INCORPORATING CLIMATE CHANGE INTO STORMWATER DESIGN – WHY AND HOW?

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ABSTRACT

The Resource Management Act Amendment Act (March 2004) requires councils to 'have particular regard to the effects of climate change'. Incorporating climate change predictions into stormwater design is important if infrastructure is to maintain the same level of service throughout its lifetime.

The New Zealand Climate Change Office (NZCCO) of the Ministry for the Environment has begun a programme to help local authorities consider climate change effects in their day-to-day functions and services. This programme has produced a range of relevant information and tools including the publication 'Preparing for Climate Change', a guide for local government in New Zealand (July 2004).

The NZCCO recommends a staged risk assessment approach to climate change assessment in stormwater planning, starting with a preliminary assessment of the likely impacts of climate change, through to more detailed analysis for areas where climate change is found to be a key factor for water resources management.

This paper outlines the information available to stormwater infrastructure designers, and discusses simple as well as more complex ways of incorporating climate change effects into stormwater design, illustrating the process with a case study undertaken in North Shore City, and a number of different climate change scenarios.

KEYWORDS

Climate change, Modelling, Catchment Management, Stormwater Planning

1. Introduction

Climate change has been regularly in the headlines over recent years. Much of the public attention has focused on options to reduce greenhouse gas emissions, and the role of international agreements to tackle climate change, such as the Kyoto Protocol. More recently, there has also been a growing awareness that even if international efforts to reduce greenhouse gas emissions are successful, some climate change is already unavoidable, and hence some adaptation to those changes will be necessary in parallel to efforts to reduce greenhouse gas emissions.

One of the major challenges of adapting to the effects of climate change is to develop robust methods that allow professionals to incorporate the likely future changes into their normal design and engineering work, despite the significant uncertainties that remain for climate change projections of parameters such as wind and rainfall.

An increase in heavy rainfall events is one of the key projected changes resulting from climate change. Since heavy rainfall events are key drivers for the design of stormwater systems, climate change would appear to require consideration in the design and upgrade of stormwater systems to ensure those systems continue to meet their design criteria throughout their planned lifetime.

This paper outlines the information currently available on climate change and its effects that is relevant for stormwater design, and outlines a methodology by which climate change information can be incorporated into normal planning and design procedures and criteria. Using a staged process, this methodology aims to minimise the costs associated with the consideration of climate change effects, and ensures that climate change is considered in the proper context of other design criteria and possible future changes.

2. How is climate change relevant to stormwater design?

Stormwater design is based on estimates of the amount of rainfall that will drain from a given catchment within a given period. Usually, historical records of observed rainfall, and the frequency distribution of heavy rainfall events, are used to determine the Annual Return Interval (ARI) for maximum rainfall over 1, 12 or 24-hour periods. This rainfall is then translated into run-off using catchment-specific models to determine maximum flows and design criteria for the stormwater system.

Climate change is expected to affect these design calculations in a number of ways, through increasing the intensity and frequency of heavy rainfall events, and through changing the antecedent moisture loading of soils and the average water contained in storage ponds.

The most significant change is expected to come from a general increase in the maximum rainfall associated with heavy rainfall events. The reason for this change is that a warmer atmosphere can generally hold more water, so that more water is available during any particular rainfall event. As a first approximation, the increased amount of rainfall over a typical 24-hour heavy rain event is scaled in proportion to the increase in temperature. The expected change of the absolute rainfall depth in design storms can relatively easily be incorporated into standard design calculations and subsequent run-off modelling.

More complex rainfall modelling may need to be applied where catchments are large with a complex topography, or have specific characteristics that warrant a more detailed investigation of changes in rainfall characteristics and their effect on fast and slow run-off components (such as a high variety of pervious and impervious surfaces and ponding areas). Where significant differences between highly pervious and impervious surfaces exist within the catchment area, it could be useful to test alternative rainfall simulations using Dynamic Time Series modelling, which employs a stochastic simulation of rainfall over a continuous time period rather than standard design storms. Preliminary findings from such a study will be presented later in this paper. For large catchments with a complex topography, a more detailed investigation of the behaviour of typical storms under a warmer atmosphere can help identify potential changes in the run-off in different parts of the catchment; one option to achieve this is to use a high-resolution atmospheric model such as RAMS (Regional Atmospheric Modelling System) to investigate the behaviour of historical storms under a warmer atmosphere. Much of New Zealand’s rainfall has an orographic component and the upwind and downwind rainfall changes over complex topography associated with wind changes can be evaluated with such a model.

Other climate changes that may be of relevance to stormwater design are changes in temperature itself (temperature influences evaporation rates from organic surfaces and hence initial water retention capacity), and changes in mean rainfall (which also affects the initial water retention capacity of pervious surfaces). Both aspects could therefore lead to a shift between the fast and slow run-off components of a stormwater model and may need to be incorporated into stormwater models to obtain a robust picture of performance under future climate conditions.

Table 1 summarises the types of climate changes that may be most relevant for stormwater system performance.

Table 1: Climate changes relevant for stormwater design.

Type of change	Relevance for stormwater planning
Increase in heavy rainfall	Increase in total rainfall depth for design storm events for durations of up to 72 hours
Change in mean rainfall	Change in antecedent soil moisture saturation
Increase in mean temperature	Change in evaporation from soils and ponds, which changes antecedent soil moisture saturation
Increase in wind	Changes in rainfall over complex topography – increases upwind of hills and ranges

3. Why and when do we have to consider climate change?

3.1 Mainstreaming climate change

Climate change is not a stand-alone issue. Councils can consider climate change effects via existing resource management, risk-assessment and decision-making processes. As a rule of thumb, wherever *current* climate (e.g. rainfall) is significant to an activity, hazard or plan, expected *future* climate should also be assessed for its impact. Where climate change effects are expected to be negligible for a particular activity, hazard or plan, no action will be necessary, although periodic review of climate change effects may still be required. Where effects are expected to be significant, these will need to be addressed.

3.2 RMA

While the need to recognise and plan for the effects of climate change is implicit in a risk-based approach to stormwater design, the Resource Management (Energy and Climate Change) Amendment Act 2004 introduced a new “other matter” into Part II of the RMA, requiring that particular regard be given to the effects of climate change (section 7(i)). In the context of the RMA, there are two ways in which particular regard may be given to the effects of climate change, and in particular the planning and design process for stormwater systems:

1. As an integral part of making decisions on resource consent applications and notices of requirement under the RMA for which the effects of climate change may be significant, and ensuring that system design led by councils explicitly addresses the question of what effect climate change is likely to have on the stormwater system performance over its design lifetime; and
2. In proactively reviewing RMA policy statements and plans to identify whether more explicit and/or up-to-date policies are needed to address the effects of climate change than are currently provided. These plans can provide important context for specific stormwater design and planning steps.

The second point directly relates to Council’s broader strategic planning initiatives. The effects of climate change can be integrated into local authorities’ longer term planning under the Local Government Act, as part of their mandate to take a sustainable development approach.

3.3 Local Government Act

The Local Government Act (LGA) outlines administrative and management responsibilities for regional and district councils, including land management, utility services, recreation assets, transportation and the associated provision of services. The LGA therefore provides an important framework for consideration and integration of climate change effects into council functions and services.

The LGA also requires councils to prepare Long Term Council Community Plans (LTCCP), which have the purpose of describing community outcomes for the district or region, providing a long-term focus for local authority decisions, and providing financial estimates to manage council/community assets. The community consultation required for preparation of LTCCPs is a cornerstone of the LGA, and includes specific consultation requirements when preparing these plans, or bylaws under the Act. Community consultation on LTCCPs may therefore represent an important vehicle to gather community views on how councils should respond to climate change, and what levels of service are considered relevant for longer term planning in a changing climate.

4. How do we incorporate climate change into design?

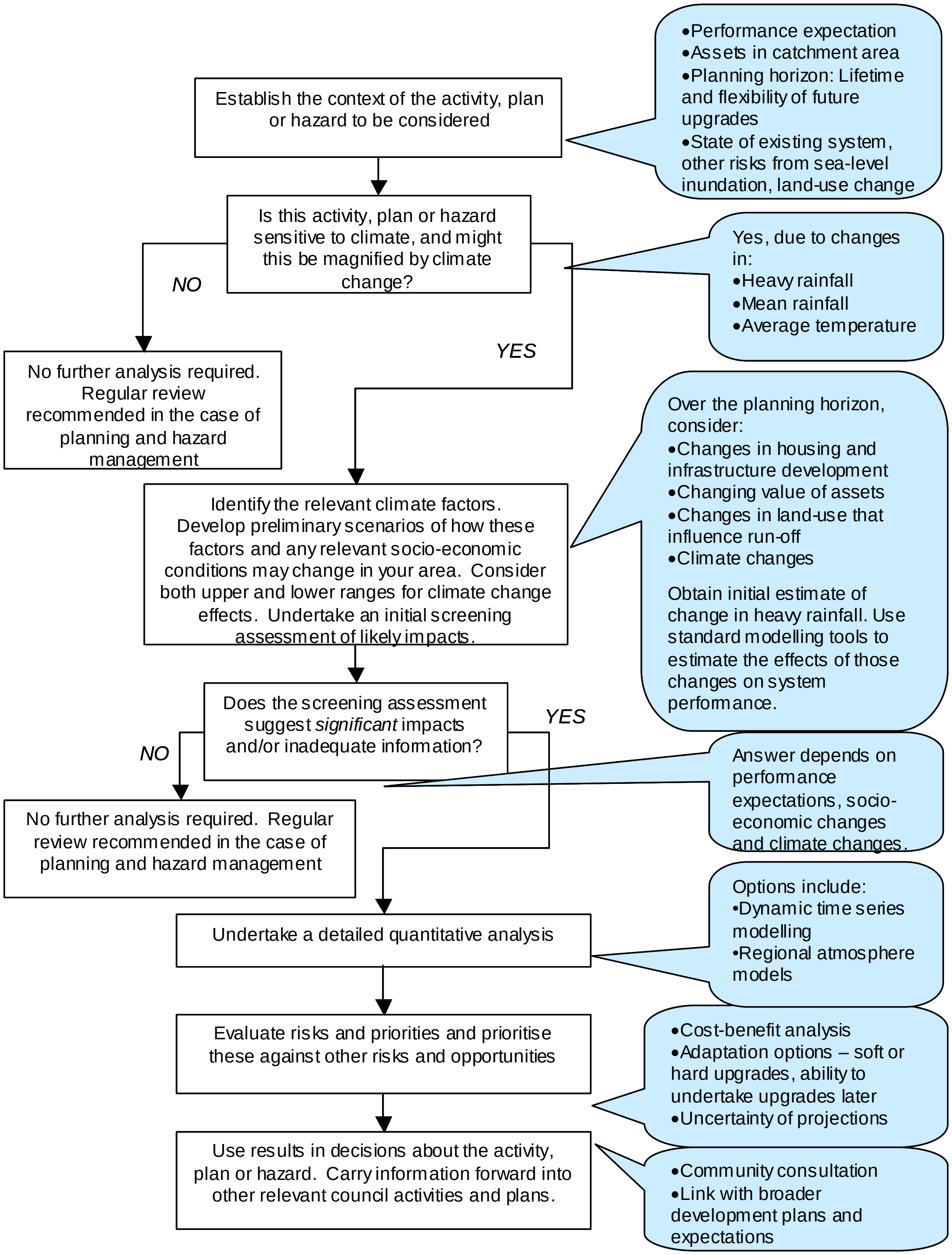
4.1 Generic risk assessment process

New Zealand Climate Change Office (NZCCO) of the Ministry for the Environment has produced generic guidance on how to assess the effects of climate change on a range of council functions and services and to develop appropriate responses. Generally, councils can use a series of steps of increasing complexity to assess whether climate change is relevant to a particular council function, how significant its impact might be, and the appropriate response.

The first step is to identify *qualitatively* whether a specific council function or service could be affected by climate change or, more generally, which council functions are vulnerable to climate variability and, therefore, to climate change. If this process identifies a possible climate change effect, an initial *quantitative* assessment or “screening” analysis should be undertaken. This consists of using a range of *scenarios* for climate change and other drivers to test *quantitatively* the likely significance of climate change, and whether existing planning and management provisions have a sufficient safety margin to cover any resulting change in risk or resource availability. If it appears that existing provisions do not adequately cover the future change in risk, a more complex scientific and technical risk assessment should be undertaken, followed by an analysis of response options to manage the risk over appropriate timeframes.

This generic assessment and decision-making framework can be directly applied to stormwater system design and planning, as illustrated in Figure 1. Many of the steps are identical to the steps that need to be undertaken in any stormwater design and planning process, including consideration of community expectations and consultation on responses. The only modification to the normal planning process is the consideration of long-term climate changes that could affect the system performance over its lifetime, or that may limit later upgrades in response to a changing climate.

Figure 1: Generic framework for climate change risk assessments, with specific examples in the context of stormwater system design and planning. The generic decision steps are from the Quality Planning Guidance Note on Effects of Climate Change under the Resource Management Act (www.qp.org.nz).



4.1.1 Step 1: Establish the Context

Table 2 outlines a number of different ways in which climate change can affect stormwater design. Different types (and locations) of stormwater catchments are likely to respond differently to the effects of climate change. The performance criteria for a catchment's stormwater system can also influence the extent to which climate change will affect the system performance.

Table 2: Climate change projections and their relevance for stormwater design.

Type of change	Range of changes for 2030s	Range of changes for 2080s	Relevance for stormwater planning	Possible additional expertise and in-depth studies
Increase in heavy rainfall	Return frequency increases with temperature (up to twofold - specific figures in Table 2)	Return frequency increases with temperature (up to fourfold - specific figures in Table 2)	Increase in total rainfall depth for design storm events for durations of up to 72 hours	More complex rainfall modelling (e.g. RAMS model) or dynamic time series modelling
Change in annual mean rainfall	-19 to +22% (depending on region)	-32 to +57% (depending on region)	Change in antecedent soil moisture saturation	Modelling of soil moisture saturation for pervious catchment areas
Increase in annual mean temperature	0.1 to 1.4ºC (with some dependence on region)	0.2 to 4.0ºC (with some dependence on region)	Change in evaporation from soils and ponds, which changes antecedent soil moisture saturation	Modelling of soil moisture saturation for pervious catchment areas
Increases in wind	Not quantified: highly location specific but with a trend nationally to increased westerlies	Not quantified: highly location specific but with a trend nationally to increased westerlies	Changes in rainfall over complex topography – increases upwind of hills and ranges	More complex airflow and rainfall modelling (e.g. RAMS model)
Sea level rise	0.2 m	0.5 m	Changes to stormwater discharge, saltwater intrusion in coastal zones	

Note: Figures provided in this Table should only be used for a preliminary screening assessment; if based on this preliminary assessment the effects of climate change are potentially significant, a more in-depth assessment using additional expertise should be carried out. Table adopted from MfE (2004a) and MfE (2004b)

The first step in undertaking an analysis of the potential effects of climate change on stormwater management is to clearly determine what type of study is being undertaken:

- Performance expectations – what level of service is required? Does the primary system need to contain a specific rainfall (i.e. the 1 in 10 year rainfall event), or do you have a secondary system (e.g. overland flow paths) that has additional capacity?
- Review the assets – are there a lot of ponds, open channels, or large, expensive infrastructure?

- What is the planning horizon for the catchment – is there flexibility to stage upgrades, or do the assets need to last for the next 100 years?
- Is the stormwater system already under-capacity, or requiring upgrades?
- What other changes need to be considered alongside climate change (e.g. change in land use)?

4.1.2 Step 2: Sensitivity test

The sensitivity of a catchment to climate can influence the extent to which a study is adjusted to consider changes in rainfall and sea level patterns. It is important to be familiar with the catchment – identify the assets in the catchment, and think about how they might perform differently given different climate scenarios. Establishing the scale of the potential change in climate and sea level rise is also important at this stage. Note that in some areas in New Zealand *mean* rainfall is projected to decrease but there may still be a risk of *heavy* rainfall events increasing in intensity.

Catchment location

The location of a catchment should be considered when determining whether or not climate change is going to have a significant impact on the stormwater system performance. The predicted magnitude of the potential changes in climate varies depending on the location of the catchment within New Zealand.

In coastal areas the receiving environment should also be reviewed to check to whether changes in sea level would make a significant difference to the performance of the stormwater system.

Land Use and Topography

The land use and topography in the catchment can have an effect on a number of stormwater planning considerations. The imperviousness and slope of the catchment affects the amount of soil storage that is available, and the speed at which the rainfall leaves the catchment in the form of stormwater. Changes in rainfall depth and intensity have less chance of being 'absorbed' within the catchment if there is a high level of imperviousness, or the slope is great.

Land use can also dictate the requirement for levels of service – highly populated areas can require a higher level of protection than open space, for example, and the effects of a slight change in rainfall can have greater consequences in an urbanized catchment.

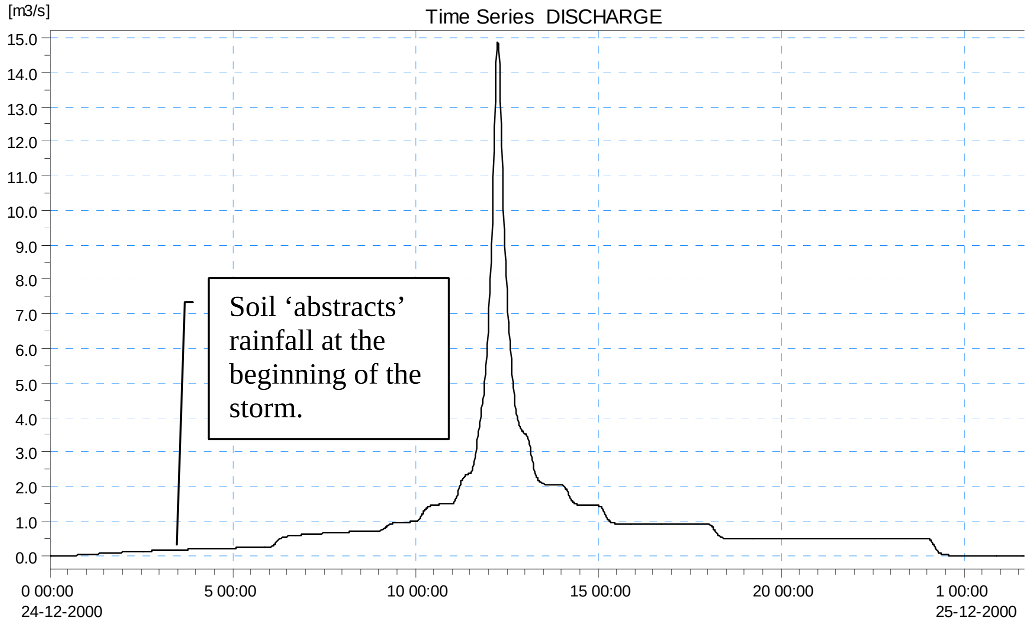
Topography also has an influence on rainfall through its interaction with wind to generate vertical motions in the atmosphere (which is why, on a large scale, the west coast of the South Island is relatively wet and the east coast relatively dry). Mean westerly winds over New Zealand are expected to increase with climate change, and the local winds associated with storms may also increase.

Yet another impact of topography is through storage in the catchments, such as in ponds and floodplains, which can have a significant effect on the ability of a catchment to cope with climate change. Ponding areas (constructed or natural) can act as a buffer for a slight increase in rainfall intensity, and protect downstream properties and infrastructure from increased flows. Floodplains may accommodate an increase in flows without a significant increase in water level.

Soil Types

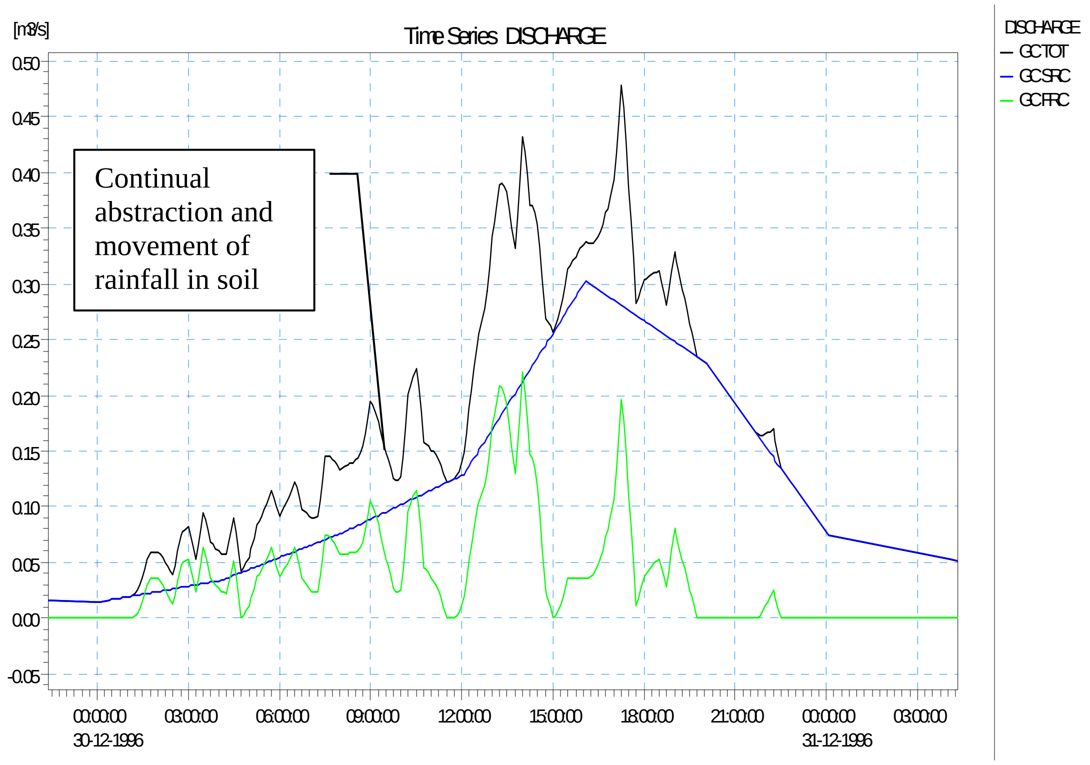
Some soil types have a greater ability to provide storage for rainfall. Soil storage is a key component in stormwater modelling, and is incorporated into stormwater models in a number of different ways. In design storm modelling, soil storage is interpreted as a preliminary abstraction of rainfall (in mm) (Figure 2); whereas dynamic or time series modelling treats the soil as a 'slow flow' component of stormwater, that moves water at a slower rate than the impervious surfaces (Figure 3). Erosion-prone soils may suffer increased erosion with increases in rainfall intensity, or changes in wetting/drying patterns. This may not be able to be incorporated into stormwater modelling and quantity management with current practices, but should be considered when managing stormwater quality from the catchment in terms of sediment loads and erosion problems.

Figure 2: Runoff from a design storm model



Soil ‘abstracts’ rainfall at the beginning of the storm.

Figure 3: Runoff from a dynamic model, showing slow response (SRC) and fast response (FRC) components



Continual abstraction and movement of rainfall in soil

Network

The stormwater network will be affected by changes in rainfall if the catchment has not managed the changes internally as discussed above. The type of infrastructure in the catchment can also influence whether or not the effects will be significant. As with floodplains, water levels in large open channels may not be significantly affected by a change in flow. However, smaller infrastructure may be more sensitive to changes, and this, coupled with the consequences of failure (i.e. surrounding land use, availability of overland flow paths) should be considered when assessing the sensitivity of the catchment to changes in climate.

Sea level can also control the flow capacity of infrastructure. Increases in sea level and tidal influence may submerge infrastructure and greatly reduce the rate at which water leaves a catchment.

4.1.3 Step 3: Initial Screening

Climate scenarios and initial screening

The following sections discuss the steps involved in a screening assessment of climate change impacts, using the Wairau Valley Catchment, North Shore City, as an example. This catchment is approximately 1300ha in size, and is characterised as a mixture of residential and industrial/commercial land uses. The catchment is highly impervious, and has a large public stormwater system, including ten ponds, and a number of highly modified stream channels.

A qualitative assessment, as described above, indicated that climate change might need to be considered in Stormwater planning in the catchment.

Identify the Climate Factors

The booklet *Preparing for Climate Change* (MfE 2004a), published by the New Zealand Climate Change Office of the Ministry for the Environment, contains a set of figures that can be used to undertake a preliminary (or “screening”) assessment of the potential relevance of future climate changes on stormwater system performance. It must be emphasised however that these figures are very generic and should not be used to drive ultimate decisions; they are only intended to provide councils and engineers with a low-cost, preliminary estimate of the potential for climate change to significantly affect system performance. If this screening assessment shows the potential for significant changes, a more detailed assessment should be undertaken that takes catchment characteristics into account.

Heavy rainfall is generally expected to increase under climate change because for a given relative humidity, warmer air holds more moisture. It is assumed that the average relative humidity of air parcels will not change, so the warmer temperatures mean that more water is available in storms to be dumped in catchments, leading to increased run-off and hence pressure on stormwater systems. As a first estimate, one can use estimated increases in temperature to calculate the percentage increase in heavy rainfall compared to current conditions.

Preparing for Climate Change contains tables for regional projections of temperature increases for a range of future greenhouse gas emissions as well as a table to calculate the percentage increase in heavy rainfall per degree temperature increase, for a range of rainfall durations and Annual Return Intervals (ARIs) of the rainfall events in question.

Due to uncertainties in future greenhouse gas emissions, as well as uncertainties in climate models, there is no single best prediction of future rainfall changes. Instead, it is recommended that a preliminary screening assessment use appropriate upper and lower estimates of future temperature changes to cover a range of possible futures. This process is illustrated in detail below.

Case Study Example

The *Preparing for Climate Change* guidelines offer information regarding potential climate change over two different periods, 1990-2030s and 1990-2080s. Because stormwater infrastructure generally has a design life of more than 30 years, the planning horizon of 1990-2080s has been used in this example.

a) Determine the likely change in mean temperature for the area

'Low' and 'high' climate change scenarios can be derived from the range for the change in annual mean temperature for Auckland given in Table 2 of *Preparing for Climate Change,* which is 0.6 to 3.8°C.

Further information is available in the full guidance manual (MfE, 2004b) and Figure 2.2 of this manual has been used to derive as well a medium climate change scenario of 2.0°C.

Table 3: Projected increase in Auckland annual mean temperature over the period 1990 to 2080s

Scenario	Increase in annual mean temperature (°C)
Low	0.6
Medium	2
High	3.8

b) Translate the change in mean temperature to a change in 24-hour rainfall

Using Table 7 of the *Preparing for Climate Change* document (which gives an estimate of the percentage increase in heavy rainfall per degree temperature increase – see appendix), and the temperature scenarios provided above, the following table has been developed to show the associated percentage increase in 24-hour rainfall depths for storms of various frequencies.

Table 4: Percentage increase in 24-hour rainfall depth for a range of events and three different climate scenarios

Rainfall Event ARI	Percentage change per degree warming	Percentage increase in 24- hour rainfall = (% change per degree warming) x (°C increase in annual mean temperature)		
		Low **(+0.6 °C)**	**Medium** **(+2°C)**	**High** **(+3.8°C)**
2 year	5.4%	3.2%	10.8%	20.5%
5 year	5.9%	3.5%	11.8%	22.4%
10 year	6.2%	3.7%	12.4%	23.6%
20 year	6.4%	3.8%	12.8%	24.3%
50 year	6.6%	4.0%	13.2%	25.1%
100 year	6.7%	4.0%	13.4%	25.5%

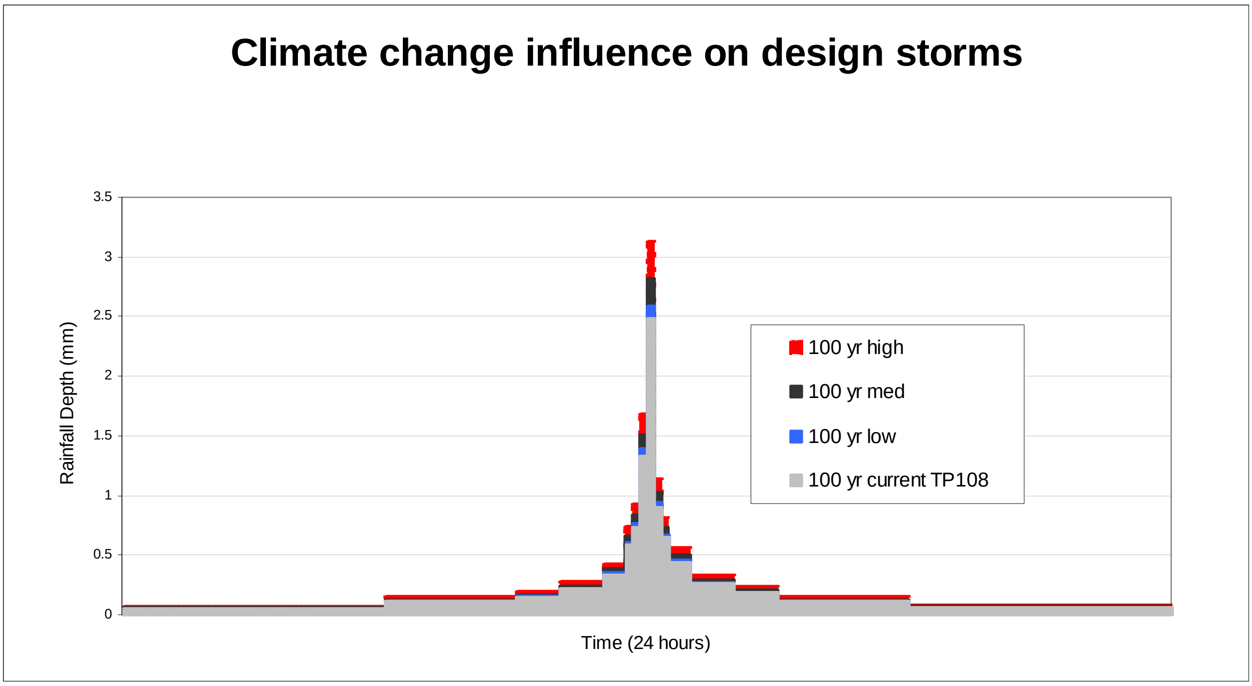
c) Translate the percentage change in rainfall depth into mm

Using design storm depths for the Wairau catchment from ARC (1999) TP108, the following table was developed to quantify the potential increase in 24-hour rainfall depth. Figure 4 depicts the influence of the increase in rainfall on the design storm shape.

Table 5: 24-hour rainfall depths for current and three future climate scenarios

Rainfall Event ARI	24-hour design storm rainfall depth (mm)			
	TP108 current climate	Future Climate Scenario		
		Low	Med	High
2 year	80	83	89	96
5 year	115	119	129	141
10 year	140	145	157	173
20 year	165	171	186	205
50 year	195	203	221	244
100 year	221	230	251	277

Figure 4: Comparison of present and three possible future design storms



In this example, the future climate scenarios can be seen to have a noticeable effect on the design storm in this catchment (up to 25% increase in rainfall depth during the storm), particularly at the peak of the storm. The relevance of this result should, in the general case, be reviewed with respect to the sensitivity of the catchment, and the identification of areas in the catchment that would be most affected by a change in the rainfall.

In the case of the Wairau Valley Catchment in North Shore, a potential 25% increase in rainfall would warrant further exploration, considering that the catchment is highly impervious, and the increased rainfall is likely to quickly impact on the stormwater system's capacity, potentially elevating the risk of flooding in the urbanised catchment.

Simple hydrological / hydraulic modelling

In order to determine how much of an impact the increased rainfall could have on the stormwater system, hydrological and hydraulic modelling can be undertaken. There are a number of methods available for this type of modelling, ranging from a simple calculation of catchment runoff (which may be appropriate for undeveloped catchments with limited infrastructure), through to more sophisticated network and floodplain models that also include routing of flows through pipes, channels, streams and ponds.

A simplified network model was developed of the Wairau Valley catchment. The current and future rainfall scenarios were developed as described above, based on the TP108 design storm for the Wairau Valley catchment, with the current design storm factored up as in the *Preparing for Climate Change* guidelines to develop the 'low', 'medium' and 'high' case storms.

The results of the models were compared in a number of different ways; catchment runoff, flows in the network, and water levels in the open channels and floodplains.

Catchment runoff

Table 6 below provides catchment runoff data for three of the subcatchments in the Wairau Valley catchment. The subcatchments have been split into impervious and pervious components, and it can be seen that in the impervious catchments, the increase in rainfall depth is directly translated into an equivalent percentage increase in peak runoff. The effect of the change in rainfall depths is enhanced in the pervious catchments because the initial abstraction of rainfall by the soil (which in design storm modelling is a constant value) is smaller in proportion to the amount of rainfall falling during the storm.

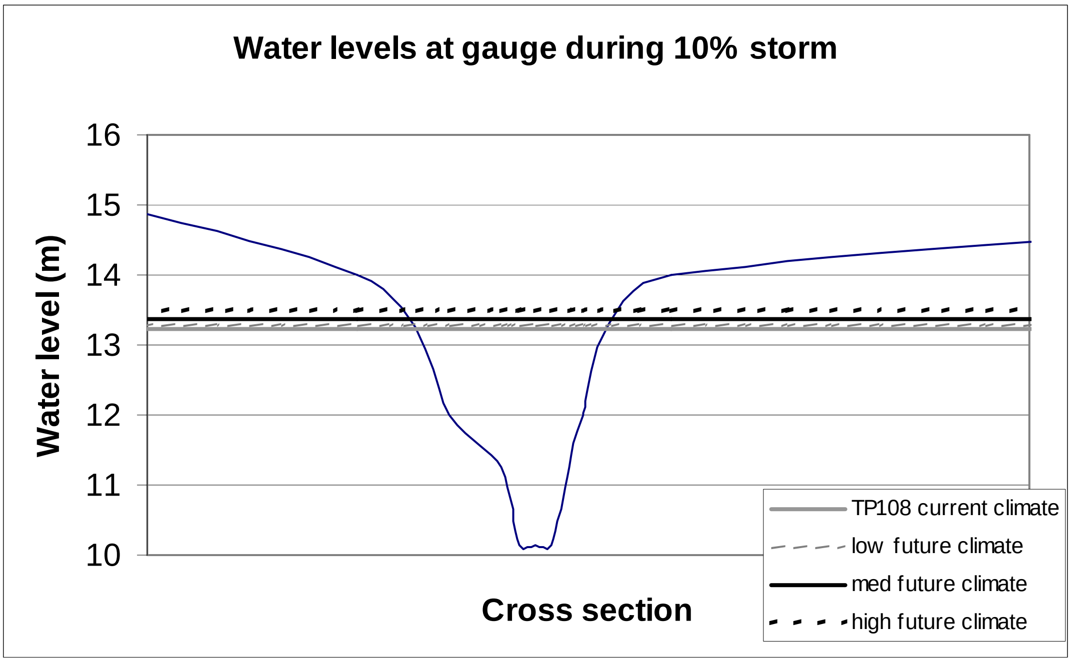
Table 6: Catchment runoff under current and 3 future climate scenarios for a 10 year ARI event

	Current	Future (low)		Future (med)		Future (high)	
Catchment	Peak discharge, m3/s	Peak discharge, m3/s	% increase from present	Peak discharge, m3/s	% increase from present	Peak discharge, m3/s	% increase from present
Cmt 1 impervious	9.851	10.221	4%	11.084	13%	12.192	24%
Cmt 1 pervious	5.712	6.02	5%	6.747	18%	7.692	35%
Cmt 2 impervious	20.259	21.021	4%	22.796	13%	25.077	24%
Cmt 2 pervious	2.436	2.575	6%	2.907	19%	3.341	37%
Cmt 3 impervious	12.962	13.449	4%	14.585	13%	16.044	24%
Cmt 3 pervious	1.451	1.543	6%	1.766	22%	2.062	42%

Water Levels

Because the Wairau catchment has large open channels, the effects of an increase in flows due to climate change did not lead to a large increase in water levels in the open channels. Figure 5 demonstrates the relatively minor effects on channel water level the potential climate change can have, where storage capacity is large.

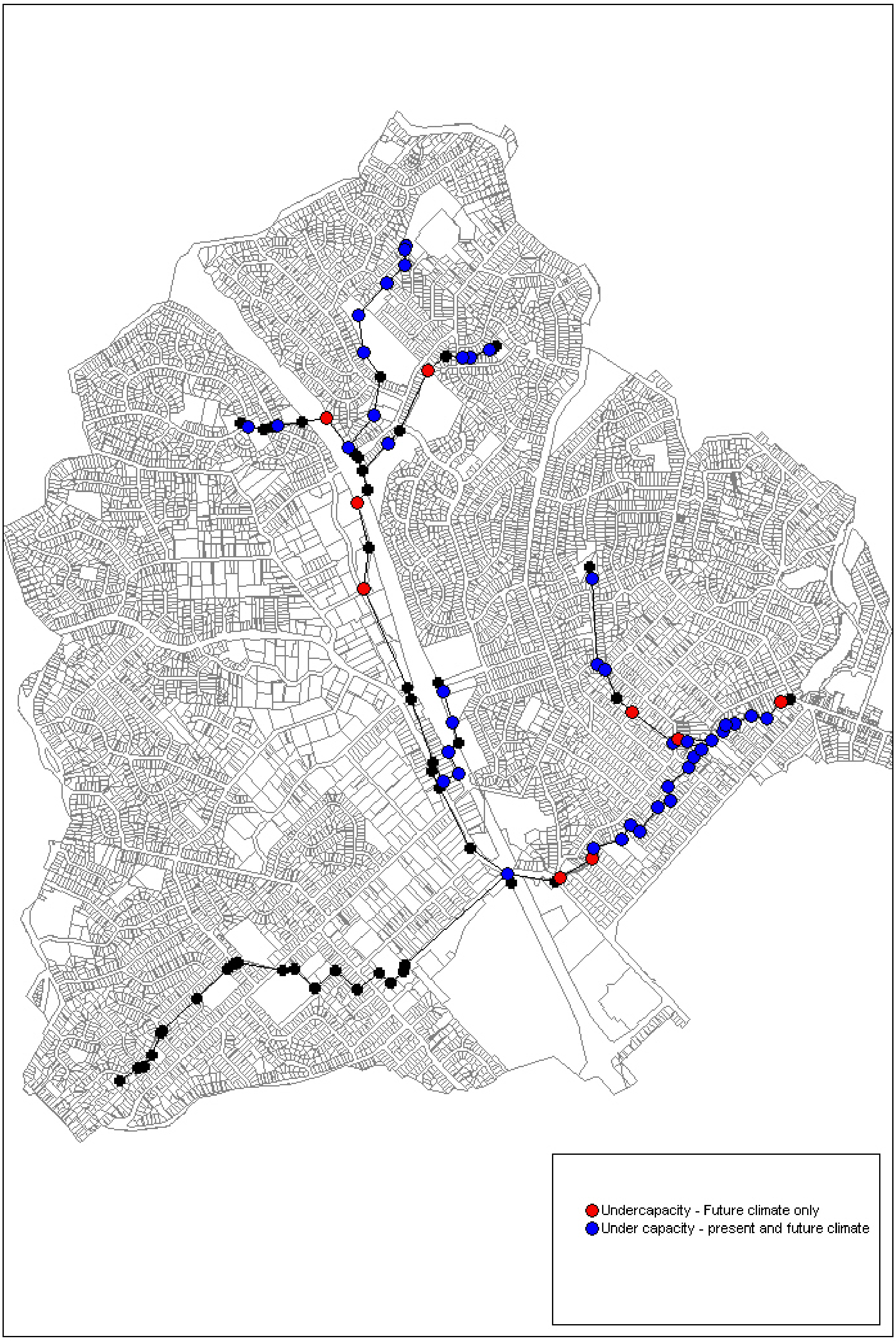
Figure 5 – Comparison of water levels for current and future climates in open channel



Flooded assets

The model was set up with 'critical levels' set for the top of banks, or ground level of manholes, to show when the flood waters breached the primary system. A total of 41 points in the model were reported as flooding during the 10 year ARI under the present climate (using the TP108 design storm model). A further 9 locations were reported to flood under the worst-case future climate scenario. Figure 6 depicts the flooded locations for the present and future scenarios. This can be used to identify where a stormwater system would need to be upgraded to meet a 10 year ARI level of service, now or in the future.

Figure 6: Flooded Locations in Wairau Catchment during 10% design storms- present and 'worst case' potential future climate



4.1.4 Step 4: Detailed analysis

Modelling

In instances where the simplistic modelling indicates that climate change may have a significant impact on the stormwater infrastructure performance in a catchment, more detailed modelling may provide greater understanding of the potential impacts of climate change. One option is to use a high-resolution (5 km or less) atmospheric model such as RAMS to explore how storms and their resulting rainfall will be modified at the particular catchment location, under a changed climate. The models, similar to those used for weather forecasting but with a higher resolution, simulate the changes in storm structure and lifetime under the impact of the local topography and the changes in temperature, humidity and larger-scale winds. The spatial and temporal pattern of the resulting rainfall can be input directly into suitable catchment hydrological and hydraulic models to determine stormwater flows, but the models are complex and generally require a high level of expertise to use.

The use of time-series rainfall data enables a hydrological and hydraulic model to explore a system's response to wet/dry periods, as well as increased rainfall depth and duration.

Where such data is available, it is expected that a dynamic modelling approach can produce a more accurate picture of catchment flows and volumes and the resulting impacts on stormwater infrastructure than the simple 'design storm' approach, for both a present and future climate. However, implementing the dynamic modelling approach, as for the high-resolution atmospheric modelling approach, is likely to require greater levels of expertise and may also be more open to errors in its application.

In 2003, North Shore City Council embarked upon such a detailed series of studies using the dynamic modelling approach to investigate the potential impact of climate change on the Wairau Valley stormwater system. The following studies were carried out;

1) Stochastic rainfall generation – the development of one 'current' and three possible 'future' climate rainfall files (each comprising 5, 30-year blocks, combined to make 150 – year time series');
2) Design storm development - development of design storms of various return intervals from the stochastic rainfall time series data;
3) Hydrological and hydraulic modelling – to compare the time series and design storm approaches, and how they predict climate change effects.

The stochastic rainfall generation model (Cowpertwait, 2003) developed the three future rainfall files, based on the following assumptions:

***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%. (representing the 'worst case)

The simplistic network model described above for the design storm modelling was also used to model the response of the stormwater system to time-series rainfall data. The main comparison was between the 'present' climate and 'Future 3' climate using both the design storm and dynamic model results.

The dynamic modelling was found to predict fewer flooding events throughout the system than the design storm method. This is attributed to the increased dry periods in the future climate time series enabling ponds and soils in the catchment to dry out and act as a 'buffer' for the increased rainfall in a particular event. The increase in dry periods is difficult to replicate in a design storm, because the high intensity 'events' in the time series are clustered together to form a single storm.

The dynamic modelling study (URS, 2004) reached the following conclusions:

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 assumption 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 than when using 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.

4.1.5 Step 5: Evaluation and decision making

QBL

Quadruple bottom line assessment requires that the social, cultural, economic and environmental impacts of a planned project be considered prior to its implementation. Stormwater management can have a significant effect on all of these assessment criteria; the requirement to protect public health and safety must be weighed against the cost, effect on the environment, and cultural sensitivity to changes in hydrological regime. Modelling results provide background information to enable this analysis to be undertaken.

The inclusion of climate change predictions in stormwater planning can have implications on the cost of a project; however it can also provide some surety that the safety of communities in the future is being considered along with the safety of the present community.

The information available (model results, cost estimates, assessment of effects) can be used to develop a plan for implementation of stormwater works. It will need to be determined whether or not works can be staged (i.e. climate change upgrades incorporated sometime in the future, or upgrades implemented now), and also whether climate change should be managed via 'hard' engineering options (e.g. pipe upgrades), or through secondary systems such as overland flow paths. This is particularly important, given that there is some uncertainty with respect to the likely magnitude of climate change effects.

4.1.6 Consultation

Community input into the options available for stormwater management is essential. With the uncertainty in climate change predictions, it is likely that there will be a variety of options that could be implemented, ranging in scale, complexity and cost. The community needs to be consulted to establish the level of protection they wish to have now, and maintain in the future.

Planning horizons affecting population and land use must also be considered when developing stormwater management options – consultation with planning stakeholders is therefore important to ensure that likely development scenarios are incorporated into the stormwater planning phase. Time frames of population and land use change are also important, particularly when determining the planning horizon for infrastructure.

5. Conclusions

This paper has discussed and illustrated a suggested framework for incorporating climate change into stormwater planning. A number of conclusions can be reached:

- Councils are legally required to consider climate change in decision making;
- Climate change has the potential to have a large impact on stormwater management and the levels of service provided by stormwater infrastructure;
- There is uncertainty in the predictions of future climate, meaning that a range of possible future climates should be considered when planning for the future;
- There are a range of possible climate scenarios for each area of New Zealand, and the stormwater management effects are also likely to be site and catchment-specific;
- There are a number of different approaches to estimating the impacts of climate change on stormwater infrastructure, ranging from simple calculations to complex models;
- A staged approach to stormwater planning is likely to be the most cost-efficient and transparent way of considering climate change.

6. Disclaimer

This paper is presented to illustrate the process of applying climate change assessment to stormwater planning. No endorsement of any particular technique for modelling rainfall and stormwater systems is intended.

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APPENDIX

Changes in peak rainfall in percent per degree temperature increase, for a range of Annual Return Intervals (ARI) and rainfall durations. Adapted from Table 7 of ‘Preparing for Climate Change’, MfE (2004a).

ARI (years) → **Duration ↓**	**2**	**5**	**10**	**20**	**30**	**50**	**60**	**70**	**80**	**90**	**100**
< 10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
30 minutes	7.4	7.5	7.6	7.6	7.7	7.7	7.7	7.7	7.7	7.7	7.7
1 hour	7.1	7.2	7.4	7.4	7.5	7.5	7.5	7.5	7.5	7.5	7.5
2 hours	6.7	7.0	7.1	7.2	7.3	7.3	7.3	7.3	7.4	7.4	7.4
3 hours	6.5	6.8	7.0	7.1	7.1	7.2	7.2	7.2	7.2	7.2	7.2
6 hours	6.3	6.6	6.8	7.0	7.0	7.1	7.1	7.1	7.1	7.1	7.1
12 hours	5.8	6.2	6.5	6.6	6.7	6.8	6.8	6.8	6.9	6.9	6.9
24 hours	5.4	5.9	6.2	6.4	6.5	6.6	6.6	6.6	6.7	6.7	6.7
48 hours	4.6	4.9	5.1	5.2	5.3	5.4	5.4	5.4	5.4	5.5	5.5
72 hours	4.3	4.6	4.8	5.0	5.1	5.2	5.2	5.2	5.3	5.3	5.3

Note: This table recommends percentage adjustments to apply to extreme rainfall per degree Celsius of warming, for a range of average recurrence intervals (ARIs) and rainfall durations. The percentage changes are mid-range estimates per degree Celsius and should only be used in a preliminary scenario study. The entries in this table for durations of 24, 48 and 72 hours are based on results from a regional climate model driven by an equilibrium climate model, and will be updated once regional model runs driven by transient climate models are available for New Zealand. The entries for 10-minute duration are based on the theoretical increase in the amount of water held in the atmosphere for a 1°C increase in temperature (8%). Entries for durations between 10 minutes and 24 hours are based on logarithmic (in time) interpolation between the 10-minute and 24 hour rates.