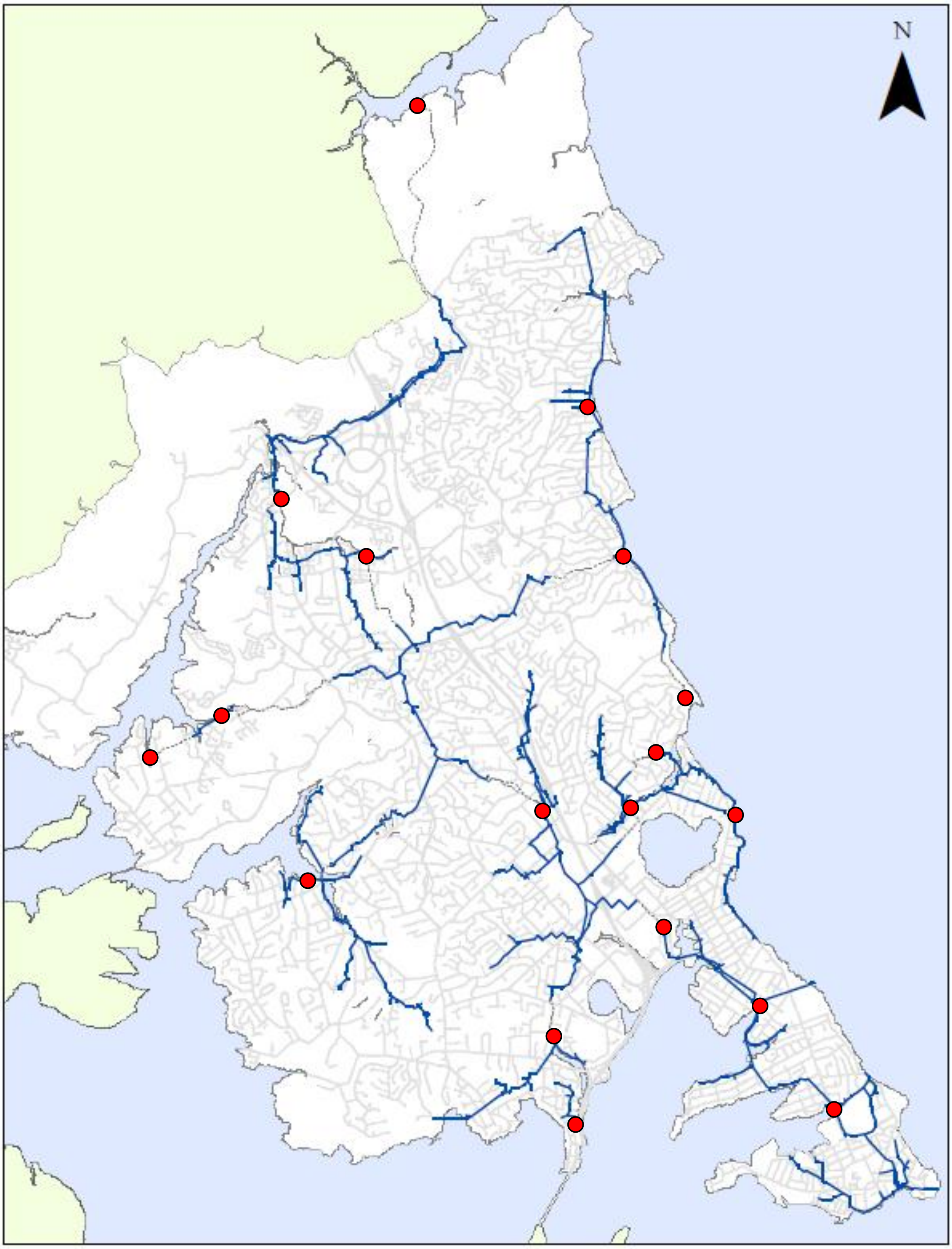

Figure 2.1: Model extent for the NSCC waste water network showing location of trunk sewers (blue lines), rising mains (grey dashed lines) and modelled pumping stations (red circles). Modified after Lockie and Brown, 2010

2.2 Network upgrade objectives

2.2.1 Target Level of Service

The Project Care target level of service is a reduction of city-wide overflow events from over 12 times per annum down to no more than one event per six months on average (i.e., two per annum) by 2021 as assessed by computer modelling.

2.2.2 Overflow classification

An overflow event is defined as an event where the spill discharge exceeds 0 l/s and is separated from previous events by at least a 24-hour dry period. Three types of overflow are defined by the NSCC:

- Constructed - Overflows from formal structures designed to release excess flow to prevent uncontrolled spills upstream. Generally these structures spill to nearby a watercourse or directly to the harbour.
- Uncontrolled - Overflows from informal structures us as manhole lids. Overflows are usually onto road / driveway surfaces from whence the spill is conveyed via the stormwater system to a nearby watercourse and harbour.
- Catchment overflows – Overflows which occur upstream of the modelled network extents and are not modelled.

These overflows are further classified according to annual spill volumes:

- Type I – Spill volume > 1 million l/yr
- Type II – Spill volume < 1 million l/yr
- Type IV – Catchment overflows from unmodelled overflows at the upstream extent of the model

3. Modelling Approach

Mathematical models are routinely used to assess the impacts of climate change on hydrological systems and associated hazard risks. Guidance for carrying out such assessments using models is provided by the Ministry for the Environment (MfE, 2008a; 2010). Tool 2.4.1 discussed modelling issues specific to urban drainage impact assessments ranging from model choice to the development of climate and network scenarios. It was noted that climate change is addressed by adjusting the input data used to force the model whereas changes in the network and water management practices are addressed by adjusting model parameters. Changes in boundary conditions associated with climate change, such as sea level rise, can also be made.

In this example, an impact assessment of a wastewater network is carried out using an existing MOUSE model. As the model was forced by only one climate change projection, the example is not consistent with the MfE guidelines, nonetheless, it can serve to illustrate a real-world modelling application. The network is modelled for projected population and deterioration out to 2060.

3.1 MOUSE

MOUSE (MOdel of Urban Sewers) was developed by the Danish Hydrological Institute (DHI) in 1985 and is used world-wide to simulate urban drainage. The model consists of a number of modules which can be coupled to provide routines for surface hydrology (rainfall/runoff simulation from permeable and impervious surfaces), flow in sewers (hydraulics of separate and combined sewers), contaminant transport, and water distribution systems. MOUSE can be integrated with other DHI products such as MIKE SHE (grid-based model of surface hydrology) and MIKE 11 and MIKE 21 (1 and 2D hydrodynamic flow models). MOUSE is currently marketed by DHI as MIKE URBAN which consists of the original MOUSE modules coupled to a GIS platform and interface.

MOUSE has been used for a number of climate change impact assessments internationally including Arnbjerg-Nielsen and Mikkelsen (2009), Arnbjerg-Nielsen and Fleischer (2009) and Semadeni-Davies et al. (2008a and b). MOUSE has also been used in previous impact assessments in the Auckland area including Shaw et al. (2005) and Kinley et al. (2007). The cited climate change studies have variously investigated the number and volume of combined sewer overflows, flooding and network capacity including the effect of detention facilities for quantity control.

3.1.1 Project CARE 2006 Model Build

The MOUSE set-up as applied in this study is known as the Project CARE 2006 Model Build and is a comprehensive representation of the trunk wastewater network which includes all significant constraints and system features. The Model Build was undertaken as part of the 2008 WNSIP revision. It uses the MOUSE 2007 software platform with the following modules:

- MOUSE_RTC – MOUSE 2007 Real Time Control (RTC)[1]
- MOUSE_RDII – MOUSE 2007 Runoff Module
- MOUSE_HD – MOUSE 2007 Hydraulic Engine
- MOUSE_LTS – MOUSE 2007 Long Term Simulation

The 2006 Model Build was developed to complete a hydraulic and hydrologic system performance assessment under current and future network conditions. Two future network scenarios were created for the WNSIP 2008 revision – city growth and eventual network deterioration due to aging and urbanisation. The model was forced for the revision using an historical 17-year rainfall series and was calibrated against recorded flow data from each of the catchments with a flow gauge. The model build, calibration and results are described in the Project CARE progress reports (Lockie, 2010; Lockie et al., 2010).

3.1.2 Catchment description

To aid modelling, the wastewater catchment serviced by the trunk sewer was split into 55 flow gauge catchments, with long term flow gauges in place in 47 of these catchments. These catchments were further divided into sub-catchments, each of around 5 ha in area. There are around 300 sub-catchments.

3.1.3 Infiltration and Inflow (I/I)

Rainfall generated flows can enter the network as either direct inflow of surface runoff or sewer infiltration of groundwater, collectively known as I/I. While separate systems like the NSCC network do not have storm-drains connected to the sanitary sewer, direct inflow can enter wastewater pipes via wrongful connections such as roof down-pipes or via informal inflow points such as man-hole covers. Sewer infiltration occurs when the watertable rises above the pipe level and is able to infiltrate via leaky

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[1] Note that while part of the WNSIP simulations, RTC was not simulated for the model runs undertaken for this study.

joints or cracks which develop as pipes age. The causes of leaks are varied and include traffic vibrations, poor workmanship during laying, slumping and tree roots. Losses from the sewer (exfiltration) via the same defects are possible when the watertable is low. There can also be infiltration of water exfiltrated from overlaying stormwater and water supply pipes.

Flows in wastewater sewers are generally defined as follows:

- Dry weather flow (DWF) is the average flow rate in the wastewater network during an extended dry period. DWF consists of a combination of foul water and groundwater infiltration less exfiltration. Dry weather infiltration and exfiltration were not calibrated in the model build.

- Wet weather flow (WWF) is the flow rate in the wastewater network occurring during wet weather and includes rainfall dependant I/I. MOUSE splits I/I into a fast response component (FRC) and a slow response component (SRC). These terms are roughly analogous to inflow and infiltration respectively. The FRC is relatively independent of antecedent conditions whereas the SRC is highly dependant on antecedent conditions. The proportions of FRC and SRC for each flow gauge catchment was developed during model calibration.

3.2 Scenario development

The response of the wastewater network was evaluated for combinations of three sets of scenarios for this tool: city growth; network deterioration; and climate change (rainfall). The former scenarios were developed as part of the 2008 WNSIP review (Lockie, 2010 and Lockie et al., 2010) and are only briefly summarised here.

3.2.1 Population (city growth)

The foul water component of wastewater is dependent on the local population and urban activities including services (schools, hospitals) and industry. City growth is the largest unknown in the planning assumptions used for future scenarios and design horizons for wastewater networks. Over the design life of the proposed capital works, the impact of growth on hydraulic loads in the network could be significant requiring considerable changes to the programme.

Like the rest of the Auckland, North Shore is experiencing unprecedented population growth which is driving development. The population equivalent (sum of resident and non-resident population) served by the waste water network was estimated by

NSCC to be 227069 on the basis of the 2006 census. The calibrated wastewater production rate used to derive the foul water load is 225 l/person/day. It is assumed that this rate will remain constant.

The projected population equivalent used in this tool for all runs is 373,845 by 2060. This projection assumes very high growth rates and was developed for the WNSIP 2008 review. The population increase is unevenly distributed around the city with Albany and Takapuna expected to have the greatest increases. The planned Long Bay development will also see a localised population increase over the next decade. Accordingly, population increases were applied to each of the model flow gauge catchments separately.

3.2.2 Network deterioration

The proportion of I/I in wastewater generally increases over time both due to ageing and development of the contributing area which increases imperviousness and inflow via private lateral connections. Two separate deterioration scenarios were developed for the 2008 WNSIP review:

- Age – an increase in the calibrated I/I of 25% per 50 years

- Development (catchment intensity) – an increase in the calibrated I/I of 1% per increase in population density of 10 people/ha with an upper limit of 50 people/ha above which there is no further increase in I/I.

The above deterioration rates were applied to each sub-catchment by increasing the calibrated FRC and SRC parameters. In the model runs carried out for this tool, development was assumed for all the runs whereas deterioration due to age was simulated for half the model runs.

3.2.3 Climate change

The 2008 WNSIP forced the Project CARE Model Build using a 17-year historical rainfall series (November 1981 to January 1999) with a 5 minute time-step. The rain gauge (NSCC07) is located at the Wairau testing station. Potential evapotranspiration was taken from the NIWA online climate database[2] (Khyber Pass, August 2006-July 2007). The potential evaporation annual data set was repeated to match the length of rainfall record under the assumption that potential evapotranspiration does not vary greatly from year to year.

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[2] www.cliflo.niwa.co.nz

This study forces the model with two synthetic rainfall series which cover the 30-year time-slices 1971-2000 (current climate) and 2071-2100 (future climate) in addition to the historical rainfall series. Evapotranspiration was not adjusted. The synthetic rainfall series were obtained from the NIWA regional climate model (RCM) which is based on the UK Met Office unified model framework (Drost et al., 2007; Baskaran et al., 2002). The RCM downscales output from the Hadley Centre HadCM3 GCM future climate projections for two gas emission scenarios (B2 and A2). At the time of modelling, only the A2 gas emission scenario future rain series was available which assumes moderately high gas emissions.

Rainfall was aggregated into 15-minute blocks to make the rainfall series, which has a 3-minute time-step (i.e., the RCM output), compatible with the MOUSE 2006 Model Build (5-minute internal time-step). High temporal resolution output, such as short-duration rainfall, also requires statistical bias correction, which is an ongoing research field for NIWA. In this study, bias correction was performed on the current rainfall series to better match the statistical characteristics of the observed historical data series (i.e., gauge NSCC07). The future climate rainfall was then bias corrected in the same way as the current climate data.

Rainfall analysis

A rainfall event analysis was undertaken to compare the observed and synthetic rainfall series. For the analysis, a rainfall event is defined as any period of rainfall which exceeds 1 mm total depth preceded by no less than a 6-hour inter-event dry period. For each rain event, maximum rainfall intensities were calculated for the following durations: 15 and 30 minutes, 1, 2, 3, 6, 12 and 24 hours. The 10, 25, 50, 75, 80, 85, 90 and 95 percentiles of the rainfall intensities (i.e., from low to high) were calculated for each of these event durations. The percentiles calculated for the different rainfall series and durations where compared as follows:

1. observed rainfall for the NSCC07 gauge (January 1980 – August 2008) against current synthetic rainfall series;

2. the current and future synthetic rainfall series; and

3. The first and last decade of the current synthetic rainfall series.

From this comparison (detailed in Lockie and Brown, 2010) it was found that:

- The historic rainfall intensities (November 1981 to January 1999) exceeded both the current and future RCM synthetic rainfalls for all durations and percentiles by between 10 and 105%

- The future RCM synthetic rainfall generally exceeded that of the current RCM for most durations and percentiles, with the notable exception of the 95 percentile for the 15 minute duration where the current RCM exceeded the future RCM by 3%.

- Comparison of the first (1971-1980) and last (1991-2000) decades of rainfall from the current RCM shows a significant variation in rainfall statistics with the first decade of rainfall generally having higher intensity rainfalls, particularly for the most extreme events (95 percentile).

- This first decade of current RCM rain also appears to contain more intense rain events (i.e., increased frequency) than those generated for the future RCM.

- In general, the current synthetic rainfall can not be considered representative of the recorded rainfall. Further work is required to produce a more ‘realistic’ rainfall time series for the current climate. Nevertheless, some information can still be gleaned from the difference between current and future RCM synthetic rainfall runs.

The effect of these findings on the simulated network performance and cost implications are discussed in Sections 4 and 5.

3.3 Model Runs

In all, 10 model runs (A-J) were undertaken for this study, four for each RCM synthetic rainfall series (current and future) and two using the historical rainfall series.

The RCM rainfall series were split into 10-year blocks and the model was forced with the first and last block of each series. This was done to assess the variance in network performance across the current and future periods derived from the RCM respectively. The objective was to check the natural variation within the RCM-generated series to assist with comparison between current and future climate rainfall. It was considered that 10 years is a statistically long enough period to run the model for, as the containment standard is one overflow per 6 months, therefore the period of record is 20 times longer than the target level of service.

Each model run assumes the 2060 city growth projection with associated changes in wastewater loads and system deterioration due to development. Runs A-E assume network deterioration due to aging. It was decided to repeat the runs (i.e., Runs F-J) without deterioration due to aging. This deterioration can be considered a safety factor which represents unknowns in the model. As such, it was thought that it may obscure the simulated impact of climate change.

The various runs are detailed below.

Population growth and network deterioration due to aging and development

Run A: model forced with first 10yrs of the synthetic current rainfall from the RCM.

Run B: model forced with last 10yrs of the synthetic current rainfall from the RCM.

Run C: model forced with first 10yrs of the synthetic future rainfall from the RCM.

Run D: model forced with last 10yrs of the synthetic future rainfall from the RCM.

Run E: model forced with historical rainfall record

Population growth and network deterioration due to development only (no aging)

Run F: model forced with first 10yrs of the synthetic current rainfall from the RCM.

Run G: model forced with last 10yrs of the synthetic current rainfall from the RCM.

Run H: model forced with first 10yrs of the synthetic future rainfall from the RCM.

Run I: model forced with last 10yrs of the synthetic future rainfall from the RCM.

Run J: model forced with historical rainfall record

4. Network Performance Analysis

The indicators of system performance assessed by Lockie and Brown (2010) are:

1. The number of simulated release points (i.e., non-complying or failure locations) where the target level of service is exceeded;

2. The average system-wide annual spill volume (note, this indicator includes spill volumes from overflow locations which meet the target level of service); and

3. The average 6-monthly spill volumes from failure locations only as defined in point 1 above.

While these indicators are all driven by the hydraulic load in the network, an increase or decrease in one does not necessarily imply a corresponding change in the other. For instance, volume increases could variously be due to increases in failure locations, the frequency of overflow events or spill volumes per overflow event. For this reason, Lockie and Brown (2010) also analysed the frequency and type of overflow for each failure location.

4.1 Network aging assumed (Runs A-E)

The network performance for Runs A-E are summarised in Figure 4.1 to 4.3. The results are discussed further below.

4.1.1 Current RCM rainfall series

There is significant variation in the simulated system performance for the RCM current climate. This finding is in keeping with the differences in rainfall between the first and last decades of the current rainfall series shown in the rainfall analysis. Such decadal variation is not inconsistent with observations and represents the kind of natural variability inherent in rainfall in this region.

The model simulates 82 system failure locations and 202 million l/yr of annual spill volume for the first decade (Run A) of the current synthetic rainfall. The 6-month spill volume from failure locations only is 28 million l/yr. Run B simulates 66 failure locations with an annual spill volume of 167 million l/yr and a 6-month spill volume of 27 million l/yr. The average performance for the two current rainfall blocks was 76 failure locations, an average spill volume of 184 million l/yr and a 6-month spill volume of 27 million l/yr.

An analysis of overflow frequencies at failure locations (not shown here) found that there are slightly more Type II overflows in Run A than B; however, the location and frequency of Type I overflows are very similar.

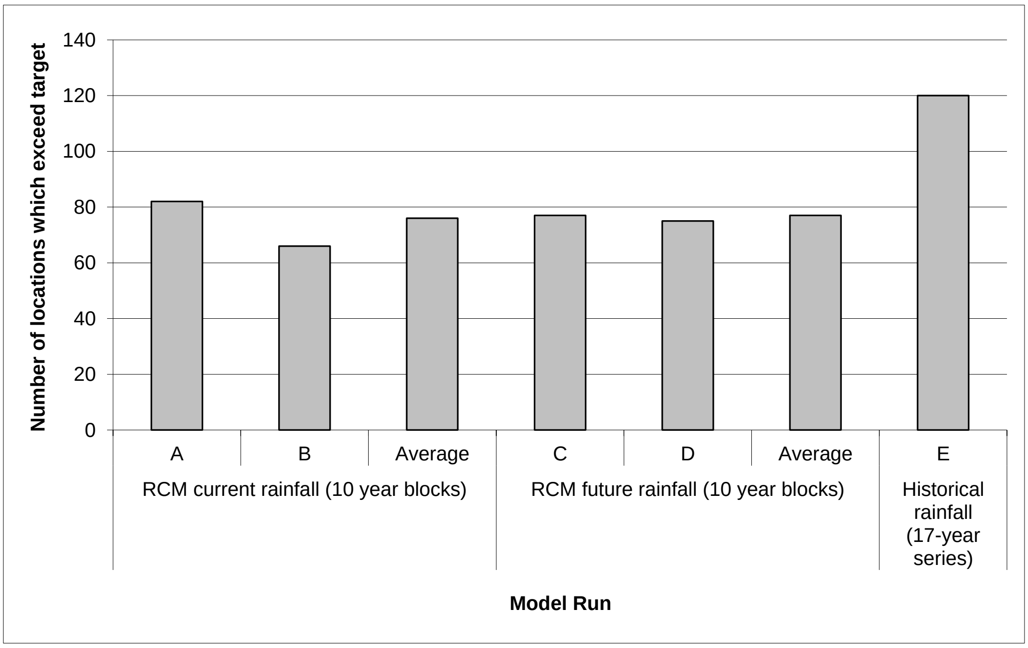

Figure 4.1: Number of failure locations for Runs A-E

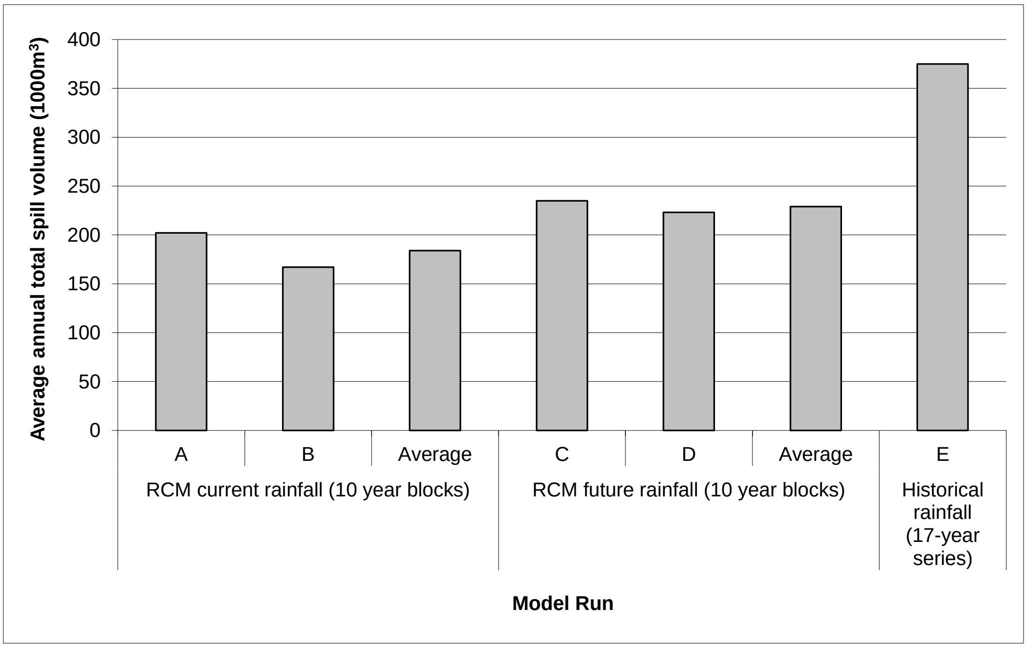

Figure 4.2: Average annual overflow volume from all overflow locations for Runs A-E

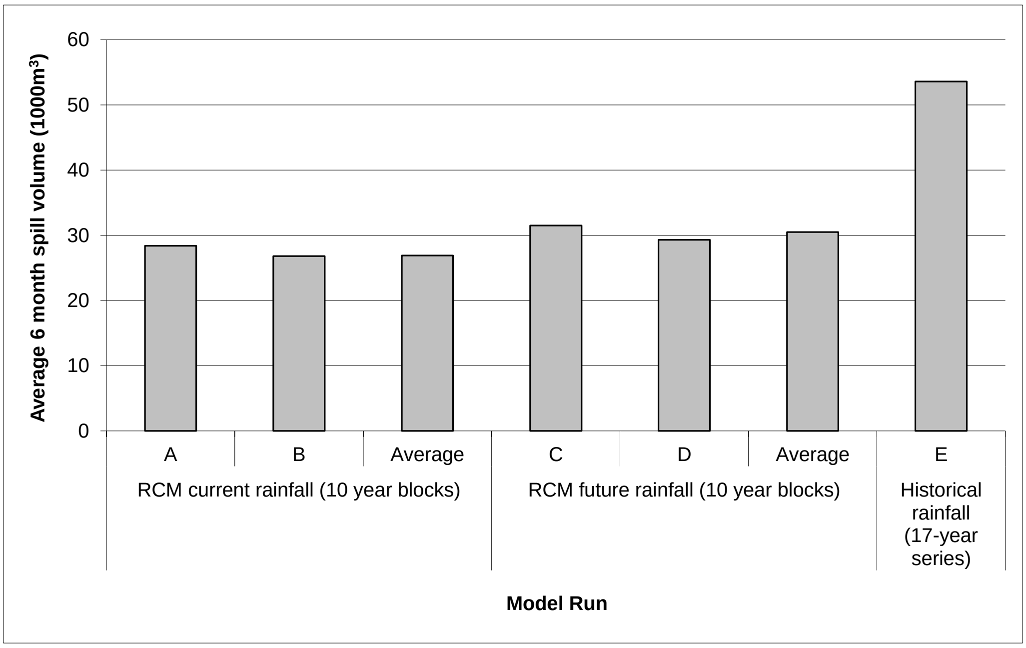

Figure 2.3: Average 6 month overflow volume from failure locations only for Runs A-E

4.1.2 Future RCM rainfall series

There is little variation in system performance between the two decades for the RCM future climate scenario. This finding is not surprising given the similarity in rainfall determined for the first and last decades of the future rainfall series. This result should not be interpreted as future rainfall being less variable than current rainfall as it could well be a sampling artefact.

For the first decade (Run C) of the future rainfall series the model simulates 77 system failure locations, 235 million l/yr of annual spill volume and a 6-month spill volume from failure locations of 32 million l/yr. For the last decade (Run D) there are 75 failures with an annual spill volume of 223 million l/yr and a 6-month spill volume of 29 million l/yr simulated. The average performance for the two current rainfall blocks was 77 failure locations, an average spill volume of 229 million l/yr and a 6-month spill volume of 31 million l/yr.

While the failure locations and overflow types are very similar, overflow frequencies are slightly increased in Run D (data not shown here).

4.1.3 Historic Rainfall Series

For the historical rainfall series (Run E) the model simulated 120 system failure locations and an annual spill volume of 375 million l/yr. The 6-month spill volume from failure locations is 54 million l/yr. These results indicate poorer system performance than simulated in either runs forced with the current synthetic rainfall series. There are 44 more failure locations and double the spill volume compared to the combined results of Runs A and B. The indicators also greatly exceed those simulated with the future synthetic rainfall series.

That the simulated network performance is poorer in comparison to the performance simulated with the current synthetic series is not surprising given the differences between the rainfall intensities of the historic and synthetic records shown in the rainfall analysis. This result indicates that despite attempts to bias correct the RCM current climate rainfall, the RCM has failed to simulate the very high temporal resolution and point-specific (a single rain gauge location) observed data with enough accuracy to be used as a realistic input for this application. Refinements to the RCM as well as bias correction methodologies are an ongoing area of research.

4.1.4 Impact of climate change

The large differences between the results simulated using the historical record (Run E) and the synthetic current rainfall series (Runs A and B) mean that a direct comparison between present system performance and the performance simulated using the synthetic future rainfall series (Runs C and D) is not possible. Instead, the relative impact of climate change is assessed by comparing the results generated using the two synthetic rainfall series.

The minimum, average and maximum differences between the current and future time periods were compared in the following ways:

Minimum impact – the run from the current time period with the poorest performance (Run A) was compared to the future run with the best performance (Run D).

Average impact – the average performance of both time periods was compared.

Maximum impact - the run from the current time period with the best performance (Run B) was compared to the future run with the poorest performance (Run C).

The results of the comparison are given in Table 4.1.

Table 4.1: Comparison of results simulated with the current and future synthetic rainfall series assuming network aging

Network performance indicator	Minimum Impact			Average Impact			Maximum Impact		
	Run		Difference	Run		Difference	Run		Difference
	A	D		A+B	C+D		B	C	
Number of failure locations	82	75	-7 (-9%)	76	77	1. (1%)	66	77	11 (17%)
Average annual spill volume (million l/yr)	202	223	21.0 (10.4%)	184	229	45.0 (24.5%)	167	235	68.0 (40.7%)
Average 6 month spill volume from failure locations (million l/yr)	28.4	29.3	0.9 (3.2%)	26.9	30.5	3.6 (13.4%)	26.8	31.5	4.7 (17.5%)

The comparisons point to an increase in annual spill volumes ranging between 10% and 40%. The 6-month spill volumes from failure locations also increase for all the comparisons. However, the minimum impact comparison suggested a slight decrease in the number of failure locations. The decrease in failure locations for the minimum impact comparison can be explained by the higher rainfall intensities for 15-minute rainfalls in the current synthetic rainfall series compared to the future synthetic rainfall series as discussed in the rainfall analysis above. These events may trigger overflows despite having lower volumes compared to future rainfalls with longer durations. That is, while the number of overflows may decrease, the spill volume associated with each increases. This finding implies that as the target level of service is based on reducing the number of failure locations, there may still be increases in overflow volumes.

4.2 No network deterioration due to aging

The network performance for Runs F-J are summarised in Figure4.4 to 4.6. The results are analysed further below.

4.2.1 Current RCM rainfall series

There is significant variation in the simulated system performance for the RCM current climate. For the first decade (Run F) of the current synthetic rainfall the model simulates 59 system failure locations, average annual spill volume of 131 million l/yr from all overflow locations and an average 6-month spill volume from failure locations of 16 million l/yr. There are 45 failure locations with an annual spill volume of 105 million l/yr and a 6-month spill volume of 15 million l/yr simulated for the last decade (Run G). The average performance for the two current rainfall blocks was 52 failure locations per year, an average spill volume of 118 million l/yr and a 6-month spill volume of 16 million l/yr.

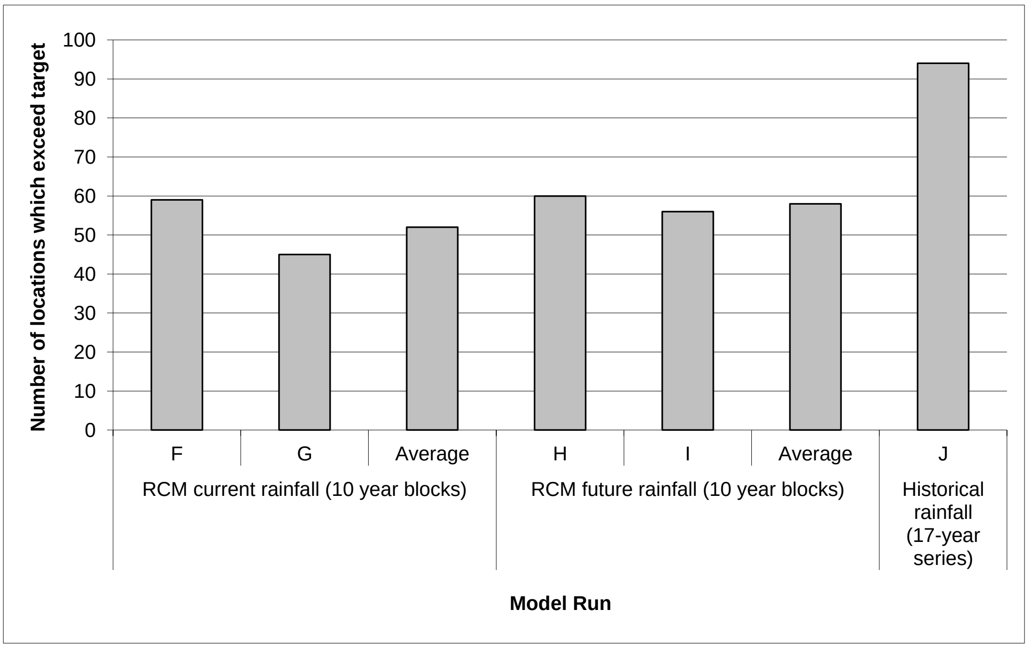

Figure 4.4: Number of spill release points for Runs F-J where the target level of service of no more than 2 spills per year is exceeded

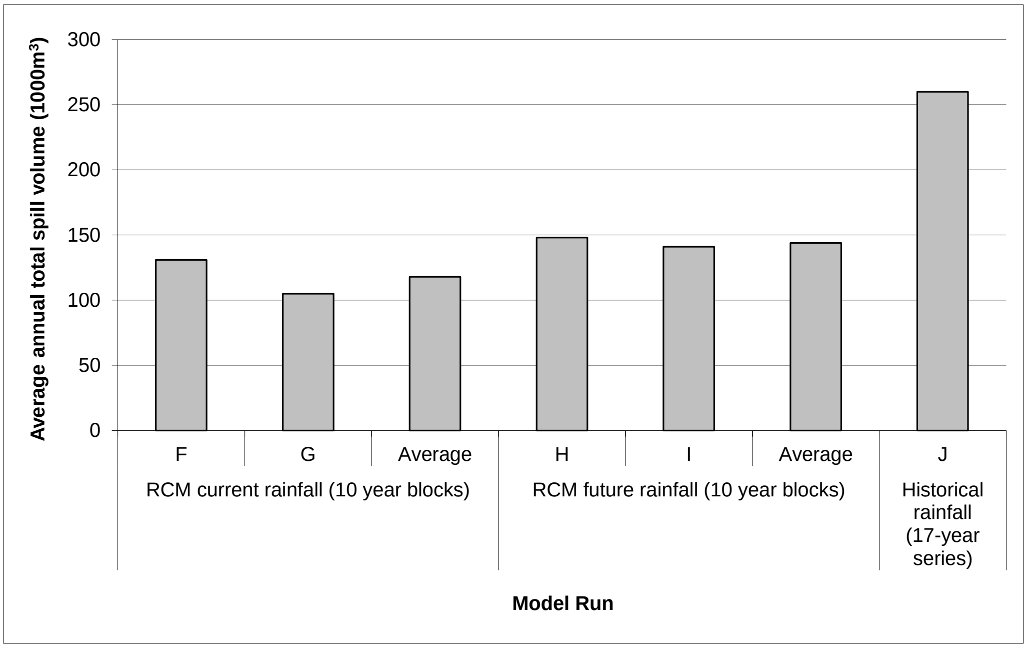

Figure 4.5: Average annual overflow volume from all overflow locations for Runs F-J

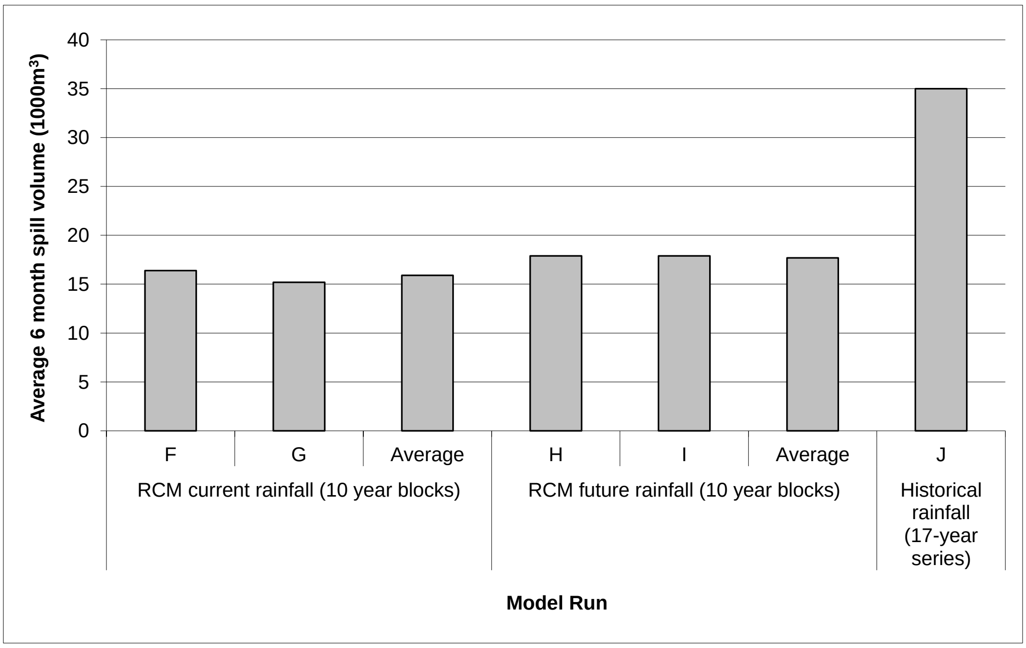

Figure 4.6: Average 6 month overflow volume from failure locations (i.e., overflow locations which do not meet the target level of service) for Runs F-J

4.2.2 Future RCM rainfall series

As with the model runs with network aging, there is little variation in system performance between the two decades modelled for the RCM future climate scenario. The first decade of the future rainfall record (Run H) generated 60 system failure locations and 148 million l/yr of annual spill volume. There were 56 failures with an annual spill volume of 141 million l/yr for the last decade (Run I). The 6-month spill volume from failure locations was 18 million l/yr for both runs. The combined performance for the two current rainfall blocks was 58 failure locations and an average spill volume of 144 million l/yr. As concluded in section 6.1.2 above, this result should not be interpreted as future rainfall being less variable than current rainfall, as it could well be a sampling artefact.

4.2.3 Historic rainfall series

Using the historical rainfall series (Run J) the model simulated 94 system failure locations, an annual spill volume of 260 million l/yr and a 6-month spill volume from failure locations of 35 million l/yr. There are 42 more failure locations and more than double the spill volume compared to the combined results of Runs F and G. The number of failure locations and spill volume also greatly exceed those simulated with the future synthetic rainfall series. Again, the results show that only the differences between the results of the simulations using the synthetic rainfall records should be used to indicate the relative impacts of climate change.

4.2.4 Impact of climate change

The current (Runs F and G) and future (Runs H and I) results simulated with the synthetic series were compared in the same way described above. Results are summarised in Table 4.2.

Again, all the comparisons point to an increase in spill volumes with climate change. With the exception of the minimum impact scenario, there is also an increase in the number of spill locations that do not meet the target level of service.

Table 4.2: Comparison of results simulated with the current and future synthetic rainfall series assuming no network aging

Network performance indicator	Minimum Impact			Average Impact			Maximum Impact		
	Run		Difference	Run		Difference	Run		Difference
	F	I		F+G	H+I		G	H	
Number of failure locations	59	56	-3.0 (-5.1%)	52	58	6.0 (11.5%)	45	60	15.0 (33.3%)
Annual spill volume (million l/yr)	131	141	10.0 (7.6%)	118	144	26.0 (22.0%)	105	148	43.0 (41.0%)
6 month spill volume from failure locations (million l/yr)	16.4	17.9	1.5 (9.1%)	15.9	17.7	1.8 (11.3%)	15.2	17.9	2.7 (17.8%)

5. Impact of climate change on the cost of capital works

5.1 Costing methodology

The analysis of the performance simulated with the historical and current synthetic rainfall scenarios showed considerable differences. This means that the results of the RCM simulations cannot be used directly to determine the effect of climate change on the size of the capital improvement works. Instead the relative differences between the current and future model runs were used to scale the cost of the capital works programme generated by the historical rainfall series. Cost estimates were developed by Lockie and Brown (2010) for three cost scenarios:

- *Anticipated Climate Change:* Assumes that capital works to meet the forecast climate change are undertaken and planned as part of NSCC's capital work programme.

- *Unanticipated Climate Change*: Assumes that no planning or account of climate change is taken upfront and that capital works are only undertaken once the impacts of the forecast climate change are experienced.

- *Unanticipated Climate Change with discounting*: As above with Net Present Value (NPV) assumptions that the required improvements to meet future degradation are delayed by 10 years from the current capital works with a discount rate of 2.5%.

The steps undertaken to scale the costs for each costing scenario are given below.

Anticipated climate change

1. Identify failure locations simulated for each run forced with the current synthetic rainfall series.

2. Cost capital works required to meet the target level of service at those locations using the NSCC cost curves.

3. Identify failure locations simulated for the runs forced with the future synthetic rainfall series.

4. Cost capital works required to meet the target level of service at those locations using the NSCC cost curves.

5. Calculate the percentage difference in the current and future costs determined in steps 2 and 4 for each of the impact comparisons (i.e., minimum, average and maximum).

6. Scale the costs determined for the 2008 WNSIP review by the percentage difference calculated in step 5.

Unanticipated Climate Change

1. Identify failure locations simulated for each run forced with the current synthetic rainfall series.

2. Cost capital works required to meet the target level of service at those locations using the NSCC cost curves

3. Find locations which degrade in performance from the current to future climate scenario.

4. Cost capital works to meet the target level of service at the degraded failure locations only.

5. Add the costs calculated in step 4 to those calculated in step 2. This step implies that capital works are carried out twice at the degraded sites, initially for current conditions and again as a delayed adaptation to climate change.

6. Calculate the percentage difference in the current and future costs determined in steps 2 and 5.

7. Scale the costs determined for the 2008 WNSIP review by the percentage difference calculated in step 6.

8. A further refinement to this cost scenario is to calculate the NPV of the delayed capital works. It is assumed that the required improvements to meet future degradation are delayed by 10 years from the current capital works with a discount rate of 2.5%.

5.2 Cost implications with assumed network aging

The costs of improvements to the network to meet the target level of service at the failure locations identified with assumed network deterioration due to aging are summarised in Table5.1. All costs are given in 2008 equivalent dollars and are compared to the WNSIP 2008 review budget estimate for capital works of $408 million. The cost scenarios were applied to the minimum, maximum and average impacts on network performance discussed above.

It must be pointed out again that the analysis is based on a change in network performance simulated with a single climate change projection. Hence, the cost implications as presented here may not hold for other climate projections.

Table 5.1: Revised capital works budget estimates ($million, 2008) to account for the impacts of climate change with assumed network deterioration due to aging

Costing scenario	Minimum impact (A to D)		Average impact (A+B to C+D)		Maximum (B to C)	
	Revised budget estimate	Difference	Revised budget estimate	Difference	Revised budget estimate	Difference
Anticipated climate change	390	-18 (-4.4%)	430	22 (5.4%)	461	53 (13.0%)
Unanticipated climate change	531	123 (30.1%)	585	177 (43.4%)	593	185 (45.3%)
Discounted unanticipated climate change*	504	96 (23.5%)	546	138 (33.8%)	553	145 (35.5%)

*NPV cost estimate is based on 2.5% discount rate and a delay of 10 years to additional capital works.

Adapting the network as part of current capital works for anticipated climate change is the most cost effective scenario for all impact levels. For this cost scenario, the estimated change in costs range from a reduction of $18 million to an increase of $53 million in 2008 dollars. The reduction in costs for the minimum impact scenario can be traced back to the lower intensity of 15-minute rainfalls in the synthetic future rainfall series compared to the current series. This resulted in fewer future failure locations, but slightly increased spill volumes.

The cost implications for unanticipated climate change with no NPV assumptions range from an increase of $123 million to $185 million. Discounting the cost of capital works (i.e. NPV cost estimated) brings the unanticipated climate change cost implications down somewhat to between $96 million and $145 million.

5.3 Cost implications with no network aging

Exclusion of the deterioration assumption results in a re-costed capital works budget as determined from the historical rainfall record of $314 million. That is, the cost of network improvements to counter deterioration due to aging is $94 million.

The cost implications of climate change with no network deterioration were estimated only for anticipated climate change and are given in Table5.2. Based on this analysis, the cost implications of climate change, while not insignificant, are small compared to the cost impact estimated with the network deterioration assumption.

Table 5.2: Revised capital works budget estimates ($million, 2008) to account for the impacts of climate change with no network deterioration

Costing scenario	Minimum impact (F to I)		Average impact (F+G to H+I)		Maximum (G to H)	
	Revised budget estimate	Difference	Revised budget estimate	Difference	Revised budget estimate	Difference
Anticipated climate change	320	6 (1.9%)	342	28 (8.9%)	373	59 (18.8%)

6. Result summary

The NSCC interest in the impact assessment was to evaluate the impacts of climate change on the performance of the trunk wastewater network and to determine the cost implications of those impacts on capital works planned as part of Project CARE. It was recognised that since only one climate projection was available, the assessment cannot be used as a planning tool for further network improvements. However, the study was seen by NSCC as a valuable pedagogic exercise to develop a methodology for future assessments.

The main findings and recommendations made by Lockie and Brown (2010) are listed below.

- The current synthetic rainfall record is not representative of observed rainfall data and has lower intensity rainfalls. Further work is needed to match the statistics of the synthetic regional rainfall to observed data.

- Network performance simulated using the historical record was poorer than the performance simulated with either of the synthetic rainfall series. For this reason, the relative impacts of climate change were evaluated by comparing the minimum, average and maximum differences between the runs simulated with current and future synthetic rainfall records.

- The estimated cost of capital works to meet the target level of service for historical rainfall is $408 million in 2008 dollars.

- The theoretical cost of climate change if accounted for prior to it occurring (i.e., adaptation to anticipated climate change during the capital works) is a minimal increase in predicted cost – approximately 5% for the average climate change impact. The theoretical cost of climate change if nothing is done until after the change occurs (i.e., future adaptation to unanticipated climate change) is a significant cost of approximately 43% (or 34% if using an NPV estimate).

- Exclusion of the deterioration due to aging assumption results in a re-costed capital works budget of $314 million for historical rainfall. Without this assumption, the estimated cost increases by 9% when anticipated climate change is factored in. The equivalent increase for unanticipated climate change was not determined.

- All model runs assumed city growth. While the growth scenario is acknowledged to be a major source of model uncertainty, the impact of growth on network performance was not assessed here.

On the basis of their findings, Lockie and Brown (2010) state that NSCC considers it prudent to make some allowance for deterioration of the system, which also provides a safety factor against other unknowns, but to incorporate both climate change and deterioration assumptions together at this stage is considered to be too conservative.

7. Concluding remarks

This tool builds on Tools 2.4.1 and 2.4.2 which overview the issues associated with modelling for climate change impact assessments and the incorporation of climate change guidance into urban water management by local government. The work was undertaken by NSCC and was commissioned by NIWA for the Auckland case-study to demonstrate the use of NIWA's Regional Climate Model in climate change impact assessments. The work was reported by Lockie and Brown (2010) and investigates the possible impacts of climate change on the performance of the North Shore wastewater network and the cost implications of those impacts on planned improvements to the network. As synthetic climate data were available for only one climate change projection (HadCM3 GCM forced with the A2 gas emission scenario), the study is not consistent with MfE (2008) guidelines for risk assessment. Nonetheless, it can provide an insight into real-world modelling applications.

A major finding of this modelling exercise was that the historical rainfall series has higher intensity rainfalls for all event durations investigated than the synthetic rainfall data generated by the RCM for both current and future synthetic rainfalls. This resulted in poorer system performance simulated using the historical rainfall series compared to either of the synthetic series.

For this reason, 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. The NPV cost, assuming a 2.5% discount rate, is somewhat lower at between 24 to 36%.

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.

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