SUMMARY REPORT

Climate Change and Infrastructure Design

Case study: Wairau Catchment, North Shore City

Prepared for

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Executive Summary

Background and Purpose

Stormwater infrastructure upgrades are often designed by simulating a rainfall event through a computer-generated model of the stormwater network. The modelling results help to identify areas where the stormwater infrastructure is under-capacity, and surrounding properties are at risk of flooding during large rainstorms.

Climate change has the potential to affect both the amount of rain falling on a catchment, and also the frequency with which large rainfall events occur. Because of this, stormwater infrastructure might need to be designed differently to take account of climate change effects.

There are also a number of different ways that rainfall can be modelled – either as a single large storm (design storm), or as a time series, statistically generated to simulate real rainfall over a certain length of time (time series / dynamic).

This study investigated the impacts of both climate change and different modelling approaches on infrastructure design within the Wairau Valley stormwater catchment in North Shore City. Four different climate data sets were produced – ‘present’, representing the present climate, and Future 1, Future 2, and Future 3, representing three different possible future climate change scenarios.

The Study

The Wairau valley stormwater catchment is a highly impervious catchment, with a large number of in-line stormwater storage ponds, and extensive open channels. Large flood plains exist alongside the open channels. The catchment naturally splits into a number of sub-catchments, each draining to a stormwater detention pond. A simplified computer model of the subcatchments, main stormwater network and ponds in the study area was constructed.

The present and all three future rainfall files were used as a time series, and design storms were also developed to represent the present and one future climate scenario (Future 3).

The model provides information on catchment runoff, and flows and levels in pipes, channels, overland flow paths and ponds. Areas in the network that are under-capacity or flooded can be identified either directly via the model results, or by comparing water levels with contour plans to show the extent of the flood plain.

Results

Results of the modelling were compared as follows:

	Comparison	Key Purpose of comparison
1	Catchment Runoff: Present Climate vs Future Climate	To assess the effects of future climate on catchment runoff – changes in intensity and rainfall quantities affect the amount of water stored in the soil, and the amount of water running off.

2	Pipe and channel flows and water levels: Present Climate vs Future Climate	Results were compared for both the design storm and dynamic modelling approaches to see what the effects of climate change would be on the ability of the stormwater network to carry flows.
3	Pipe and Channel Flows: Dynamic model vs Design storm model	To assess the differences in design outcomes using different modelling approaches.

The results showed that the simulated future climate produced greater catchment runoff than the present climate. The flows in the channels were also increased due to the future climate, however the water levels were only slightly higher because of the large size of the channels (a large amount of water can be stored with only a slight increase in water level).

It was noted, however, that the increase in flows was less than expected in the future climate scenarios where the dry periods between rainstorms was increased –it is thought that the storage in the catchment (ponds and soil storage) had a longer period of time to ‘recover’ after each rainstorm, and therefore had more storage capacity than if the rain events followed one another in quick succession.

Findings

In summary, the following conclusions were reached:

1. Design Storm vs. Dynamic Modelling:

a. In the Wairau catchment, a dynamic modelling approach yields 10% -15% lower flows and fewer flooded locations than the design storm model for the ‘Present’ climate.

b. Given the results above, and working on the basis that dynamic modelling provides a more accurate representation of rainfall characteristics and channel flows in the Wairau catchment, fewer stormwater upgrades will be necessary when using a dynamic modelling approach rather than a design storm approach under both the ‘Present’ and ‘Future’ climate scenarios. (Modelling showed 50% less channel would be affected over the Wairau catchment as a whole).

2. ‘Present’ Climate vs. potential ‘Future’ Climate:

a. Both the design storm and dynamic modelling approaches predict higher flows and increased flood risk in the Wairau catchment as a consequence of climate change (36% increase in length of stormwater channel affected under the design storm modelling, 6% increase under the dynamic modelling).

b. These increased flows and flood risks appear greater when using a design storm modelling approach. This suggests that using a dynamic modelling approach can potentially minimise the costs of upgrading stormwater infrastructure to meet the needs of a changing climate. (For example, under a ‘Future 3’ dynamic modelling scenario for the Wairau catchment, the community can expect negligible additional costs over and above usual upgrade expenditure in order to ‘future-proof’ stormwater infrastructure to meet the needs of a changing climate).

c. Catchment characteristics and infrastructure (i.e. soil characteristics, presence of ponds) can have a significant influence on modelled flows and water levels.

Comment

It is recognised that not all councils will have access to the historical rainfall data required to undertake a dynamic modelling approach. In this case, the design storm approach will adequately serve council needs, including for consideration of stormwater infrastructure design needs in a changing climate. Where such historical data is available, it is expected that the dynamic modelling approach can produce a more accurate picture of catchment flows / water levels and the resulting impacts on stormwater infrastructure for both a present and future climate. However, implementing the dynamic modelling approach is likely to require greater levels of expertise and may also be more open to errors in its application.

1.1 How Is Stormwater Infrastructure Designed?

Design criteria for a stormwater system usually has a frequency or probability attached to it – for example, a stormwater network (pipes, channels, overland flow paths) is sometimes designed to carry a rainfall event with a 1% chance of occurring in any given year.

Stormwater infrastructure upgrades are designed by simulating a rainfall event through a computer – generated model of the stormwater network. The results of such a modelling exercise help to identify areas where the stormwater infrastructure is under-capacity, and surrounding properties are at risk of flooding during large rainstorms.

The simulated rainfall event is often called a ‘design storm’. A 1% AEP (annual exceedence probability) design storm is a short-duration (often 24 hour) rainfall event that has been developed to simulate a large storm that would most likely occur only once in 100 years.

An alternative method is to run a model with a time-series of real rainfall. Because of a lack of long-term rain gauges in New Zealand, however, it is rare to find a complete 100-year record.

1.2 How Could Climate Change Affect Stormwater Infrastructure?

Climate change has the potential to affect both the amount of rain falling on a catchment, and also the frequency with which heavy rainfall events occur. Because of this, stormwater infrastructure might need to be designed differently to take account of climate change.

1.3 The Study

An investigation was undertaken into the effects of different possible future climate scenarios, and different modelling approaches on stormwater infrastructure design. The project was instigated and managed by North Shore City Council, and partial funding was received from the NSCCO.

This report summarises the results of the project, with particular emphasis on the impact of climate change and modelling approaches on:

- Infrastructure Performance; and
- Infrastructure design

1.4 Project Background

North Shore City Council (NSCC) have historically undertaken catchment modelling and stormwater infrastructure design based on a 'design storm' approach as specified by the Auckland Regional Council in their '*Guidelines for Stormwater Runoff Modelling in the Auckland Region*' (TP108: ARC, 1999). Following the successful use of time-series modelling in the planning of NSCC's wastewater network upgrades, NSCC sought to investigate the implications of using a dynamic time-series modelling approach to stormwater planning and infrastructure design.

The Wairau catchment in North Shore City was chosen for this case study, due to the availability of almost 20 years' continuous rainfall and flow data for its central drainage channel, the Wairau Creek. Implications of infrastructure upgrade in this area are also potentially significantly expensive due to the high flows, encroaching development, and highly engineered infrastructure.

During the preparatory stages of this investigation, consideration was also given to the potential climate change impacts on infrastructure design. At this stage, NSCC approached the New Zealand Climate Change Office (NZCCO) of the Ministry for the Environment (MfE), offering to include the Wairau catchment as a Case Study of how a council could consider the implications of climate change in its activities.

As part of its portfolio of climate change work, NZCCO has begun a programme to assist regional councils and territorial authorities to better understand and take into account climate change effects when carrying out their day-to-day operations. In particular, the programme aims to develop guidance materials for local authorities to assist them in assessing and managing the risks of climate change in their planning process. The climate change component of this report was, therefore, able to be partly funded by NZCCO.

This paper summarises some of the results of this study, in particular, the results of the time-series and design storm modelling, discussing how various different rainfall scenarios would affect the Wairau Catchment and its drainage infrastructure, and discussing these effects and how they might also apply to other catchments.

1.5 Project Objectives

The main objectives of this project were to:

1. Compare the use of a "Design Storm" to the use of a "Dynamic Time Series" modelling approach for the design of stormwater infrastructure in the Wairau Catchment and determine the potential catchment management and infrastructure design implications of each approach.
2. Determine the potential impact of climate change on the design requirements for stormwater infrastructure in the Wairau Catchment and the stormwater planning implications.

1.6 Study Approach

This study consisted of three distinct phases; stochastic rainfall generation, design storm development, and hydrological and hydraulic modelling of the stormwater network.

Stochastic Rainfall Generation – Current and Future Climate Scenarios

The existing 30-year rainfall record from the Wairau rain gauge was used to generate a number of stochastic rainfall series ‘blocks’ with the same rainfall characteristics, using a Neyman Scott Rectangular Pulses (NRSP) model. Five such 30-year series were created, providing a total of 150 years of rainfall time series data referred to as the “Present” scenario.

Assumptions regarding possible future climate change were used to generate similar stochastic rainfall series for three potential future scenarios.

This work was carried out by Dr Paul Cowpertwait of Massey University (Cowpertwait, 2003) and resulted in four synthetic 150-year continuous rainfall series with 5-minute increments.

Design Storm Development

In order that the “Dynamic modelling approach” could be properly compared to a “Design storm modelling approach”, it was essential that the two approaches were based on the same rainfall data. This required the development of design storms using the same methodology as was used to develop the design storm in the ARC’s stormwater runoff modelling guidelines (ARC, 1999). Intensity duration frequency curves and design storms were developed for two of the stochastically generated rainfall series- “Present” and “Future 3”.

This work was carried out by Beca Carter Hollings & Ferner Ltd who were also responsible for the preparation of the ARC’s TP108 (ARC, 1999).

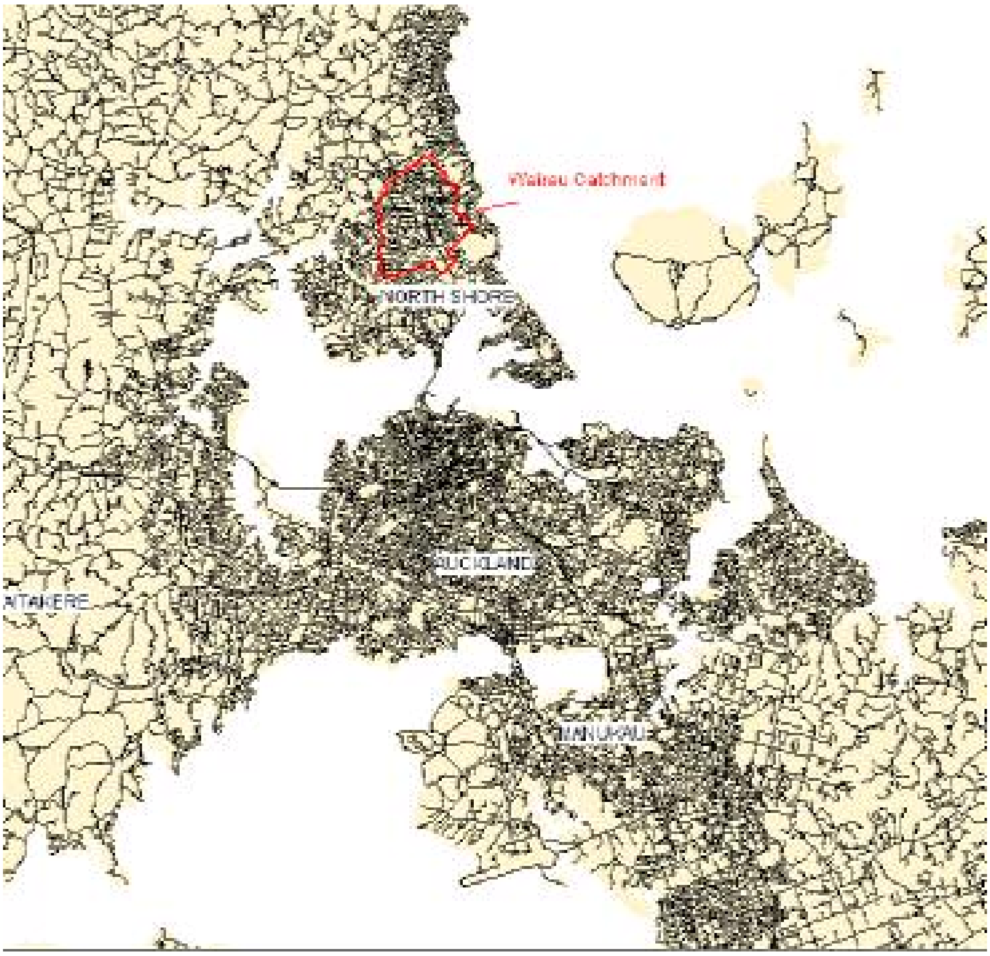
Hydrological and Hydraulic Modelling

URS were commissioned to carry out hydrological and hydraulic modelling of the Wairau stormwater catchment and network in order to compare the two different approaches to modelling. The modelling was carried out using the latest version of DHI’s MOUSE software, and the model was calibrated for both the dynamic and design storm modelling using actual recorded rainfall events in the catchment and corresponding flows recorded at a site on the main channel of the Wairau Creek.

1.7 The Wairau Catchment

The Wairau catchment is in North Shore City, and has a stormwater drainage area of approximately 1,300 hectares. The catchment has relatively steep terrain in the upper catchment areas, draining to a central valley and creek, and comprises a mixture of residential and industrial land use. The overall imperviousness of the Wairau catchment was estimated at 47% (Harrison Grierson, 2002). The stormwater system in the upper parts of the catchment is predominantly piped, and there are no longer any significant natural stream channels in the catchment. The catchment drains to the Wairau Creek, a highly modified stream channel with a number of in-line stormwater detention ponds, and then to the Wairau Estuary and the Hauraki Gulf. Rainfall and stormwater flows in the Wairau catchment have been monitored continuously since 1981. The Wairau catchment has a fast response to rainfall, and the drainage infrastructure is significant. Because of the large, highly engineered infrastructure, and built-up catchment, stormwater infrastructure upgrades can be costly. There are also a large number (1,280) of houses affected by the '100 year flood hazard' area, and there is a need to define this area as accurately as possible, in order to correctly ascertain the public health and safety risk, potential property damage and consequent NSCC liability.

Figure 1-1: Wairau Catchment Location



2.1 Rainfall Data

2.1.1 Time Series Rainfall

The following rainfall time series' were used in this modelling analysis:

- 1981-2003 rain and flow gauge data provided by NSCC, (used for model calibration)
- 1 'Present' 150-year Stochastically generated rainfall time series, and
- 3 'Future' 150-year Stochastically generated rainfall time series.

The stochastically generated time series' are discussed in Cowpertwait (2003), and are derived from a 150-year series representing the "Present" climate scenario (which has the same statistical characteristics as the 30 years of gauged rainfall from the Wairau rain gauge). This was generated using a Neyman-Scott Rectangular Pulses (NSRP) model, which produced five 30-year series. These were then combined to form a single 150-year series of rainfall at 5-minute intervals.

Three "Future" 150-year series were then stochastically generated to reflect alternative future rainfall scenarios. The three alternative 'Future' rainfall data sets were based on the following assumptions with respect to potential climate change after consultation with NIWA staff:

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%.

For the Present and Future 1 series, only 100 years of the data was used, whilst for the Future 2 and Future 3 series, 110 years was used. This was due to limitations in computing capacity.

2.1.2 Design Storms

Beca (2003) undertook an analysis of the 'Present' and 'Future 3' stochastically generated 150-year rainfall series in order to develop Intensity Duration Frequency (IDF) curves for each of these scenarios. These IDF curves were then used to develop typical temporal 24-hour design storm profiles. Design rainfall depths taken from the IDF curves with a range of durations up to 24 hours were nested, and then normalised by the 24-hour rainfall depth. This was the same approach as was used to produce the design storm in the ARC's TP108.

The 10% AEP 24-hour depth was calculated as 121.26 mm for the 'Present' design storm, and 168.45 mm for the 'Future 3' design storm – a difference of 39%.

2.2 Modelling Approach

A computer model of the main components of the Wairau stormwater drainage network was developed using DHI's MOUSE 2003 software. In this case study, catchment runoff from all scenarios is routed through the same open channel network, a simplification of the Wairau Valley stormwater drainage system, characterised by large, open channels. One of the key features of the hydraulic model, specific to this catchment, is that the majority of the runoff was routed through stormwater ponds prior to entering the main network.

This hydraulic model simulates 8.6 km of open channel, 1.3 km of piped network and ten inline stormwater ponds.

For the hydrological models, the Wairau catchment was divided into 17 sub-catchments ranging in size between 22 ha and 216 ha. MOUSE has the ability to use several hydrological methods to estimate catchment runoff.

Dynamic Modelling

For the dynamic simulations, a calibrated Mouse RDII model was used in combination with a surface runoff model (in this case, Model A, a time/area method with a convergent time area curve number) in order to split the runoff into a 'fast' and 'slow' component (FRC and SRC respectively).

This model was calibrated using a number of rainfall events and corresponding flow data from the gauged records provided by NSCC. There are 14 parameters that can be manipulated in the RDII parameter set, most of which are of an empirical nature and difficult to estimate from geophysical measurements. Worley and AWT (2000) presented a calibrated set of RDII parameters for the Wairau catchment, which were then adopted for this project. A few minor adjustments were made to several of the parameters while calibrating the dynamic hydraulic/hydrological model to the gauge data.

Once calibrated, the RDII model was used to run 100 years of stochastic rainfall data from each of the "Present" and "Future 3" rainfall sets and 110 years of rainfall from the "Future 1" and "Future 2" scenarios. The LTS (Long Time-Series Simulation) module of MOUSE was used to reduce modelling time and summarise results from these simulations.

Design Storm Modelling

Design storms are commonly used with a unit hydrograph method of runoff estimation. Methodology recommended by Auckland Regional Council's TP108 (ARC, 1999) was followed for this analysis. Generally, the UHM method produces a single runoff hydrograph from a catchment, and fast and slow response components were simulated by splitting each of the sub-catchments into impervious and pervious sections, the impervious areas having a faster response time than the pervious components.

Design storms used in this simulation were developed from the stochastically generated 'Present' and 'Future 3' time series (Beca, 2003), rather than the Auckland regional design storm. This model was also calibrated using rainfall events and corresponding flow data from the gauged records provided by NSCC.

3.1 Comparison of Results

The results from the 4 dynamic simulations and the "Present" and "Future 3" design storms are compared below. For consistency, all comparisons are made at the 10% AEP level (Annual Exceedence Probability, i.e. a 1 in 10 year storm event). Below is a summary of the comparisons made.

Table 3-1: Modelling Comparisons Made

	Comparison	**Key Purpose of comparison**
1	Catchment Runoff: Present Climate vs Future Climate	To assess the effects of future climate on catchment runoff – changes in intensity and rainfall quantities affect the amount of water stored in the soil, and the amount of water running off.
2	Pipe and channel flows and water levels: Present Climate vs Future Climate	Results were compared for both the design storm and dynamic modelling approaches to see what the effects of climate change would be on the ability of the stormwater network to carry flows.
3	Pipe and Channel Flows Dynamic model vs Design storm model	To assess the differences in design outcomes using different modelling approaches.

3.1.1 Catchment Runoff

Catchment runoff is the amount of water leaving a catchment, and is calculated using the hydrological model only – the transformation of rainfall into a runoff hydrograph. Catchment runoff results are reported as a 'peak' or maximum runoff for an entire storm event or time series.

These were directly compared for the design storms modelled, and it was found that the peak runoff from the catchments was between 36% and 68% greater as a result of the Future 3 design storm, when compared with the Present design storm, with the larger differences being in the pervious catchments (due to the initial soil abstraction of rainfall being set under the TP108 methodology). Table 3-2 below provides results from three of the modelled catchments.

Table 3-2: Peak Catchment Runoff Comparison – Design Storms

Catchment		10% AEP Maximum Catchment Runoff (m^3/s)		% Increase in runoff
		Present Climate	Future Climate (Future '3')	
Golf Course	**Pervious Component (57 ha)**	7.6	11.7	55%
	Impervious Component (8 ha)	1.9	2.5	36%
Porana North	**Pervious Component (4 ha)**	0.7	1.1	44%
	Impervious Component (34 ha)	8.2	11.2	36%
Takapuna North	**Pervious Component (44 ha)**	6.4	9.8	55%
	Impervious Component (48 ha)	11.5	15.6	36%

Because the dynamic modelling results were from the full 100 or 110-year series (and thus the peak catchment runoff was the maximum for the entire time series), and because the rainfall events provoking the 10% AEP event in the catchment are different for all parts of the catchment, direct comparisons of catchment runoff from these models cannot be made.

3.1.2 Flows in Channels

The design storm modelling approach produces theoretical maximum flows with a certain annual exceedance probability at a given point in the system

Each time-series contains 150 years of randomly generated rainfall events, based on historical patterns. However, there is no certainty that a 1% AEP event did actually occur within the time series, although there is more confidence that the smaller frequency events (eg a 10% AEP flow) have occurred on a number of occasions.

MOUSE LTS software analyses extreme event data and identifies the 10% AEP flow by ranking the data. Probability distributions are usually applied to ranked rainfall and flow data to relate the magnitude of extreme events to their frequency occurrence. Analysis undertaken with flow results at the gauge showed that the MOUSE LTS estimates of event frequency did not produce consistent results. Annual extreme flows for the time series data were analysed using three different probability distributions commonly used in New Zealand; Gumbel (Extreme Value Type I), Log-Pearson Type III, and Log-normal. The Log-Pearson III and Gumbel distributions produced very similar results, and the results of the Log-Pearson III analyses are presented in Table 3-3 below. Water levels corresponding to the 10% AEP flow have been estimated based on events of similar size occurring in the time series'.

Table 3-3: Comparison of 10% AEP flows and Water Levels – Design storm and Dynamic Models

Link / Location		10% AEP flow (m^3/s)					
		Present Climate		Future Climate			
		Design	Dynamic	Design - Future 3	Dynamic – Future 1	Dynamic – Future 2	Dynamic – Future 3
R25a Mid Catchment (Gauge site) Top of channel = 12.0m	Flow (m^3/s)	61	55	80	57	55	57
	Water level (m)	13.1	13.0*	13.4	13.0*	13.0*	13.0*
R30out Lower Catchment (Outlet) Top of Channel = 6.0m	Flow (m^3/s)	85	70	115	72	70	73
	Water level (m)	6.0	5.8*	6.6	5.7*	5.8*	5.8*

* Approximation from MOUSE results

Present Climate vs Future Climate - Design Storm Model

The 'Future 3' design storm predicts flows approximately 30% to 40% greater than those resulting from the 'Present' design storm in both the mid and lower- catchment channels. This is comparable to the 40% difference in 24-hour rainfall volume during the design storms. The associated water level rise in the mid-catchment is 2%. At the outlet, water levels rise by 10%.

Present Climate vs Future Climate – Dynamic Model

Climate change comparisons showed that the dynamic model predicted a maximum increase under climate change of 4% for the 1 in 10 year flows at the outlet of the stormwater system. Channel flows increase from Future 1 to Future 3, with Future 3 producing the largest changes in flow. Of interest are the lower than expected flows of Future 2 – the increase in dry periods in the climate scenario are possibly providing additional storage within the catchment. The extended dry periods in the Future 3 scenario, however, are causing high intensity rainfall events, which are not buffered to the same extent as the lower intensity events in the Future 2 scenario. Water level rise associated with these changes in flow is negligible.

Design Storm vs Time Series

When comparing the design storm flows to the dynamic model flows, the 'present' time series dynamic model produces channel flows that are lower than the 10% AEP flows from the 'present' design storm model. The dynamic model predicts flows at the gauge that are 10% lower than those predicted with the design storm model at the gauge, and 15% lower at the outlet.

Water levels associated with the changes in flow change only slightly in the channels, due to the large cross sectional areas in the channels and flood plains providing additional storage.

The "Future 3" dynamic model predicts flows that are 29% and 37% lower (for the mid and lower-catchment channels respectively) than the 'Future 3' design storm model 10% AEP flows. This is a much greater difference than the present design storm / present dynamic model comparison, and it is possible that additional storage in the catchment soils and network (ponds and channels) is available as a result of the increased dry periods in the 'Future 3' time series, 'buffering' the increased rainfall. Because the increased dry periods in the Future 3 time series lead to higher intensities during storms, grouping these together to form a design storm does not account for the dry periods, and this may need to be reviewed with respect to adjusting the design storm.

The different approach in modelling rainfall and run-off in the design storm and dynamic time series models makes it difficult to fully resolve the differences in run-off for the present climate, and the changes under future scenarios. Use of dynamic time series modelling under climate change scenarios requires significant scientific expertise; results from dynamic time series modelling should not necessarily be treated as representing a more realistic representation of present or future conditions.

3.1.3 Flooded Nodes and Links

A number of nodes were investigated with respect to the comparison of the number of times the water level rises above an identified 'critical level'. This level has been set at either the top of the lined channel, or the top of the bank, depending on the location (proximity to houses, shape of the channel).

Figures 3-1 and 3-2 below identify the locations where the water level at a location in the network exceeds the critical level assigned to that point, under both the present climate scenario, and the future climate scenario.

Because all of the nodes which flooded under the present climate scenario also flooded under the future climate scenario, results are presented as:

- Areas that would need upgrading, regardless of the climate scenario used; and
- ‘Additional’ areas that would only need upgrading if the future climate scenario were applied

Figure 3-1: Areas Requiring Upgrade for 10 year Design Criteria (design storm)

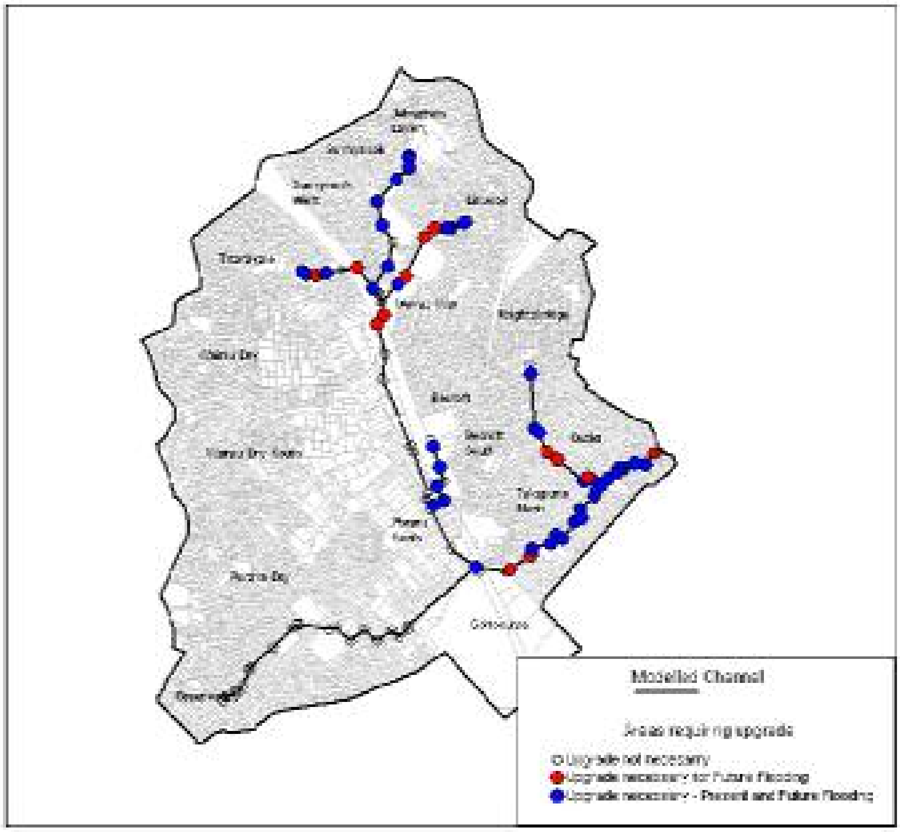
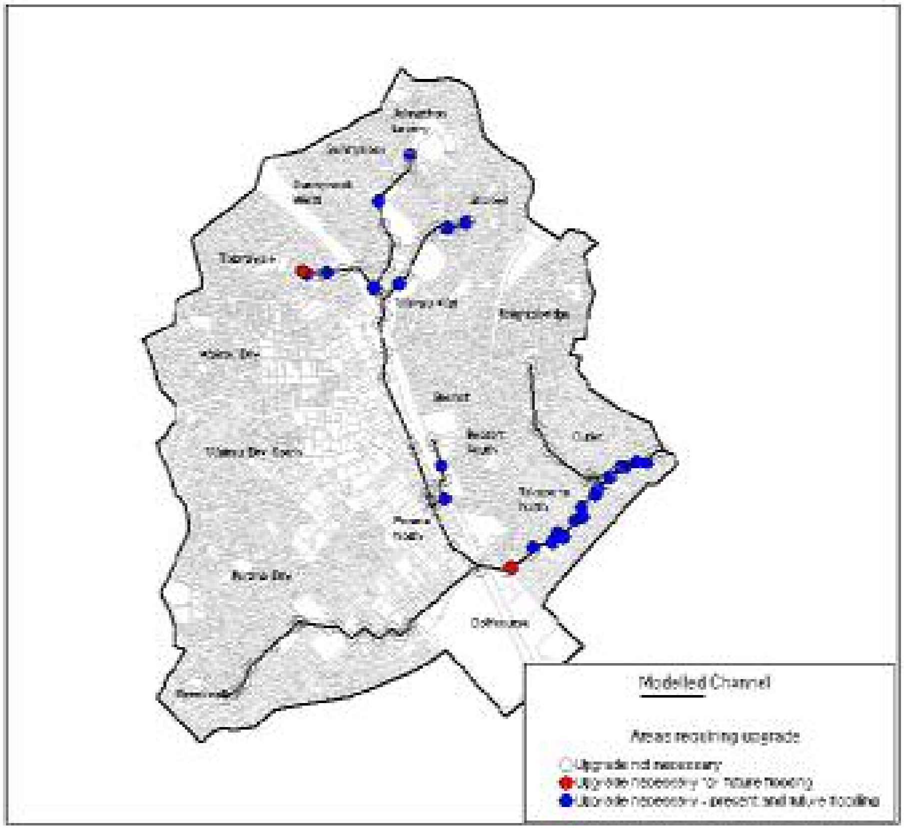


Figure 3-2: Areas Requiring Upgrade For 10 Year Design Criteria (Dynamic Model)



Present vs Future Climate

In both the design storm and dynamic modelling examples, the Future scenario yielded a higher number of flooding nodes than the Present scenario. Under the present design storm, 45 locations had a water level greater than the critical level. This rose to 55 locations when the Future design storm was modelled.

The difference between the present dynamic model and the Future 3 dynamic model was not so great, with an additional two points in the system identified as flooding in the Future, over and above those susceptible under the Present dynamic model.

3.2 Number of Floods vs Design Requirements

The flooding locations can be investigated further by looking at the number of times a particular link or node in the model overflows. If a link is to carry the flow resulting from a 10% AEP design storm, and overflows 10 times during a 100-year series for the same climatic conditions, it could be identified as having a 1 in 10 year level of service. If, on the other hand, it only overflows twice during the 100-year series, the link could potentially be over-designed (i.e. the design storm used may have been too conservative). Table 3-4 below displays a number of example locations throughout the model where there is a significant change in the flooding occurrences under the different climate change scenarios.

Table 3-4: Flooded Location Examples in the Lower Catchment for a 10% AEP Event

Node	Number of floods					
	Present Climate		Future Climate			
	Design Storm Floods?	Dynamic Number of floods/100 years	F1 Dynamic Number of floods/100 years	F2 Dynamic Number of floods/110 years	F3 Design Storm Floods?	F3 Dynamic Number of floods/110 years
J-13c **LOS* 10%** **Top of bank 12m**	No (max level 11.9m)	2	4	5	Yes (max level 12.2m)	7
J-13b **LOS 5%** **Top of bank 12m**	No (max level 12.0m)	4	8	9	Yes (max level 12.4m)	11
J-20e	Yes	22	28	23	Yes	31

LOS 10% **Top of bank 6m**	(max level 6.8m)				(max level 7.1m)	

*LOS = Level Of Service for that location (Protection required against rain events of a given frequency)

The results from the first node (J-13c) show that during the present design storm, the channel would not overflow (it is in fact, sized almost exactly to accommodate the flow from this design storm). Additionally, when tested with the present time series, the water level in the channel would only top the banks in two storms. Because the required level of service is the 10% storm, it would be acceptable for the water to overtop the banks 10 times in 100 years. This link is therefore capable of maintaining the current level of service under the future climate change scenarios, and is possibly over-designed for the current climate.

Node J-13b, on the other hand, accommodates the ‘present’ 10% AEP design storm flows, and additionally appears to be within the acceptable flooding limits for the ‘present’ climate scenario for the 5% AEP level of service required at that link, however this shows that the 10% ‘present’ design storm simulates a 20% AEP flow under the present dynamic model at this point. Additionally, under future climate change scenarios, the number of floods in 100 years would most likely mean that the level of service would not be maintained.

Node J-20e would appear to be under-designed – Figures 3-1 and 3-2 above highlight the number of locations in the Wairau catchment where this is the case.

4.1 Upgrades

Figures 3-1 and 3-2 above can be used to display the areas where network upgrades would be recommended, using either the design storms or the dynamic modelling approach. In order for a comparison to be made, all upgrades have assumed a 10-year level of service requirement for the whole network.

It can be seen that more upgrades would be necessary under the future scenario than the present, and that the dynamic models identify fewer locations in need of upgrades than the design storms. However in both the dynamic and design storm models, the future scenario merely extends an area that is predicted to flood under the present scenario.

The total length of channel affected under each scenario is as presented in Table 4-1 below:

Table 4-1: Length of Channel Potentially Subject to Flooding in a 10% AEP Event

	Scenario	**Length of channel potentially requiring upgrade**
Present Climate	Design storm	4,700m
	Dynamic Model	3,100m
Future Climate	F3 Design Storm	6,400m
	F3 Dynamic Model	3,300m

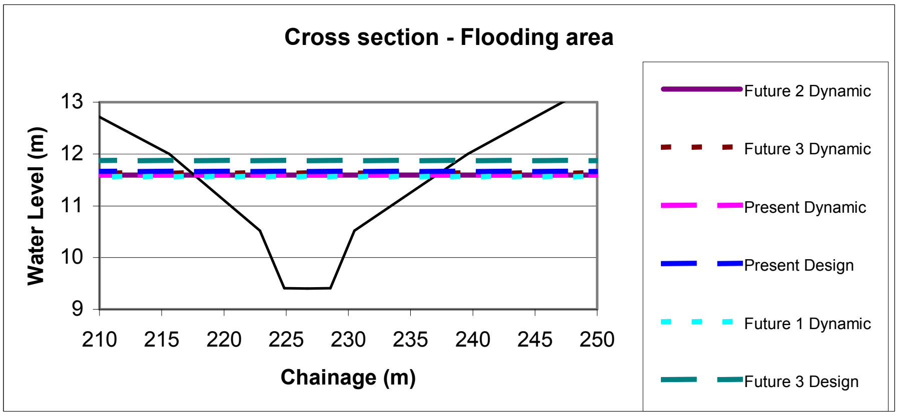
4.1.1 Costs

A range of options could be reviewed with respect to potential solutions for channel capacity and flooding issues in the Wairau catchment. For example, the issues in the Jonathon Lavery and Becroft sub-catchments may be addressed by an increase in efficiency of the current stormwater ponds. In these locations, the cost differences between the extent of works required under each modelled scenario may be minimal.

However, the lower catchment issues may require land purchase – many of the channels are closely surrounded by houses, and any works in the channel would require additional drainage easement purchase.

Figure 4-1 is a typical cross section through the Takapuna North area is J-13d, a trapezoidal channel, with a ‘critical level’ of 10.5m. It can be seen that this channel is in need of upgrade under any modelling scenario, in order to convey the 1 in 10 year flows without overland flow. It is also displayed in this diagram that the differences in water levels are quite small at this point between the different modelling scenarios.

Figure 4-1: Section Through Channel in Takapuna North with Modelled Water Levels at 10-year Flows



To re-design this channel for the appropriate flows, additional land, excavation and re-instatement would be required. An alternative is to purchase flood – inundated land.

In order to look at the cost implications of the different modelling and climate approaches, and based on an assumption that 10m additional land each side of the channel would be sufficient to manage the flows, the difference in cost can be compared based on the length of channel required to be mitigated (refer Table 4-2 below).

Assumption: 10m additional easement each side of channel. Cost: $1000 / m^2

Table 4-2: Potential Land Costs for Channel Upgrades in Takapuna North Section of Wairau

Scenario	**Length of channel (m)**	**Total Land Cost**
Present Design Storm	1412	$28m
Present Dynamic Model	1372	$28m
Future Design Storm	2253	$44m
Future Dynamic Model	1553	$32m

In this area, the extent of the issues is such that both the present design and dynamic models provide similar estimates of affected channel. The difference lies in the cost of allowing for the additional length at risk due to the future climate change. Elsewhere in the catchment, there are more significant differences between the "Present" design and dynamic model results.

5.1 Conclusions

This study has reached the following conclusions for the Wairau catchment:

1. Design Storm vs. Dynamic Modelling:

c. The dynamic modelling approach yields lower flows (10% - 15% lower for the Wairau catchment) and fewer flooded locations than the design storm model for the 'Present' climate.

d. This decrease in flooded locations and flows results in the prediction of fewer potential stormwater upgrades with the dynamic modelling approach for the present climate scenario (50% less channel affected over the whole Wairau catchment – refer Table 4-1).

2. 'Present' Climate vs. Potential 'Future' Climate:

d. Both the design storm and dynamic modelling approaches predict a greater number of stormwater infrastructure issues as a consequence of climate change (36% increase in length of channel affected under the design storm modelling, 6% increase under the dynamic modelling).

e. Climate change effects appear greater when using a design storm modelling approach.

f. Catchment characteristics and infrastructure (i.e soil characteristics, presence of ponds) can have a significant influence on modelled flows and water levels.

5.2 Study Limitations

The following notes are provided to identify individual catchment characteristics of the Wairau catchment that may have had an influence on modelling results:

a. The large number of in-line ponds influences catchment storage and upper-catchment flows, and is particularly noticeable for the dynamic modelling. Given the differences between dynamic time series and design storm modelling it is difficult to verify the correct imlementation of the design storm modelling approach to simulate climate change.

b. The large infrastructure and wide flood plains in the catchment minimise the effects of increased flows on water levels.

c. The model calibration was undertaken at one point in the mid-catchment. It is difficult therefore to accurately isolate the effects of individual catchments (i.e. pervious vs. impervious).

Further Work

SECTION 6

It is the intention of North Shore City Council to extend this study, and investigate the following with a view to providing guidance regarding the appropriate application of modelling methods to take account of climate change in different catchments:

a. Application of design storm and dynamic modelling methods to catchments elsewhere in the city.

b. Investigation into different catchment characteristics and in-system storage, and the response to rainfall.

c. Detailed flood plain survey and modelling in the Wairau catchment to assess the sensitivity of flow increases on flood plain extents.

d. Review of modelling specifications specific to infrastructure upgrades and flood plain management.

e. Review of the design storm generation methodology used, and its applicability to different climate scenarios (i.e. response to increases in dry periods).

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