WATER SECURITY OR WATER RESILIENCE?

CLIMATE RESILIENT WATER MANAGEMENT IN WELLINGTON NEW ZEALAND

by

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Climate change is not "a problem" waiting for "a solution". It is an environmental, cultural and political phenomenon that is reshaping the way we think about ourselves, about our societies and about humanity's place on Earth.

Mike Hulme, 2009

Abstract

A confluence of factors including population growth, climate change, resource constraints and legacy effects poses significant challenges to the sustainability of cities worldwide. With the deep complexity inherent in socio-ecological systems, ‘solutions’ sometimes shift the problem in space or time or drive the system in the opposite direction than intended. A case study into climate change adaptation and community resilience in the context of urban water management was undertaken in Wellington, New Zealand, using a ‘post normal’ science approach. Climate change and water demand scenarios for 2040 and 2090 were analysed using Greater Wellington Water’s ‘sustainable yield’ model and downscaled general circulation climate model data. Semi-structured interviews and a systems modelling workshop were conducted in order to gain an understanding of the local context for adaptation, resilience and response option selection. With a 20% reduction of aggregate per capita demand and greater storage capacity, Wellington has sufficient water from current sources to smooth increased flow variability due to climate change and to meet increased demand from the projected increase in population. Adaptation pathways and the potential for ‘maladaptation’ is explored and an integrated framework for optimising urban water resilience developed.

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Glossary of Terms

Community – used in a socio-ecological system sense, to represent an interdependent population of people, including households and businesses.

Exposure – relates to biophysical factors such as climatic variables, including the variability and frequency of extremes.

Institution – The term ‘institution’ is used in a very broad sense:

> *Institutions are the conventions, norms and formally sanctioned rules of a society. They provide expectations, stability and meaning essential to human existence and coordination. Institutions regularise life, support values and produce and protect interests* (Vatn 2005, p.60).

Sensitivity – the degree to which a system is affected by a given exposure and relates to both biophysical and socio-economic factors (IPCC 2007b). For example watered lawns are drought sensitive, and the installation of inefficient appliances and fixtures leads to a legacy effect of excessive water consumption, which over time increases community sensitivity to the impacts of drought.

Structural demand management – Structural strategies target contextual and external barriers to water conservation, including the uptake of resource efficient technology and practices.

Water Conservation – Saving water in general, including through water efficiency.

Water Efficiency – focuses on the reducing the intensity of water use for a given activity, e.g. water efficient showerheads.

Other key terms are defined either within section 2.1, or as they are discussed in the text.

Glossary of abbreviations

ASP – Annual Shortfall Probability

ARP – Annual Return Period

CCRI – New Zealand Climate Change Research Institute

CLD – Causal Loop Diagram

FRST – Foundation for Research Science and Technology

GCM – General Circulation Model

GL – Gigalitre

GW – Greater Wellington

GWW – Greater Wellington Water

HCC – Hutt City Council

IPCC – Intergovernmental Panel on Climate Change

KCDC – Kapiti Coast District Council

kL – Kilolitres = 1 kL = 1000 L

L – Litres

ML – Megalitres 1 ML = 1,000,000 L

NGO – Non Government Organisatiion

NIWA – National Institute of Water and Atmospheric Research

PAW – Potential or potentially available water

PCD – Aggregate per capita demand, TSD divided by population

PCC – Porirua City Council

RMA – Resource Management Act 2001

SYM – GWW's 'Sustainable Yield Model'.

TSD – Total System Demand

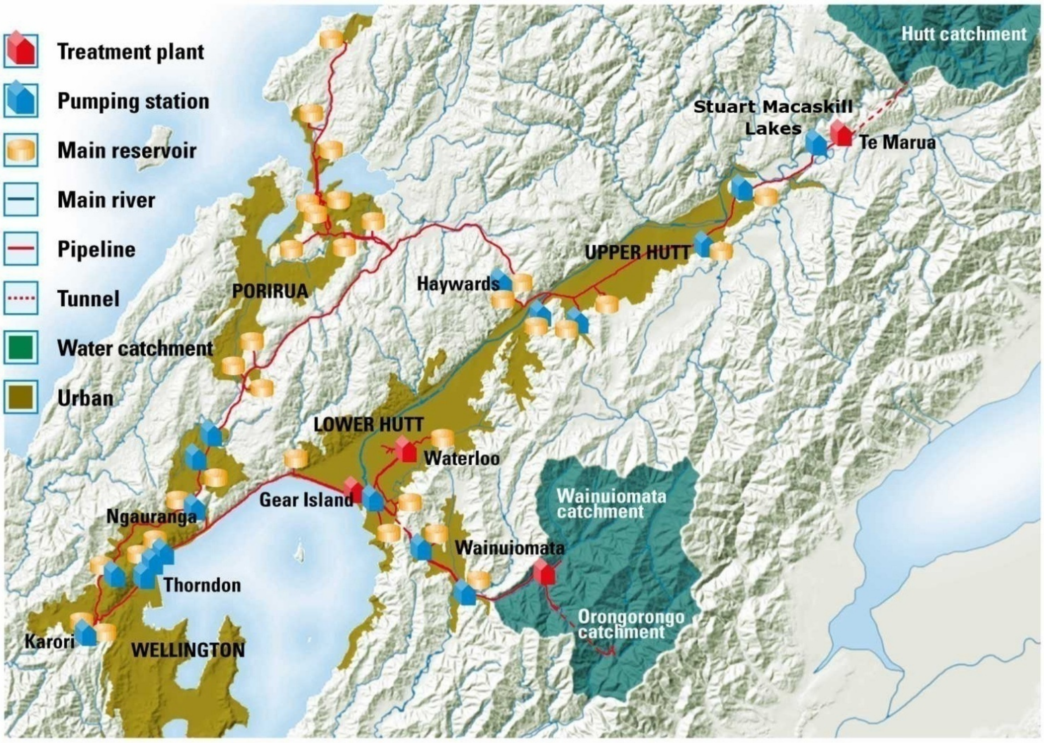
UHCC – Upper Hutt City Council

WCC – Wellington City Council

1 Introduction

The year 2010 began with record snowfalls in the United States and Britain, followed by floods in China and Pakistan, wild-fires in Russia, and a heat-wave for most of the northern hemisphere. Likewise 2011 brought widespread flooding in Australia and Thailand, and a succession of severe storms for many in the northern hemisphere. As demonstrated in Figure 1.1 climate change brings an increased likelihood of such extreme events (Hennesy et al. 2007). Moreover science is beginning to make direct links between climate change and extreme weather (Min et al. 2011), as well as to quantify the influence of a changed climate for particular extreme events (Schiermeier 2011). Extreme weather events are considered 'extreme' relative to the historic variability for the specific place affected and often the scale and impact of headline capturing events from overseas seem far greater than what could be experienced in Wellington, New Zealand. The question therefore arises as to the relative merits of situating a case study in Wellington. 'Wellington' includes the four cities of the region serviced by the one water supply network: Upper Hutt, Lower Hutt, Porirua and Wellington, as illustrated in Figure 1.1.

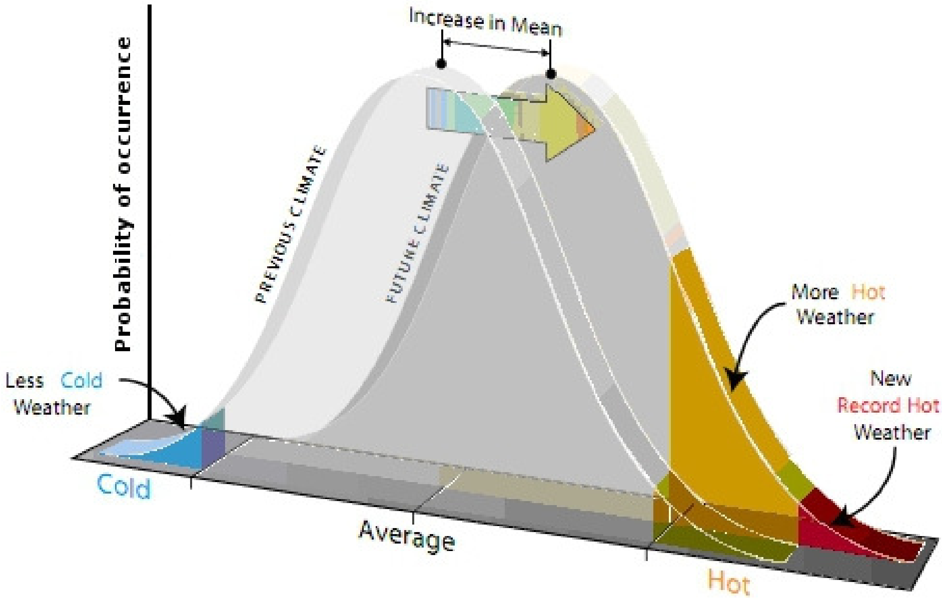
Figure 1.1. Case study location, showing Wellington's reticulated water system which services Upper Hutt, Lower Hutt, Porirua and Wellington (GWRC 2010).



1.1 Why Wellington?

In general New Zealand's climate is expected to warm less than the global average since it is surrounded by ocean (Hennessy et. al. 2007), but as shown in Figure 1.2, any increase in mean temperature can be expected to produce an increase in record hot weather. Wellington can therefore expect climate change to bring new record hot weather, but due to our moderate climate, Wellington's extremes will also be moderate in comparison to other parts of New Zealand and overseas. Wellington could therefore be considered to be 'geographically blessed' relative to the changes projected for other parts of the world or even other parts of New Zealand, such as our eastern regions (Ecoclimate 2008).

Figure 1.2. Climate change and increased risk of extremes. With regard to temperature, an increase in mean temperature within reference climate conditions results in a significant increase in the occurrence of hot weather, including record hot weather (Reisinger et al. 2010).



Wellington's current water supply system is mainly 'run-of-river', and Wellington's citizens generally perceive that water is plentiful (MfE 2009), a belief that is reflected in cultural values and norms relating to water use (Stern et al. 1999). Meanwhile considerable 'unseen' effort goes into managing urban water supply systems for 'water security', an approach which primarily focuses on managing *supply* variability. Successful management for water security serves to reinforce the perception that water is plentiful and that water variability can be controlled. Yet, as previously explained, climate change increases the risk of an event occurring which surpasses historical norms, bringing an increased frequency of 'extreme' events. Moreover urban water supply systems are built to 'manage' the variability in water availability only within 'engineeringly' feasible and financially viable parameters. Therefore, as the frequency and magnitude of extremes increases, so does the risk of 'management failure', as well as the costs of managing supply side water variability.

If the community perceives that water managers have the situation 'under control' and that water is plentiful, then just as Moscow and London are ill-equipped to cope with temperatures which surpass their own historical norms but are common in cities such as Sydney, Wellington could be ill-equipped to withstand an ‘extremely’ dry summer. Therefore with regard to resilience to ‘extreme’ drought, our geographical blessing could be a mixed one.

The potential impacts of climate change must also be considered individually for every region, especially when examining long-term infrastructure projects. This is highlighted by the experience of Melbourne, where average rainfall in the city’s water supply catchments decreased by about 19% in the years 1997-2008 compared to 1950-1997, reducing dam inflows by about 40% (Jones 2010). Regional scale analysis may indicate the potential for such shifts, which can then be taken into account when comparing options such as the proposed Whakatikei dam which would cost approximately $142 million to build (GW 2008b)[1].

1.2 Research Context

This research project is part of a wider Foundation for Research Science and Technology (FRST) funded project on climate change vulnerability, adaptation and resilience. The wider project was a joint study led by Victoria University’s Climate Change Research Institute (CCRI) and involving the University of Otago (Wellington), and Victoria University’s School of Geography, Environment and Earth Sciences.

The aim of the wider CCRI-FRST project is to develop and explore a vulnerability, adaptation and resilience framework. A successful framework will enable end-users to identify areas where near-term proactive adaptation is desirable even if the time-specific vulnerability itself becomes high only at some point in the future. The principal results from this research programme are intended to encompass multiple social

[1] The potential storage capacity of this proposed dam is 8,400 ML, of which 5,000 ML is considered ‘usable storage’ (GW 2008b).

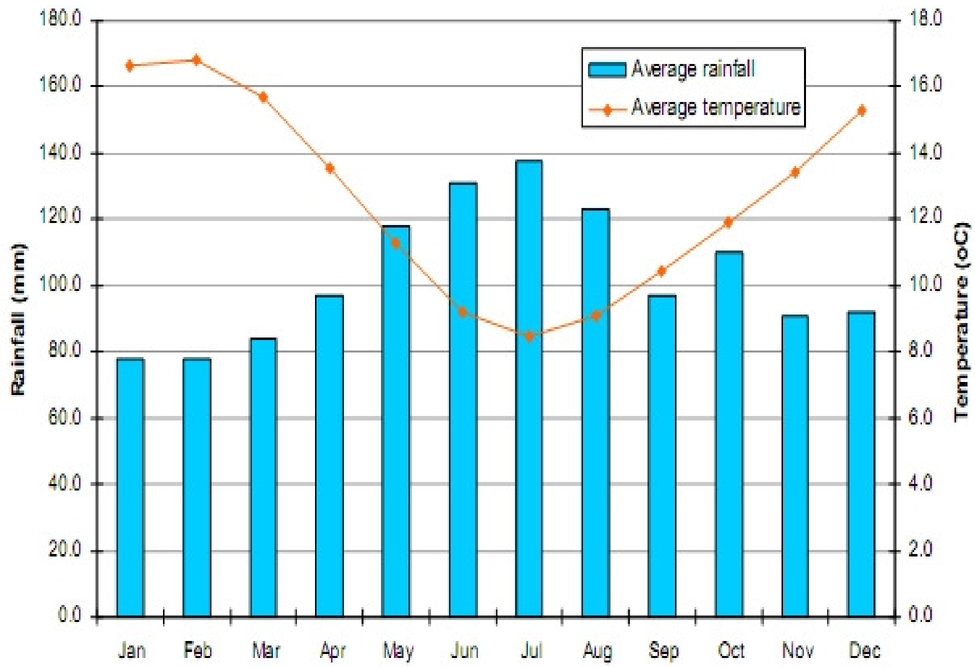
and physical factors and therefore be relevant to a wide range of situations of vulnerability to climate change.

The research project reported in this thesis is a case study of water supply management for the four cities of Wellington, Porirua, Lower Hutt and Upper Hutt which are serviced by the one reticulated network. It was conducted with the cooperation of the Greater Wellington Regional Council (GW), the National Institute of Water and Atmospheric Research (NIWA), and the Climate Change Research Institute.

1.3 Wellington's Water Management Context

Wellington is part of the temperate south-western North Island climate zone that also includes New Plymouth, Wanganui and Palmerston North. This zone is exposed to disturbed weather systems from the Tasman Sea and is often quite windy but with few climate extremes. In general, maximum daily air temperature ranges from 19°C to 24°C in summer and seldom exceeds 30°C (NIWA 2010). As shown in Figure 1.3, on average, January and February are the hottest and driest months.

Figure 1.3. Annual average rainfall and temperature for Wellington from 1978 to 2007 (GW 2008).



Greater Wellington Water (GWW) treats and distributes 'bulk' water to Upper and Lower Hutt, Porirua and Wellington cities. Water is sourced from the Waiwhetu Aquifer and the Hutt, Orongorongo and Wainuiomata Rivers. On average 40% of Wellington's water comes from the aquifer and 60% from rivers (MWH 2011). The 3000 ML Stuart Macaskill water storage lakes[2] at Te Marua provide a few weeks of summer storage (MWH 2011) and the Waiwhetu aquifer[3] also acts as a buffer during dry periods Williams 2011, pers comm). In the year to June 2010, GWW supplied an average of 145 million litres (ML) of bulk water daily to 390,000 people (GW 2010).

Under the Resource Management Act 1991 (RMA), Regional Authorities such as Greater Wellington Regional Council (GW) are responsible for the management, use and allocation of freshwater resources. The purpose of the RMA is *"to promote the sustainable management of natural and physical resources… to meet the reasonably foreseeable needs of future generations"*. GWW's purpose statement reflects this legislative influence:

> *We aim to provide enough high-quality water each day, now and in the future, to meet the reasonable needs of the people of our region's four cities, in a cost-effective and environmentally responsible way.*
> (GW 2010, p.2)

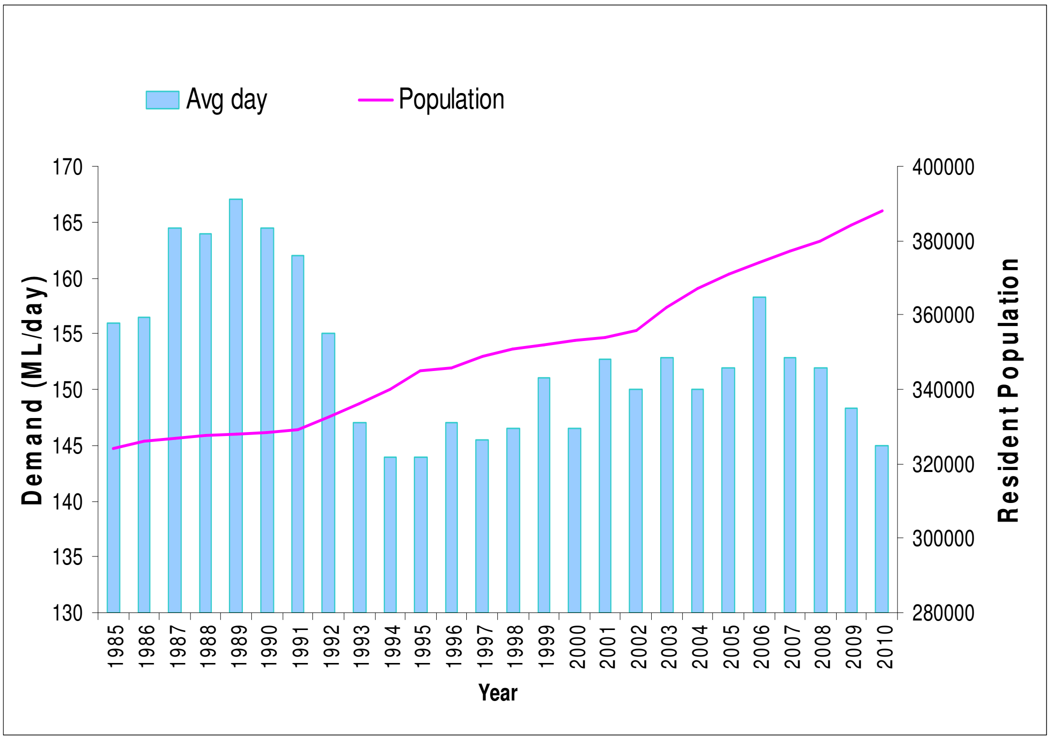
Capacity Infrastructure Services Limited, a Council-Controlled Trading Organisation owned by Wellington and Hutt City Councils, manages the water infrastructure (including wastewater) and retailing services for the water that GW delivers to Wellington, Hutt and Upper Hutt City Councils. Capacity does not own the water, stormwater and wastewater assets, set policies, or control rates and user charges; these roles remain with the councils (Capacity 2010).

[2] The storage capacity of the Stuart Macaskill Lakes will be 3390 ML once current upgrades are complete (Shaw and McCarthy 2009).
[3] Abstraction occurs at Waterloo and Gear Island, ranging from 20 – 120 ML/day, and averaging 60 ML/day (GW 2008c).

> *Capacity Infrastructure Services plans and manages the development and maintenance of the 'three waters' – drinking, storm and waste water. This includes maintaining pipes, managing and monitoring pump stations and providing advice and information on water conservation to preserve the Wellington region's water wealth now and into the future* (Capacity 2010, p.2).

GWW aims to meet a 2% 'security of supply' or Annual Shortfall Probability (ASP) standard, i.e. they aim to meet demand 49 out of 50 years. The security of supply standard represents a level of service to customers, indicating the frequency with which water restrictions could be imposed in order to manage demand (WCC 2009). As seen in Figure 1.4, since the early 1990s demand for water has not kept pace with population growth due to factors such as the decline in manufacturing in Wellington since the 1980s, urban intensification, infrastructure renewal and increased public awareness of the need for water conservation (Williams and McCarthy 2010, pers comm.).

Figure 1.4. Average daily demand (Avg day) and resident population (serviced by water reticulation network) for Wellington 1985 to 2010 (Graph updated from GW 2008).



As bulk supplier, GWW charges a water levy to its city council customers based on the relative percentage of water they use. Wellington City uses the majority (54%) of the water, Lower Hutt (25.3%), Porirua (11.7%) and Upper Hutt (9.2%) (GW 2010). Most commercial and industrial consumers are metered; however only one percent of domestic water users have meters (GW 2008). In Wellington City, meters are voluntary for residential consumers unless the residence has a swimming pool greater than 10kL in capacity (WCC, undated). The vast majority of domestic water users are not charged for water on a user pays basis, but only in relation to their property value.

1.4 Research Aim and Objectives

In addressing long-term change, local government must decide, and justify to communities, when and where near-term proactive climate adaptation measures are necessary, and where adaptation measures can wait until the projected changing stresses actually materialise. There is a risk that poorly thought out adaptation measures may affect long-term resilience to future stresses, and any justification for waiting should preferably be based on some clear principles, criteria and analysis. In relation to this temporal dynamic there will be a variety of possible policy options or combinations of options to be considered, each with a range of advantages and disadvantages.

The aim of this research project is to gain a detailed understanding of the key factors and determinants influencing water use and management in Wellington, and how key response options could affect future community and institutional adaptive capacity, and increase or decrease resilience to water shortages.

1.4.1 Research Question

This research project addresses the following central question:
What adaptive capacity and resilience features could different options or combinations of options provide for managing Wellington's water? What factors or conditions might lead to greater adaptive capacity and resilience, and what vulnerabilities might lead to insufficient adaptation or even maladaptation[4]?

Answering this question necessitates breaking it down into the following objectives:

Objective 1: Problem analysis; climate change and Wellington's supply and demand drivers

The aim of objective one is to answer the following research question:
How might climate change trends interact with water supply and demand factors to create water security and management issues for Wellington?

In order to answer this question it was broken down into the following components:

- How might climate change affect water supply and demand in Wellington?
- How might underlying trends and factors interact with climate change?
- What net effects may arise from this confluence of factors?
- What are the key implications for the management of water supply and demand in Wellington?

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[4] Maladaptation is defined as "*action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups*" (Barnett and O'Neill 2010), 'other groups' could also include future citizens.

Objective 2: Problem analysis; climate change adaptation and Wellington's response context

The aim of this objective is to answer the following research question: *How might individuals and key groups or institutions in Wellington adapt to water shocks, constraints, response measures or policy changes and what might impede or facilitate adaptation by these actors?*

In order to answer this central research question it was broken down into the following sub-questions:

- What are the characteristics of Wellington's particular 'water context' that might shape adaptation to water shocks, constraints, response measures or policy reforms?
- How have people, institutions and communities responded or adapted to 'water shocks', shortages, or policy and trend changes in the past?

Objective 3: Analysis and discussion; adaptive capacity, resilience, and options for Wellington

The aim of this objective is to answer the following research question: *Looking at a range of key options for Wellington including institutional arrangements for governance and management, what are the implications of these options for community resilience, and how might they be utilised in order to optimise community resilience to water shortages?*

In order to answer this central research question it was broken down into the following sub-questions:

- Looking at a range of key options for Wellington including changes to institutional arrangements for governance and management, what are the implications of these options for community resilience?
- How might key options for responding to water shortages be utilised in order to optimise community resilience?

2 Methodology

This Chapter outlines the conceptual framework of this research project, and presents the specific methods used to address the research question.

2.1 Key Concepts and Research Framework

This section outlines the key concepts behind the methodology and analysis of this research project.

2.1.1 Resilience

A focus on resilience may help to shift policy responses from the present control-orientated approaches that presume a stable system, to *"managing the capacity of social-ecological systems to cope with, adapt to, and shape change"* (Folke et al. 2002, p.4). Key aspects of resilience are **diversity**, **modularity** (division and separation of system components) and **redundancy** (overlapping functions) (Walker 2009). Identifying where a system or entity is vulnerable can provide insights for designing and implementing interventions to increase resilience and inform decision-making (Walker 2009). **Resilience** is the ability of a system to absorb disturbances while retaining the same basic structure, ways of functioning and self-organisation (IPCC 2007). Holling (1996) defines two types of resilience; the first definition is consistent with the more traditional and static view of a stable system near an equilibrium steady state. This traditional view Holling characterises as engineering resilience, a property measurable by the system's resistance to disturbance and its speed of return to equilibrium. By contrast, Holling's second definition of ecological resilience is a more dynamic concept. Far from equilibrium, instabilities can flip the system into an alternate state. The key measurement of ecological resilience is the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour (Holling

1996). Holling (1973) notes that in more benign and less variable climatic regions, ecological communities are much less able to absorb chance extremes, since the high degree of stability that the system exists within lowers its resilience or coping capacity to withstand disruption. By contrast an ecological community existing within an unstable climate region may be highly resilient (Holling 1973).

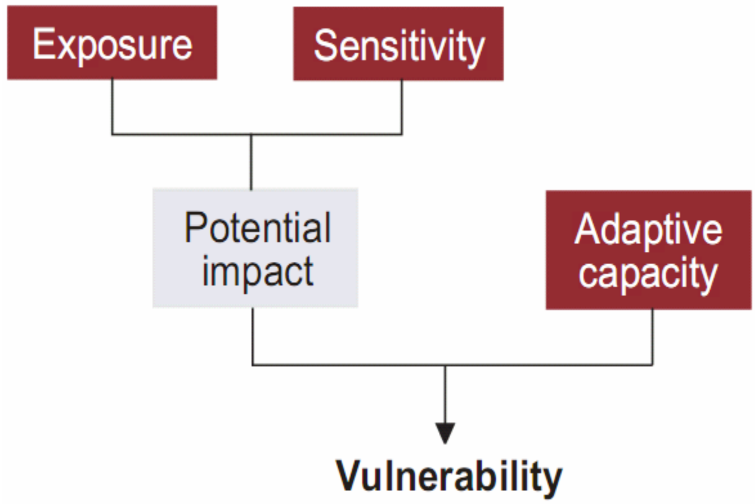
2.1.2 Adaptation

> *Adaptation in the context of human dimensions of global change usually refers to a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity* (Smit and Wandel 2006, p.282).

The following schematic articulates one view of how **vulnerability, exposure**, **sensitivity** and **adaptive capacity** can be related (Fig. 2.1). In this schematic, policy interventions aiming to reduce vulnerability (in order to increase resilience) can either reduce exposure or sensitivity, or increase adaptive capacity. Vulnerability is the negative antithesis of resilience, and is defined by the Intergovernmental Panel on Climate Change (IPCC) as:

> *"[T]he degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.*"

Figure 2.1. Vulnerability schematic (Allen Consulting Group 2005).



Adaptive capacity describes the ability of a system to adapt to climate change in order to moderate potential damages, make use of opportunities, or cope with adverse impacts (IPCC 2007). Climate change adaptation measures are not generally undertaken in response to climate change alone and *"tend to be on-going processes, reflecting many factors or stresses, rather than discrete measures to address climate change specifically"* (Adger et al. 2007, p.720).

Just as Holling (1996, 1973) makes a distinction between a traditional view of resilience and a more dynamic approach, Nelson, Adger and Brown (2007) identify two contrasting approaches to adaptation. The first is a traditional approach, orientated towards technological responses to risks, or towards reducing vulnerabilities of specific groups of people to risks; the second is a systems and resilience approach. The systems approach emphasises the development of *"sources of resilience in order to maintain robustness to uncertainty and to maintain the flexibility necessary to respond to change"* (Nelson et al. 2007, p.412). Nelson et al. (2007, p.397) define **adaptation** as *"the decision-making process and the set of actions undertaken to maintain the capacity to deal with future change or perturbations to a social-ecological system without undergoing significant changes in function, structural identity, or feedbacks of that system while maintaining the option to develop"*. This definition acknowledges Holling's (1996, 1973) dynamic view of resilience, *"where the natural state of the system is one of change rather than of equilibrium"* (Nelson et al. 2007, p.398).

2.1.3 Adaptive Management

> *Management of natural resources is often conducted under great uncertainty regarding future conditions, relationships among components, user response to management, management objectives, and even abundance of the resource itself. However, we know that human use of resources and the need for management will continue in spite of this uncertainty. If we hope to improve management, we must learn as we go* (Johnson 1999, online).

Adaptive management is a policy framework that acknowledges uncertainty, due to 'incomplete and elusive' system knowledge, and also the need to proceed based on the best available information (Johnson 1999, Walters and Holling 1990). Adaptive management is an iterative process which links knowledge to action, and action to knowledge (Stankey, Clark and Bormann 2005), essentially it is 'learning by doing' (Walters and Holling 1990), "…*policies become hypotheses and management actions become the experiments to test those hypotheses*" (Folke et al. 2005, p.447, citing Gunderson, Holling and Light 1995).

Kusel et al. (1996) characterise two types of adaptive management, these being 'participation-limited' and 'integrated' forms. In participation-limited adaptive management the public is generally excluded from active involvement, while in integrated or **participatory adaptive management** the public is part of the process "*and public input is genuinely integrated into the process and evaluated on a par with other information"* (Kusel et al. 1996).

> *Not only is the science incomplete, the system itself is a moving target, evolving because of the impacts of management and the progressive expansion of the scale of human influences on the planet* (Walters and Holling 1990, p.2067).

2.1.4 Complexity and Socio-ecological Systems

Rather than thinking of human communities and ecological systems as separate entities, it is more appropriate to think of these entities as coupled, integrated **socio-ecological systems**; human societies are a part of the biosphere, and are embedded within ecological systems (Folke et al. 2002). Complexity is an overriding characteristic of such systems, to the point that interventions sometimes drive the system in the opposite direction than that intended (Meadows 1999). Most importantly, ecosystems do not respond in linear, predictable, or controllable ways to human use (Folke et al. 2002).

Holling, Gunderson and Ludwig (2002) provide a number of examples of ‘management failures’ regarding renewable resources and make two key observations. The first is on the pathology of traditional resource exploitation and management: that following initial resource development success, management agencies become rigid and myopic, economic sectors dependent, ecosystems fragile, and the public lose trust in governance. This pathology arises from the presumption (which follows from, and is reinforced by the initial success) that nature’s uncertainty has been replaced by the perceived certainty of human control (Holling et al. 2002). The short-term success reinforces the belief that humans are independent of nature (Human Exception Paradigm, Corral-Verdugo et al. 2008) and as a consequence, the knowledge, incentives and institutions for monitoring and responding to environmental feedbacks are neglected; and societies become vulnerable without recognising it (Folke et al. 2002).

Holling et al. (2002) call their second observation “the trap of the expert”, based on their finding that:

> *“the great complexity, diversity and opportunity in complex regional systems emerge from a handful of critical variables and processes that operate over distinctly different scales in space and time”* (Holling et al. 2002, p.7).

In unraveling this observation Holling et al. (2002) note that failure largely stems from the disciplinary hubris of expert perspectives, and that political compromise or stakeholder mediation is irrelevant if ignorant of the integrated and complex nature of social and ecological systems. Environment and resource problems represent the interaction of ecological, economic and social issues, yet attempts at integrated solutions tend to neglect at least one of these three areas (Holling et al. 2002). While expert environmental, economic or social perspectives are often each correct in that they are "partially tested and credible representations of one part of reality", being partial, they are too simplistic to provide an integrative framework that bridges disciplines and scales (Holling et al. 2002). Moreover there is growing evidence to show that 'solutions' and strategies that are based on the partial perspectives of experts are unsustainable (Holling et al. 2002), and that expert-based approaches are insufficient for addressing the complex, post-normal problems of socio-ecological systems (Funtowicz and Ravetz 1993).

2.1.5 Complex Systems Science

> *"An extended peer community is at the heart of post-normal science, and not some afterthought provided by the benevolence of the authorities"* (Ravetz 2006, p.277).

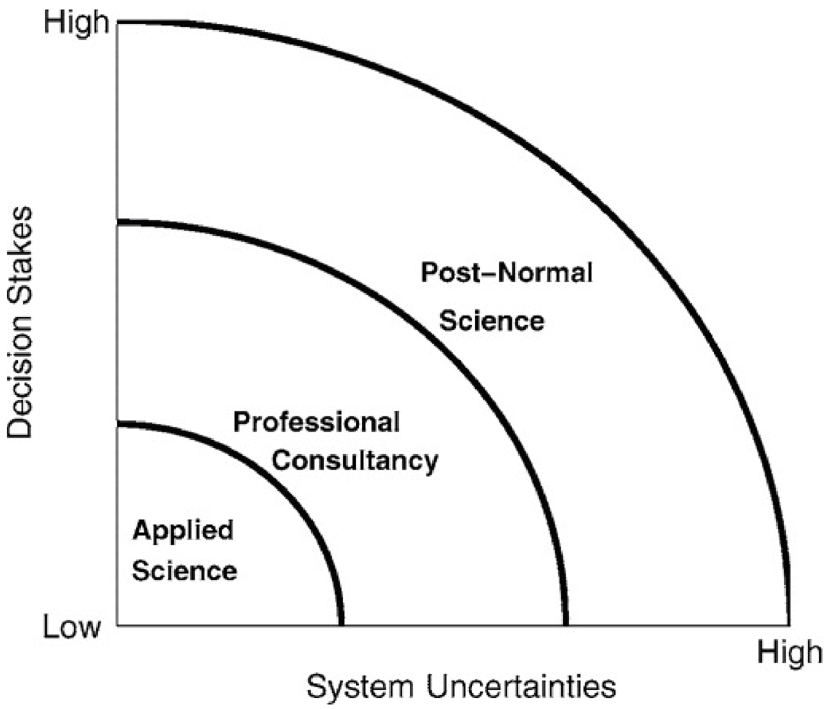
Complex systems science, also known as post-normal science (Ravetz 2006) has evolved in response to policy issues involving risk, uncertainty and the environment, and where the quality and rigour of information and knowledge are uncertain (Funtowicz and Ravetz 1993). Such issues have been defined by Rittel and Webber (1973) as 'wicked' problems, and the issue of addressing climate change has been characterised as a *"super wicked problem"* (Levin et al. 2007). While science and engineering have performed well when applied to 'tame' or benign problems, where the task is clear, and where judging whether the problem has been 'solved' is also clear, such clarity does not exist for wicked problems

(Rittel and Webber 1973). Under such conditions Funtowicz and Ravetz (1991, 1993) argue that science must become 'post-normal':

> *"When legitimate contrasting views are openly used to challenge scientific arguments, we are in the realm of post-normal science"* (Munda 2004, p.664).

Moreover where *"facts are uncertain, values in dispute, stakes high and decisions urgent"* (Funtowicz and Ravetz 1991, p.138, see also Fig. 2.2), waiting for clarification from traditional 'normal' science becomes inappropriate. An example is the considerable uncertainty with the amount of sea-level rise that could be expected this century due to climate change (Beavan et al. 2010, Vermeer and Rahmstorf 2009), and the associated implications for building long-lived infrastructure such as roads on the coast.

Figure 2.2. The 'Post-Normal Science diagram' showing three types of problem-solving strategies (Ravetz 2006, Funtowicz and Ravetz, 1993).



Rittel and Webber (1973) provide 10 characteristics of wicked problems which include the following insights:

- There is no definitive formulation of the 'problem'. Strategies for resolving the problem will influence how the problem is understood, and both the understanding and the 'solutions' tend to be depend on the particular 'world-views' of the actors involved.
- The problem cannot be definitively 'solved', strategies can only be judged on their adequacy according to the various actors' viewpoints.
- Every situation is likely to be one-of-a-kind, and every intervention is consequential in that it leaves irreversible traces.
- *"Every wicked problem can be considered to be a symptom of another problem* (Rittel and Webber 1973, p.165).*"*

The development of Wellington's urban water system in the context of long-term climate change can be characterised as a wicked problem based on the following points:

- Future exposure to water shortages can be expected to rise due to climate change, and a drought that tests the limits of an urban water system could happen in any given summer.
- A water shortage will be a symptom of other problems such as inefficient water use, the legacy of past decisions, underlying structures and world-views.
- Responses and interventions could adversely affect long-term vulnerability to water shortages, even if some actors consider the problem to be resolved in the short to medium term.
- There is an opportunity cost in terms of path dependency and lock-in, if a maladaptive path is taken, versus a resilience optimising path.
- The local social, economic, cultural and environmental context will provide unique factors and perspectives on the understanding of and the response to the problem.

- Should a ‘shortage crisis’ emerge in any given summer, facts will be uncertain, values in dispute, stakes high and urgent decisions demanded.

Post-normal science provides an egalitarian approach to wicked problems which seeks to open the problem to more stakeholders, in contrast to hierarchical or competitive strategies (Rayner 2006, cited in Frame 2009). The main elements of post-normal science are the involvement of an ‘**extended peer community**’ and enhanced uncertainty management (including technical and methodological), both elements are evident in the IPCC process (Saloranta 2001). The extended peer community consists of stakeholders representing ‘**multiple legitimate perspectives’** (Ravetz 2006, Saloranta 2001), and also takes part in the problem solving process by introducing ‘extended facts’ into the dialogue, including personal or anecdotal experiences to enable a richer picture of the issue to emerge (Saloranta 2001).

2.1.6 Human Reasoning and Limits to Rational Decision-making

> *“Reasoning is a simulation of the world fleshed out with our knowledge”* (Johnson-Laird 2010, p.1).

A further layer of system complexity is added by the dynamics of human cognition. For example our brains tend to receive, process and remember a limited amount of information on several variables (‘seven plus or minus two’), rather than a lot of information on any one variable (Miller 1956). Miller (1956) proposed that this ability has evolutionary origins as it enables us to take into account several concurrent variables in order to make practical decisions quickly. Essentially we develop and construct an understanding of the world around us using simplified **mental models** (Johnson-Laird 1995) based on our knowledge of several variables for a given problem. Our mental models therefore act as frameworks for reasoning (Johnson-Laird 2010), but the necessary simplifications within our mental models also influence the way we receive and interpret or filter information. For example we are naturally more receptive to information that comes from a source that we identify with or trust, or that affirms our existing views (Kahan 2006, Klayman and Ha 1989), and we tend to dismiss information that creates '**dissonance**' with our pre-existing or adopted mental models (Festinger 1957).

A critical cognitive limitation with regard to decision-making and complex systems is that we have a limited capacity to take account of feedback delays, and side effects of decisions, to the extent that we display some tendencies that are complexity-averse (Doerner, 1980). An additional consideration for decision-making is 'bounded rationality', a decision process described by Simon (1978). Key mechanisms of bounded rationality are the requirement to actively search for choice alternatives and '**satisficing**'. That is, in seeking alternatives, decision-makers seek options that adequately meet criteria targets, rather than continue searching until an alternative is found which meets all the preset optimisation targets (Simon 1978). Rationality is bounded due to the need to make a trade-off between judgment accuracy and cognitive costs; deliberation is costly, especially when human cognition is viewed as a scarce resource, and the costs of gathering and analyzing information is acknowledged (Conlisk 1996).

One implication of the human reasoning abilities as discussed above is that in making decisions about a particular pathway or option to take with regards to averting or responding to a water shortage, individuals and interest groups will be taking into account only a limited set of variables (and which relate to the particular 'world-views' of each actor). For example it is difficult to think about the many variables that could influence water management over an extended period of increasing climate impacts as well as consider the advantages and disadvantages of a number of supply *and* demand options with regard to these variables. As such there is a tendency to focus on oversimplified models which omit crucial contingencies and possibilities. A further implication is that where post-normal science seeks to strengthen decision-making through incorporating an extended peer community, who bring multiple legitimate perspectives into the process, getting a diverse group of people to sufficiently consider other mental models to the extent that they are prepared to even momentarily relinquish their own is a significant challenge.

> *Rationality is bounded when it falls short of omniscience. And the failures of omniscience are largely failures of knowing all the alternatives, uncertainty about relevant exogenous events, and inability to calculate consequences* (Simon 1978, p.356).

2.2 Overview of Research Methods

An overarching implication of the above conceptual framework is that there is a risk that poorly thought out adaptation measures may adversely affect long-term resilience to future stresses. Moreover, a conventional approach, based on partial, expert perspectives, and that fails to incorporate a systemic understanding of the issue is potentially a pathway to *"management failure"* (Holling et al. 2002), or *"maladaptation"* (Barnett and O'Neill 2010).

This research framework incorporates a socio-ecological systems perspective, uses key elements of complex systems science, and acknowledges the limitations of human reasoning with regard to addressing complex or 'wicked' problems. This framework was chosen in order to generate a 'rich picture' overview of urban water management in the context of long-term climate change, including a deeper understanding of and appreciation for the complex interconnections and feedbacks of the system. Moreover, it considers and addresses key challenges and limitations for research, and for the application of research, at the science-policy interface. The primary advantage of this research framework is that it enables water management to be seen and communicated as a multi-dimensional system challenge.

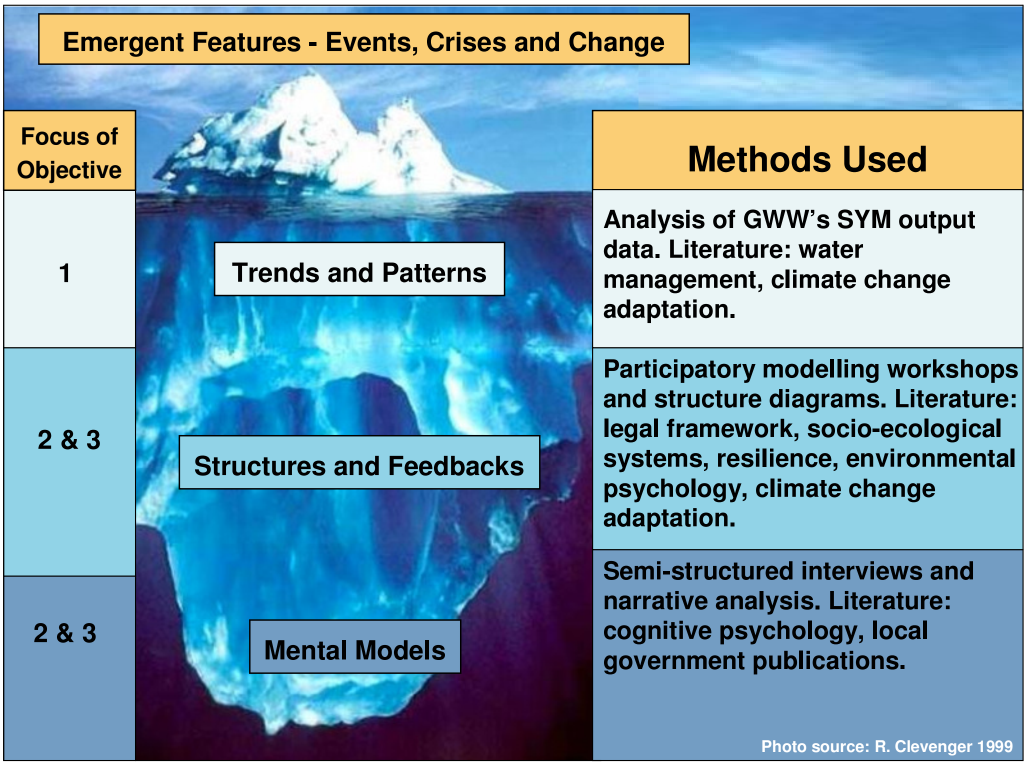
This section provides an overview of the various methods and analyses used in order to address the research objectives. This research project was necessarily broad and interdisciplinary, and the level of detail that could be achieved under each objective had to be balanced with the need to acquire a broad overview across all the objectives. Ravetz (2006, p.277) helpfully articulates a key point that helps focus such a research task, where, at the interface of science and policy, the focus needs to be on the broader relationship to the real-world situation:

> *"…when science is involved in the policy process, it is usually not the deep theoretical obscurities that are at stake, but its relation to a real-world situation... in general, the real world has so much variability and uncertainty, that it will be the more coarse, rough-and-ready aspects of the scientific evidence that are relevant."*

Fundamentally, as articulated by Funtowicz and Ravetz (1993), in relation to complex systems, science needs to serve the information needs of decision-makers in a timely manner where *"facts are uncertain, values in dispute, stakes high and decisions urgent"*. It is therefore up to the decision-makers and the extended peer community (which includes scientists) to identify when and where more time is available, where more certainty is required, and to allocate resources accordingly. But firstly a multi-dimensional overview of the system and its dynamics is required.

The composition of a complex issue can be understood using the metaphor of an iceberg (Maani and Cavana 2007, see also Fig. 2.3). The events we usually observe represent the 'tip of the iceberg' and most of the problem is hidden below the surface as patterns, structures and mental models. The analogy also serves to illustrate 'four levels of thinking', the problem being that in most decision situations very few people delve below the surface layers of events or patterns (Maani and Cavana 2007). Simple solutions that apparently address emergent events and symptoms of the underlying system may only be 'quick fixes' that either shift the problem in space or time, or further increase the emergent symptoms in the long run (Meadows 1999). To get serious about complex problems we should first understand the patterns, structures and mental models beneath those events. Figure 2.3 relates these underlying system features to the research objectives and methods used to attain a deeper level of understanding for this project.

Figure 2.3. The Iceberg Model and the objectives and methodologies used for this research project. Systems thinking attempts to identify and address underlying conditions, 'events' are seen as emergent features of complex systems.

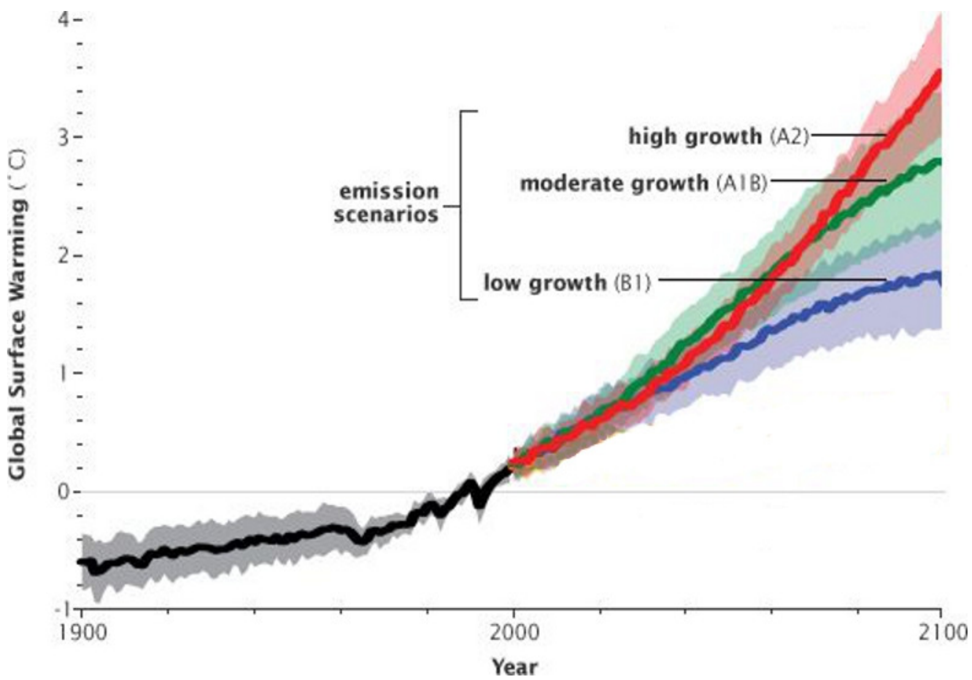


2.3 Objective One

Analysis for Objective One relies primarily on hydrological and climate modelling data. GWW uses a computer model, the Sustainable Yield Model (SYM), to enable water managers to assess the response of the water supply system to changes in infrastructure or operational practice, as well as changes in climate and demand scenarios. GWW's use of the SYM for water resource modelling is considered best practice in international water management (MWH 2001). The National Institute of

Water and Atmospheric research (NIWA) produces supply and demand input files for the SYM using synthetic daily climatic and water demand sequences that are based directly on climate and water demand data for the four city councils supplied by GWW[5]. NIWA input files were produced for each of three Intergovernmental Panel on Climate Change (IPCC) emissions scenarios (B1, A1B, A2) for '2040' (averaged over the 2030 to 2049 period[6]) and '2090' (averaged over the 2080 to 2099 period). The trajectories for the A2, A1B and B1 scenarios in relation to global surface warming are shown in Figure 2.4. In addition a 'low-carbon' 2°C stabilisation scenario was used to produce input files for the SYM. Figure 2.5 shows the trajectory for this low-carbon or rapidly decarbonising world scenario in relation to the IPCC A2 scenario. Figure 2.6 shows the progression of observed emissions from fossil fuels against the three IPCC scenarios used for the present study. Scenario descriptions are included in Appendix One.

Figure 2.4. IPCC emissions scenarios by global average surface warming (Adapted from Riebeek 2010 and Meehl et al. 2007). Temperature is relative to the1980-1999 average and the coloured shaded areas represent variation between model projections (Meehl et al. 2007).



[5] Upper Hutt, Lower Hutt, Porirua and Wellington City Councils.
[6] This 20 year averaging removes *"much but not all"* of the natural variability as represented by the models (Resinger et al. 2010).

Figure 2.5 Global average temperature increase relative to pre-industrial times for the A2 "high carbon world" and the low-carbon "Rapidly decarbonising world" scenarios (relative to 1860-1899, subtract 0.75℃ to compare with Figure 2.4). The vertical bars to the right indicate the likely range (66% probability) for each scenario during 2090-2099 (Reisinger et al. 2010).

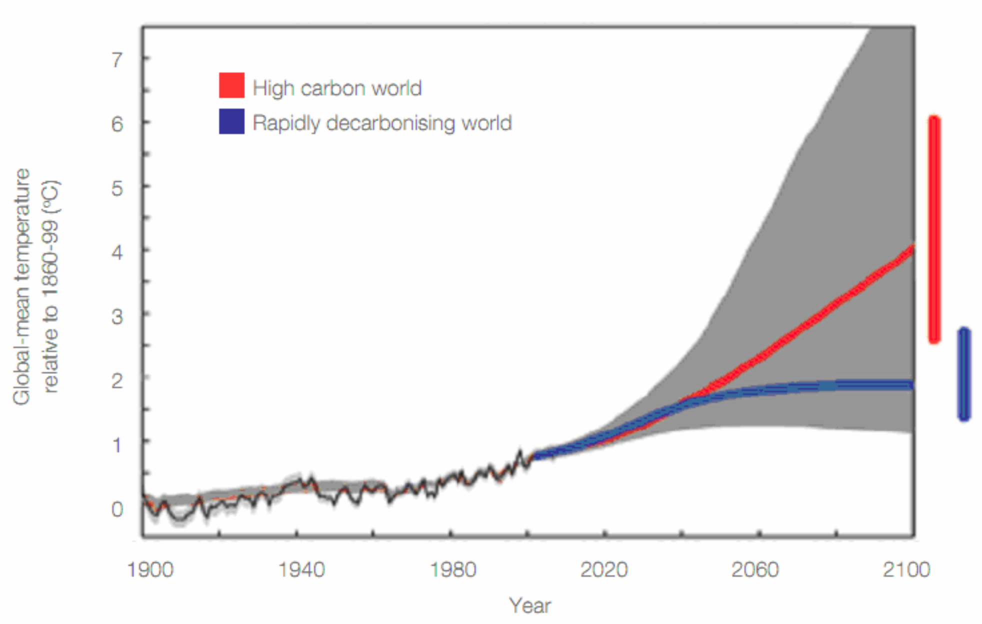
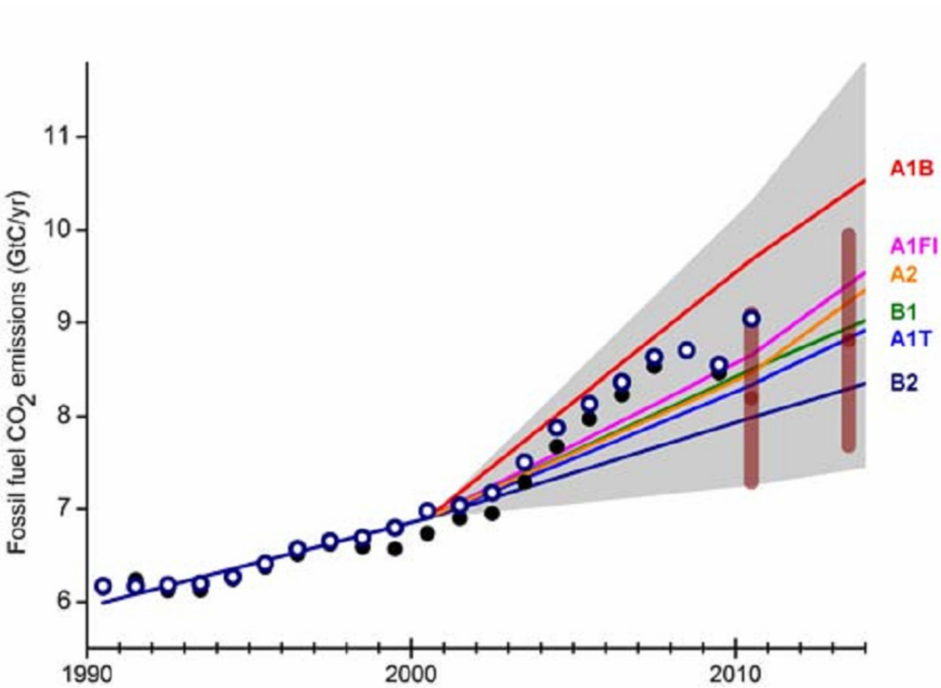


Figure 2.6. Modelled and observed (circles) annual global industrial CO_2 emissions from fossil fuels for 1990 to 2010.
Estimates from US EPA (1990 to 2009) and BP (1990 to 2010). Coloured lines show the marker scenarios for emissions used in climate models for the last two IPCC assessment reports and the grey band shows the full range of these SRE S scenarios. The two vertical bars in 2010 and 2013 show the range of emissio ns covered by Representative Concentration Pathways being used for the next I PCC assessment[7].



[7] Manning MR, et al. Misrepresentation of the IPCC CO2 emission scenarios. Nature Geoscience. 2010;3:376-7.

Turning to the Wellington region, The NIWA input files for GWW's Sustainable Yield Model (SYM) are based on a number of relevant regional climate parameters. These parameters were derived from daily data sequences based on 12 different downscaled climate model projections as well as a projection based on the average of these 12 models, for each of the IPCC scenarios for 2040 and 2090. The 12 model average provides a useful general projection for each scenario, while the individual models themselves provide some indication of a range of possibilities and the level of 'agreement' between models, based on the present level of understanding of the climate system. The 'low-carbon' scenario was used for 2090 only as the scenarios do not differ significantly in 2040 (Fig. 2.5). The General Circulation Model set is listed in Appendix One, and further background on using this model set for New Zealand scenario analysis is available in Reisinger et al. (2010).

The **water supply** input files produced for the SYM by NIWA contain locally-based daily data on river flows at water intake sites, aquifer recharge rates, maximum daily temperatures and potential evaporation for the region. The SYM combines this information with infrastructure capacity and consent parameters[8] for the bulk supply system to give a supply picture. The **demand** input files provide the SYM with daily per capita demand at eight demand centers (e.g. Porirua, Lower Hutt, Wellington North), based on historic demand and local climate variables such as sunshine hours, temperature and evaporation (Ibbitt 2010, 2007). The demand data is also fitted to a per capita long-term mean consumption of 404 litres per day (L/day) which corresponds to average aggregate per-capita consumption for the total of the eight demand centers over the period June 2004 - June 2009 (Williams 2010). The SYM multiplies projected per capita demand (PCD) by projected population in order to get an aggregate flow volume at the demand

[8] Under the Resource Management Act (1991) resource consent is required for water abstraction. In order to minimise adverse affects of water abstraction, such an activity must comply with specific consent conditions, which are rule based parameters.

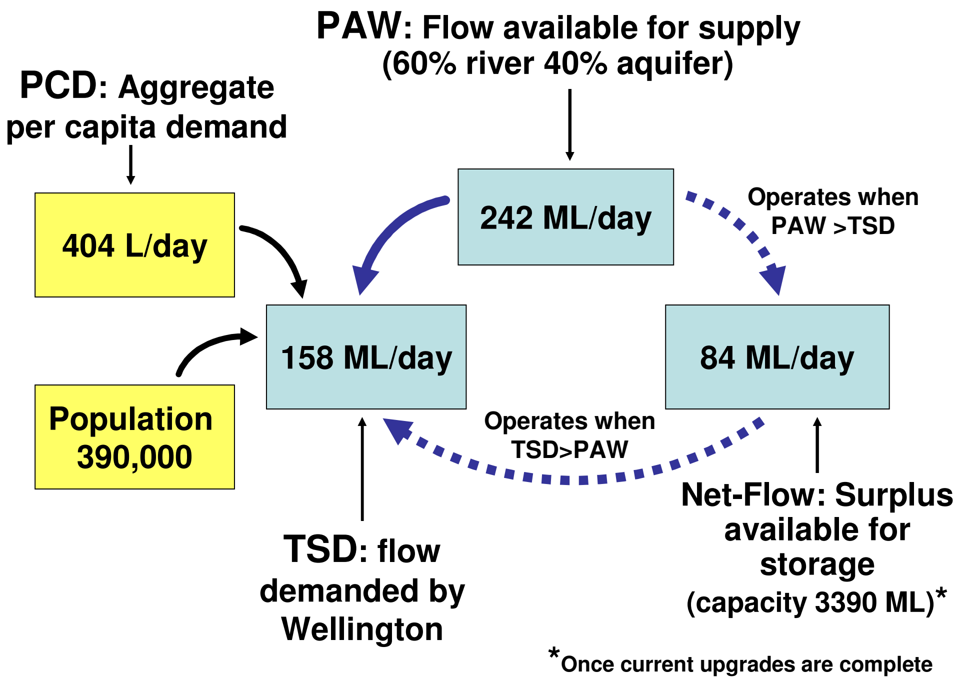
centers. Population projections for the SYM are based on an analysis of the latest Statistics New Zealand projections (Williams 2011, pers comm). For this research project, the SYM was used to generate daily Potentially Available Water (PAW) and Per Capita Demand (PCD) data, providing both supply and demand projections, without storage.

This information was explored in the context of other drivers of supply and demand identified by reviewing available literature and information from peer-reviewed journals, and government, industry, university and Crown Research Institute publications and websites.

2.3.1 Data Analysis

Data for Potentially Available Water (PAW), Total System Demand (TSD) and Per Capita Demand (PCD) were received as Sustainable Yield Model (SYM) outputs from Greater Wellington Water. PAW represents daily available volume in ML from Te Marua, Waterloo and Wainuiomata water treatment plants combined, and incorporates existing consent limits and treatment plant capacities. The influence of storage such as the Stuart MaCaskill Lakes is not included in the PAW measure. TSD was calculated by the sum product of the PCD for each of the eight demand centres and the corresponding population (Williams 2010). PCD is essentially the aggregated TSD divided by population. Net-flow was also used for this analysis, and calculated by subtracting TSD from PAW. The relationship between these measures is shown in Figure 2.7 below.

Figure 2.7. Relationships between PCD, PAW, TSD and Net-flow with their respective daily average current values.



The data sets consisted of scenario projections for a 115 year daily data sequence from each of 12 General Circulation Models (GCMs) and the 12 model average, for three IPCC emissions scenarios for 2040 and four for 2090[9]. Line graphs and box plots were used in order to present the data graphically and to compare the range of scenarios and models. Figure 2.8 shows the conventions used in this analysis to display the data using box plots, and how the box plots relate to the probability density of the data. Figure 2.9 shows how the boxplots relate to flow variability over time. The 'box' contains 50% of the data, and 96% of the data is within the whiskers (2nd and 98th percentiles). The 2nd and 98th percentiles were used as the lower whisker relates to GWW's 2% security of supply standard (one-in-50 years 'annual shortfall probability') in the 'running net flow' graphs.

[9] These were described in Chapter Two.

Figure 2.8. Box plot relationship to probability density for this analysis. The 'box' contains 50% of the data and 96% of the data is within the whiskers (2nd and 98th percentiles). Only the lowest and highest data points will be plotted as 'outliers'.

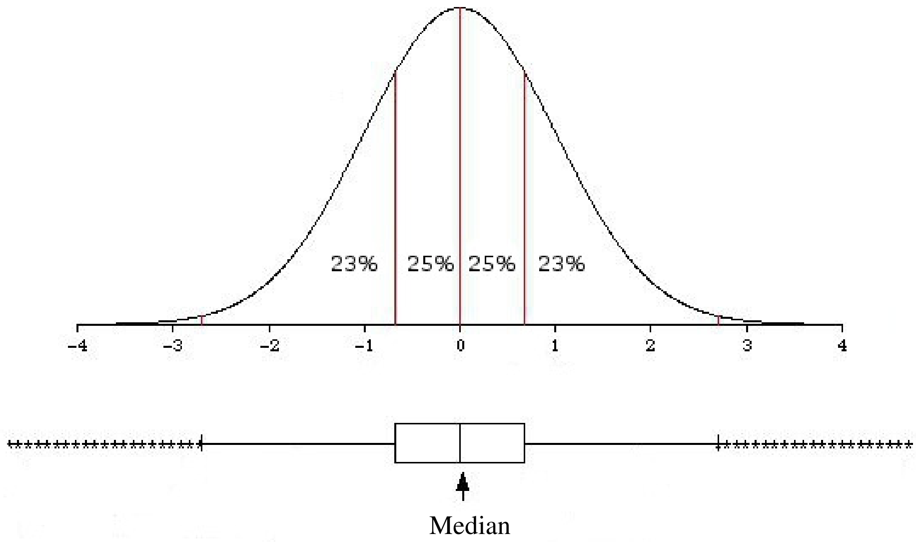
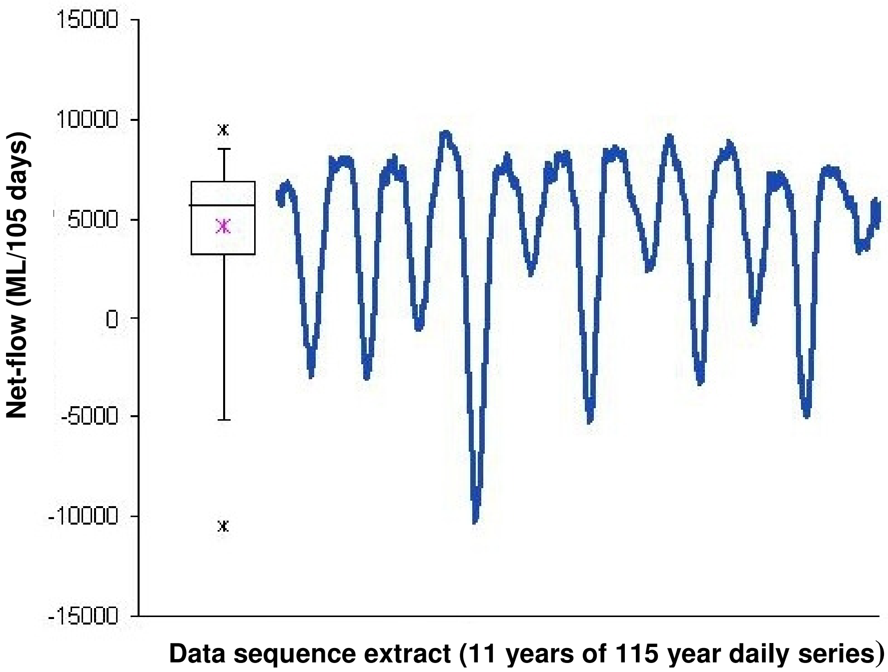


Figure 2.9. Box plot showing distribution of values for 105 day running net-flow (PAW – TSD) for the 2040 A2 scenario. The pink asterisk indicates the mean and the plotted blue line adjacent to the box is for an eleven-year sample of the data series.



2.3.2 Scenario and Model Selection

"Many of the impacts of climate change are due to extreme weather events, not changes in average values of climatic parameters" (Climate Commission 2011, p.38).

The projected climate parameters for the SYM input files are averaged over a 20 year period, and this averaging is necessary in order to capture changes in long-term climate versus more short-term variation. Averaging removes much of the natural variability as represented in the models (Reisinger et al. 2010), yet variability is a significant consideration at the local scale (Jones 2010). The implication here is that the impact of events such as El Nino and La Nina cycles are additional to the change in climate as represented by the model projections. Not surprisingly, the most likely failing of local-level analysis is that it under-represents climate variability (Jones 2010), and, as highlighted above by the Climate Commission (of Australia, 2011), many of the impacts of climate change are the result of the 'surprises' that come with extreme weather. Walker (2005) highlights that a focus on average conditions, rather than extreme events can lead to flawed assumptions and partial solutions.

While caution should always be taken when interpreting the results of a single model or projection, at the same time no one model can be ruled out (Kundzewicz et al. 2007). Current trends show the IPCC projections to be conservative since many variables are tracking at or above the level of the 'high' IPCC projections (Jones 2010). However, if significant mitigation can be achieved, the potential impacts of high projections will be reduced (Jones 2010). Yet past and present emissions represent a commitment to further warming for the next *few decades*; mitigation policies take time to implement and have an effect; and sufficient mitigation policy commitments are lacking (Jones 2010). Therefore in selecting specific models and scenarios for analysis from the data set generated by the SYM a key principle was that prudent adaptation planning needs to take high projections into account.

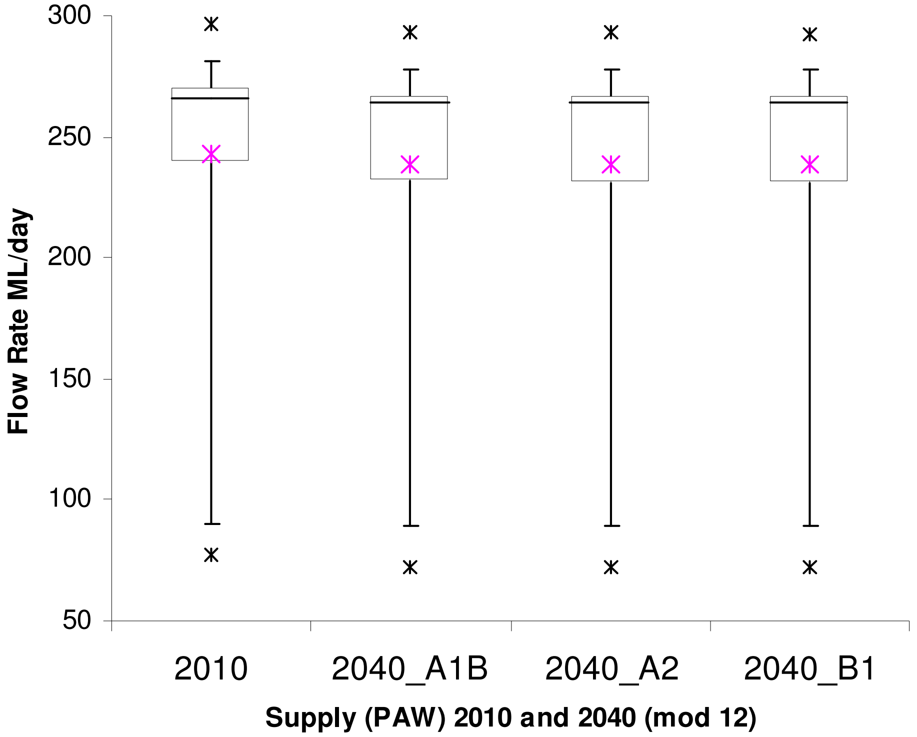
Firstly the projected demand (TSD) and supply (PAW) flows for the climate scenarios were explored using the 12 model average to check the variation between the projections for 2040 and 2090 (Fig. 2.10 and 2.11).

As there was very little variation between flows for the scenarios in 2040, the A2 scenario was selected in order to compare the 2040 projections with the 2090 scenarios and 2010. The differences between scenarios for 2090 were greater than for 2040, and the A2 and low-carbon scenarios were selected for comparative analysis.

Daily net-flow was then calculated for the A2 scenario in order to look at the variation between models for 2040 (Fig. 2.12). The miub model was selected as it captures the greatest range over both 2040 and 2090, particularly in terms of the extent of deficits that Wellington may need to adapt to. Figure 2.12 also shows considerable ‘agreement’ between models, particularly for 2040.

Annual running balances (running net-flows) were calculated in order to explore the annual water balance for various scenarios. A final data treatment was to explore a scenario where average aggregate daily per capita demand is reduced from 400 L to 300 L. This was done by multiplying the applicable PCD data by a factor of 0.75 for the 2040 or 2090 scenario.

Figure 2.10. Projected supply and demand flows for 2010 and by scenario for 2040. The boxes show the first and third quartiles and median. Whiskers go to the 2nd and 98th percentiles, and the largest and smallest data points are marked as the 'outliers' with black crosses. The means are shown with pink crosses.



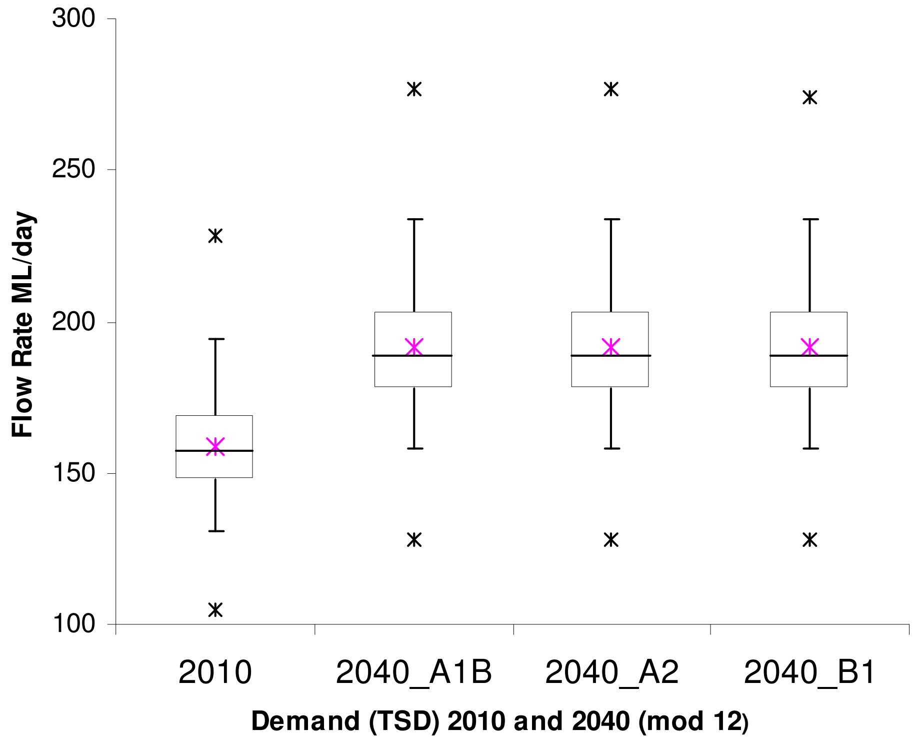
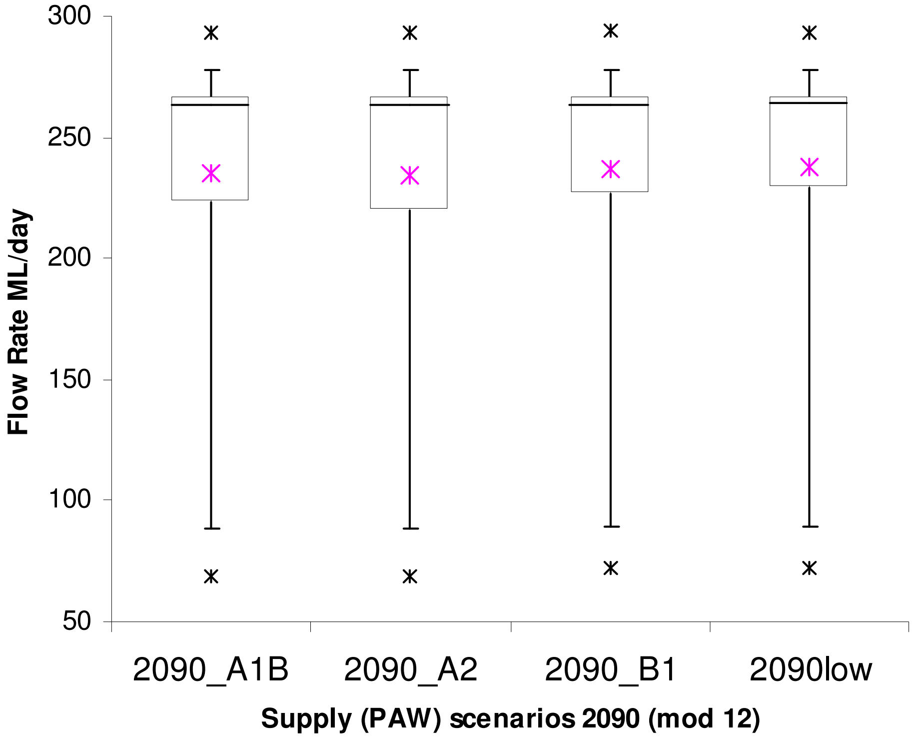


Figure 2.11. Projected supply and demand flows by scenario for 2090.



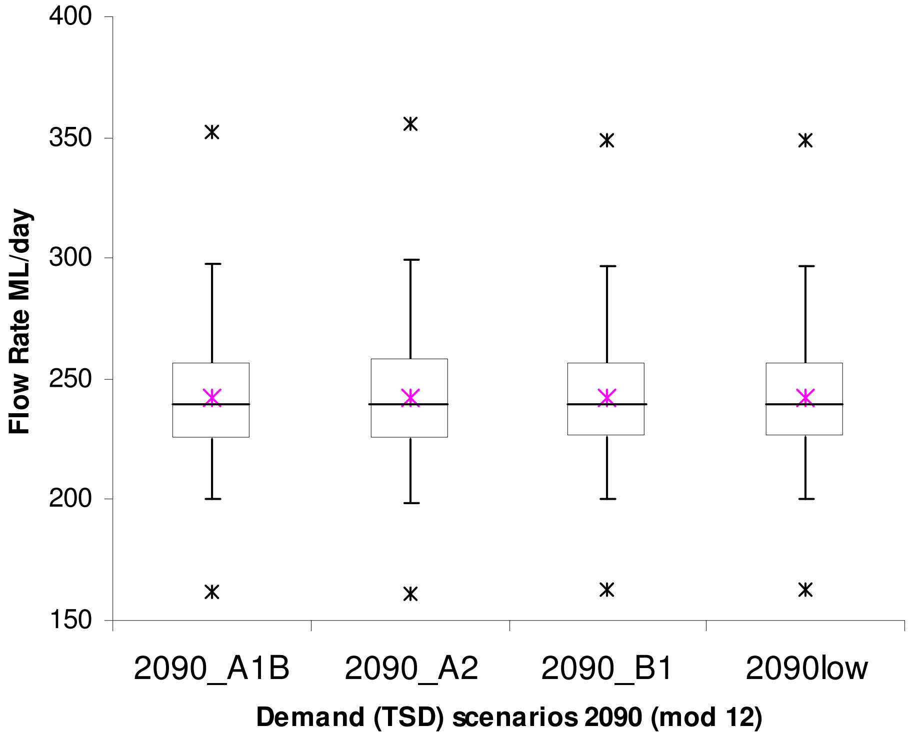
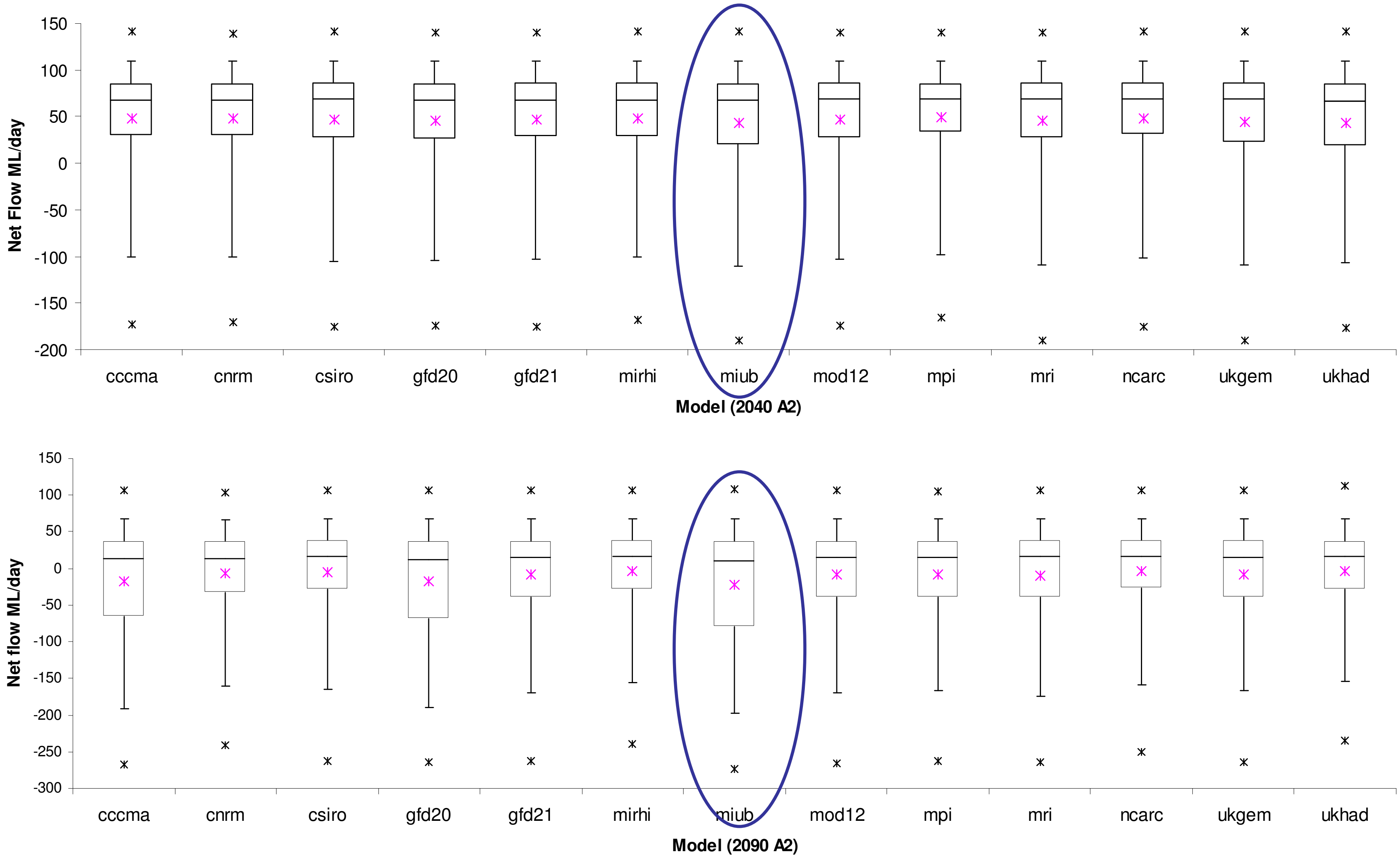


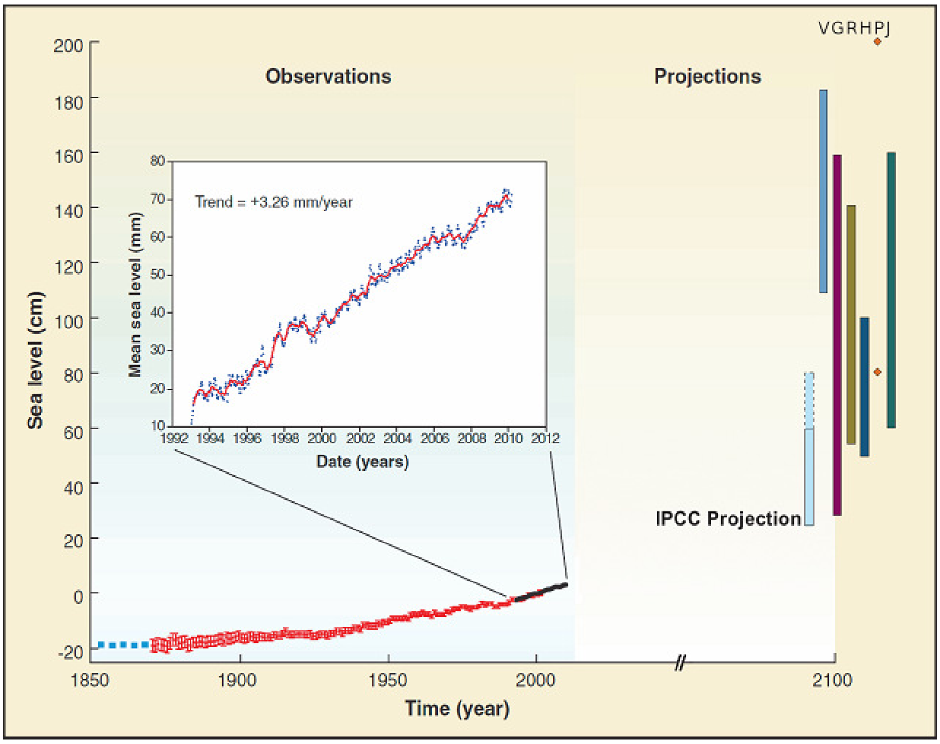
Figure 2.12. Net-flow (PAW-TSD) by model for the A2 scenario for 2040 and 2090. The miub model projections are circled.



2.3.3 Limitations and Uncertainty

Water abstraction from the Waiwhetu aquifer may need to be reduced in order to counter an increased risk of saline intrusion as a result of sea-level rise (Ibbitt and Mullan 2007). However the projected Potentially Available Water (PAW) data used in the present study excludes the effects of sea-level rise on the Waiwhetu Aquifer. This was due to insufficient information regarding the impact of the more recent and higher sea-level rise projections on the aquifer (Beavan et al. 2010, Vermeer and Rahmstorf 2009), and since sea-level parameters within the SYM are based on the IPCC third and fourth assessment reports (Ibbitt and Mullan 2007); as seen in Figure 2.13, the IPCC projections for sea-level rise are much lower than the more recent projections. The projections by Vermeer and Rahmstorf (2009) are the highest, with a range of 20 to 40 centimeters by 2040, and 60 to 160 centimeters by 2090; in which case abstraction from the Waiwhetu Aquifer may be affected by 2040. The primary implications of sea level rise for uncertainty with PAW projections will be for the high emissions scenarios towards the end of the century.

Figure 2.13 IPCC sea-level rise projections for the A1F1 (greatest emissions) against more recent work[10]. The IPCC was unable to provide an upperbound for sea-level rise and the dotted area above the IPCC projection relates to dynamic ice behaviour for which inadequate information was available to include in that projection (Beavan et al. 2010, graph adapted from Nicholls and Cazenave 2010).

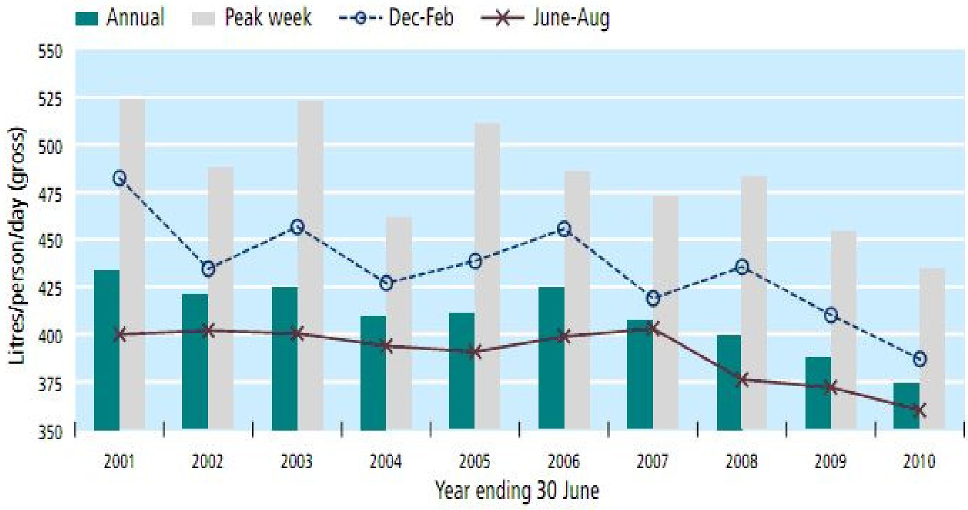


Total System Demand (TSD) data was based on aggregate per capita consumption of 404 L /day which is relatively high, for example in comparison with Auckland and major Australasian cities which average 310 L/day (Kenway et al. 2008). As seen in Figure 2.14, aggregate per capita water consumption in Wellington was 374 L/day in the 2009-2010 year and in recent years has been trending downward at an increasing rate (GW

[10] VGRHPJ in the top right of the graph refer to the authors as follows:
Vermeer and Rahmstorf (2009).
Grinstead, A., et al. 2009. Reconstructing sea-level from paleo and projected temperatures 200 to 2100AD", *Climate Dynamics,* 34:461.
Rahmstorf, S. et al. 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science,* 315:368.
Horton, R. et al. 2008. Sea-level rise projections for current generation CGCMs based on the semi-empirical method. *Geophysical Research Letters, 35:02715.*
Pfeffer, W.T., et al. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise, *Science*, 321:1340.
Jevrejeva, S., et al. 2010. How will sea-level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters*, 37:07703

2010). It has dropped an average of 1.5% p.a. over the last 10 years, and dropped 3.3% p.a. averaged over the last 4 years (GW 2010). Since it is possible that Wellington's Per Capita Demand (PCD) could change significantly by 2040, a scenario for average PCD of 300 L/day was introduced into the analysis for this objective.

Figure 2.14. Declining per Capita Demand in Wellington 2001- 2010 (GW 2010).



In addition to the uncertainties discussed for the PCD and PAW projections, the potential for greater than expected population growth due to 'climate migration' also creates substantial uncertainties for projected TSD. Projections of population growth are based on current trends; but New Zealand is a relatively sparsely populated country, and may escape some of the more severe impacts of climate change (Hennesy et al. 2007). Already millions of people have been displaced in recent years due to extreme weather in Malaysia, Pakistan, China, the Philippines, and Sri Lanka (ADB 2011). Therefore as the global average temperature increases there is considerable potential for climate change to increase Wellington's population particularly due to immigration from the Pacific and Australia (Reisinger et al. 2010, p.31), Asia (ADB 2011) and returning expatriates.

Sea-level rise, changing consumption patterns, and climate change as a driver of human migration introduce significant uncertainties into the analysis for this objective, particularly towards the end of the century. GWW's approach to uncertainty is to use the best data available and to regularly review their forward plans (McCarthy 2011, pers comm.). While assuming that present trends will continue causes unease, the apparent certainty provided by historical water data in comparison with the uncertainty of future projections tends to result in a greater emphasis on historical data for forward planning (McCarthy 2011, pers comm.). Analysis for this objective used a combination of emissions and demand scenarios, based on both historical data and on recent trends in order to explore the relative contribution of key variables; for example the potential for a 'greater than expected' decline in per capita demand to offset population growth. However due to the uncertainties with these factors, caveats need to be made, which stresses the importance of an adaptive management approach.

Objective one is addressed in Chapter Three: Climate Change and Wellington's Supply and Demand Drivers

2.4 Objective Two

Smit and Wandel (2006) identify the following characteristics of analysis where the purpose of climate change adaptation research is concerned with its practical application.

- It investigates the adaptive capacity and adaptive needs of a particular region or community, identifying such needs from the community, based on what the community identifies as important.
- It identifies a means of implementing adaptation initiatives or enhancing adaptive capacity.
- It enables the identification and development of particular adaptive measures or practices tailored to the needs of that community.

- It employs the experience and knowledge of community members.
- It identifies and documents the decision-making processes into which adaptations to climate change can be integrated.

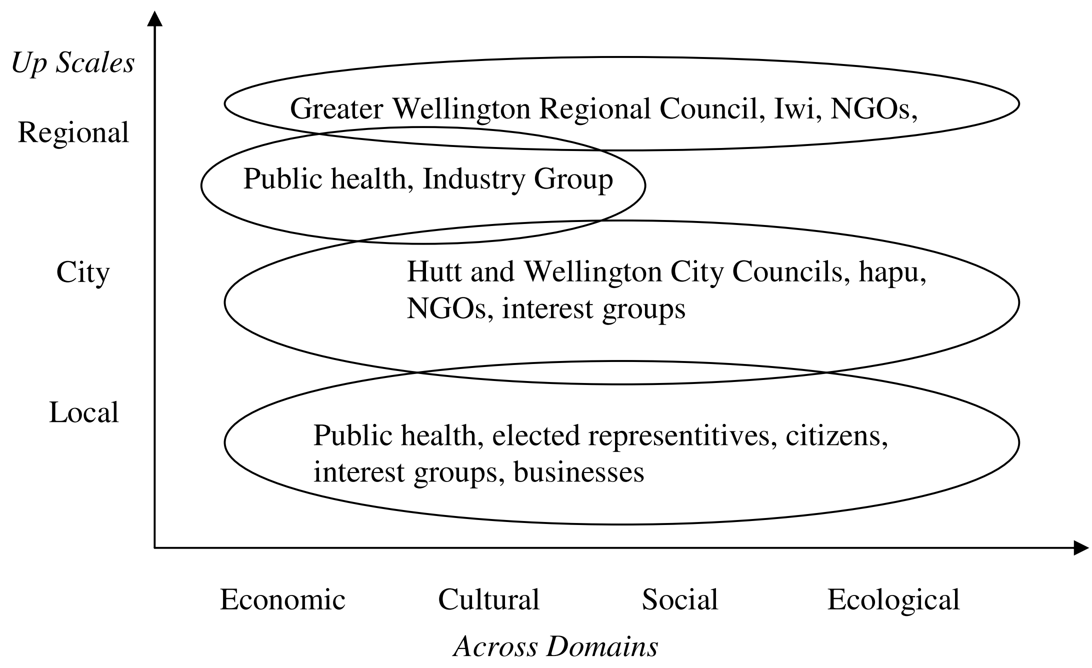
> *"The distinctive motivation here is to identify what can be done in a practical sense, in what way and by whom, in order to moderate the vulnerability to the conditions that are problematic for the community"* (Smit and Wandell 2006, p.285).

The focus of such research is to document the ways in which the community experiences the changing system conditions, and the decision-making processes of (or that influence) the system, to the extent that such processes accommodate adaptation or provide means to improve adaptive capacity (Smit and Wandel 2006). Research tools include semi-structured interviews, participant observation, and focus groups, and incorporate insights from local and regional decision-makers, resource managers, scientists, and published and unpublished literature (Smit and Wandel 2006).

In accordance with the above framework, Objective Two (Climate Change Adaptation and Wellington's Response Context) was addressed using a range of research tools and by collating available documentation relevant to Wellington's context from local government documents, peer-reviewed journals and government, industry, university and Crown Research Institute publications and websites, and through recorded semi-structured interviews with key informants and residential water users.

Key themes for the interviews were developed based on analysis of local media coverage of the issues and relevant academic literature. The Central Research Question - Theory Question – Interview Question framework (Wengraf 2001) was used to develop tailored interview questions. Secondary themes and relevant threads of narrative that emerged during the interviews were explored using 'probes', such as asking for specific examples or for clarification. Stakeholder mapping (Fig. 2.15) was used to assist in targeting a good spread of participants and eight interviews were conducted with 13 participants. Interviewees included five local government water policy and management personnel, an elected city councilor, one Non Government Organisation (NGO) representative and five 'citizens' as domestic water users. A short preliminary discussion was held with an iwi representative; however a recorded interview was not obtained.

Figure 2.15. Stakeholder Scales and Domains. Adaptation of schematic presented by Mortimer (2010).



The key themes used to promote discussion regarding community concerns were:

- Water metering, volumetric pricing, and water privatisation
- Further reducing the minimum flow of the Hutt River at Kaitoke
- Building a new dam on the Whakatikei River

- Demand management and distributed storage initiatives
- Summer outdoor water use and 'water cultures'.

Not all of the key themes were discussed with all interviewees. The themes used to open discussion with local government water policy and management representatives were:

- The framing of the issue and of response strategies
- Water 'system' management
- The temporal dynamics of risk and uncertainty in decision-making.

Community and Local Government interviewees were identified through their previous involvement in Wellington's water management issues, as well as through personal connections and networks, and through literature, local media coverage and press releases produced by organisations such as businesses, NGOs and local government. In the interests of transparency and knowledge sharing, local government and water management representatives, and representatives of interest or stakeholder groups agreed to participate on the basis that the opinions or information that they provided could be included in this report and attributed to them. The views expressed by these interviewees were their personal opinions that do not necessarily reflect the position of the organisations that they represent.

Multi-factorial 'rich-picture' case studies were conducted, using semi-structured interviews of three sets of householders as residential water users. Ideally (time and resources permitting) more participants would have been found and more interviews conducted. However, only three households meeting the required criteria were found within the time available. The key requirement in selecting participants was that the household or householder had lived in Wellington and then moved to another location where they needed to adapt to a more restricted water use context. Care was taken in selecting these interviewees so that while the data is not statistically representative, it is contextually rich due to the very relevant experiences of the interviewees. As the information provided by interviewees as residential water users was of a more personal nature, and the identity of these interviewees has been kept confidential. Key themes used to promote discussion were:

- Household values and culture regarding water.
- Key water related issues and effects on household, including in the future.
- Experience of water management contexts contrasting with Wellington and how household and members adapted to change.
- Summer water use.
- Sources used to access information on water issues.

Research for this objective received approval from Victoria University's Human Ethics Committee (Approval No. 17691, see Appendix 7).

2.4.1 Limitations

This research project incorporated a variety of methods within its three objectives and needed to be completed within a year. Time was significantly constrained, especially with regard to engaging broadly with the 'extended peer community'. For example the specific perspectives of tangata whenua have not been incorporated. The capacity of iwi to engage in research tends to be stretched and research competes with a range of iwi priorities. In order to engage sufficiently with iwi representatives, first the project must be of significance to the iwi, and secondly time must be invested in building a relationship based on ongoing and mutual benefit (Darren King, NIWA, pers. comm.). This project failed to successfully engage with iwi representatives due to the researchers' lack of prior involvement with tangata whenua, and the time constraints of a year-long mixed-methods research project.

Objective Two is addressed in Chapter Four: Climate Change Adaptation and Wellington's Response Context.

2.5 Objective Three

A six hour systems modelling workshop was conducted in January 2011, with a 3 hour follow-up session in February 2011. The organising question for the workshop was:

> *What are the issues and factors that should be considered in deciding between options (or packages of options) for managing water in Wellington?*

The first workshop session used the hexagons method to capture issues identified by the participants during a brainstorming session (Hodgson 1992). Issues identified by the participants were written onto coloured hexagonal shaped cards and these 'hexagons' were then clustered according to common themes (Maani and Cavana 2007). Variable names were assigned to each cluster so that the structure and interconnections of the issues and their relationships could be mapped using a 'causal loop diagram' (CLD) (Maani and Cavana 2007), referred to in this study as a 'structure diagram'. Structure diagrams provide a means to explore and interpret the relationships and interactions between many system variables. Guidance for interpreting the structure diagrams and the conventions used in the present study are included in Appendix Two. Workshop participants are listed in Appendix Four, and the 'issues and factors' generated by the brainstorming and hexagons process are included in Appendix Six.

Structure diagrams are used in Chapter Five to show underlying feedbacks and structures according to the 'mental models' of the researcher, drawing on the empirical data from hydrological and climate modelling as presented in Chapter Three, qualitative data from interviews as presented in Chapter Four, combined with relevant theory and literature, and the knowledge elicited from the workshop participants as ‘extended peers’. Another systems thinking tool used in Chapter Five is the behaviour over time (BOT) graph. The BOT graph is often used in conjunction with structure diagrams, and indicates the trend over time (x axis) for a variable of interest according to a performance measure on the y axis. An example of a BOT graph is given in conjunction with the structure diagram in Appendix Two.

As with the interviewees for Objective Two, workshop participants were identified through their previous involvement in Wellington’s water management issues, as well as through personal connections and networks, and through literature, local media coverage, and press releases produced by organisations such as businesses, NGOs and local government. In total 22 people participated over the two sessions. Research supervisor Ralph Chapman attended as the moderator, and systems modeller Jason Markham provided technical, methodological and facilitative support for the workshop sessions. Collaboration was achieved from the diverse range of views present through the constructive use of ‘dissonance’ (Festinger 1957, Kahan 2006), whereby participants were asked to use any feeling of disagreement with others as a stimulus to put forward and work through their own associated views and ideas using the collaborative modelling process. Workshop participants are listed in Appendix Four.

Literature was accessed through peer-reviewed journals, government and local government, and industry, university and Crown Research Institute publications and websites.

Research for this objective received approval from Victoria University’s Human Ethics Committee (approval No. 18191, see Appendix 7).

2.5.1 Limitations

A structure diagram represents a cognitive map, or shared mental model of an issue, based on the knowledge and perspectives of the group of participants, at the time it is generated. The workshop process requires a considerable level of commitment from participants, particularly in terms of time, and is therefore restricted to those who have the capacity to make this commitment. There is considerable pressure on the researcher to minimise the time commitment, and a considerable effort was made to include and accommodate a diversity of perspectives. After 9 hours, over one and a half days it was necessary to 'satisfice', despite that another hour or two would have captured more, and given the participants a bit more time to test the model. However it is always necessary to 'satisfice', and in a dynamic system, a shared mental model will never be complete. The utility of such a model is in the insights that it provides, within the above limitations, and as a tool for testing and further developing the participants own mental models.

Insights from the workshop, including the shared mental model (shown in Appendix Six) were used to develop further structure diagrams based on the researchers understanding of the issue. The structure diagrams presented in Chapter Five therefore represent the partial view of the researcher, based on an understanding that was current at the time this research was undertaken.

Objective Three is addressed in Chapter Five: Analysis and Integration

3 Climate Change and Water Supply and Demand Drivers

This chapter addresses Objective One by providing an overview of the interactions between climate change and water supply and demand drivers for Wellington.

3.1 Introduction

Climate change will impact fresh water systems through changes in temperature and precipitation and through sea-level rise (Kundzewicz et al. 2007). In addition both the frequency and severity of extreme weather events such as flooding and drought are expected to increase in New Zealand (Hennesy et. al. 2007). Climate change is therefore expected to exacerbate key urban water security risks.

At current rates of water consumption Wellington's bulk water provider, Greater Wellington Water (GWW) has been struggling to meet its 2% security of supply standard. Meeting this standard will become increasingly difficult as the frequency of drought increases, and Wellington's population grows.

This chapter analyses a range of climate change and water consumption scenario projections for Wellington, to explore the implications of these scenarios for water security and management in Wellington. The Results section presents findings from climate and hydrological modelling data as they relate to key water supply and demand factors in Wellington. The Discussion elaborates on the implications of these findings in relation to key water management options (augmentation of storage and supply and demand management) and for responding to a drought. The conclusion to this chapter highlights key urban water management implications for Wellington.

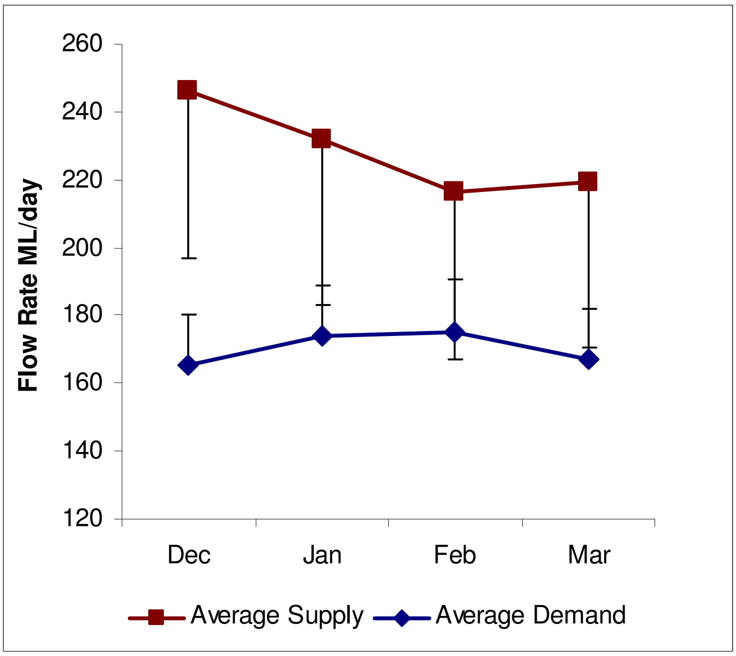
3.2 Results

How might climate change affect water supply and demand in Wellington, and how might underlying trends and factors interconnect with climate change?

3.2.1 General Trends and Potential Effects

As shown in Figures 3.1, 3.2 and 3.3, a key dynamic of Wellington's water system is the seasonality of supply and demand; demand is greatest in summer when supply is most restricted. Whilst there is sufficient water to meet projected demand under present average summer conditions, substantial 'overlap' between Total System Demand (TSD) and Potentially Available Water (PAW) occurs during January, February and March at just one standard deviation (Fig. 3.1). In other words, if supply is on the low side of the median and demand were on the high side, in theory supply would not meet demand.

Figure 3.1. Average daily supply (PAW) -1 standard deviation, and average daily demand (TSD) + 1 standard deviation in ML/day, from December to March under present climate variability.



By 2040 climate change could decrease PAW by 5% or 12 ML per day on average for January and February (Fig. 2.4), with a corresponding 4.5 litre or 1% increase in average per capita demand (PCD) (Fig. 2.5). The 12 ML difference in PAW is the gap between 'current' and the 2040 scenarios for 'Jan/Feb'. The projected decrease in PAW between 2040 and 2090 is 5.5%, and the projected increase in PCD from 2010 to 2090 due to climate change is 3%. The combined effect of climate change and population growth on demand would be an average increase of 2.1 ML/day for January and February 2040. With average PCD modelled at 404 L/day, and the projected population increase, climate change accounts for 14.1 ML of water for January and February 2040 (i.e. in relation to a reduction in net-flow), or a average daily shortfall of an equivalent volume of water sufficient to supply 35,000 people.

Figure 3.2. Average daily supply (PAW) 2040 and 2090 by month and IPCC A2, B1 and low-carbon scenarios (Mod 12).

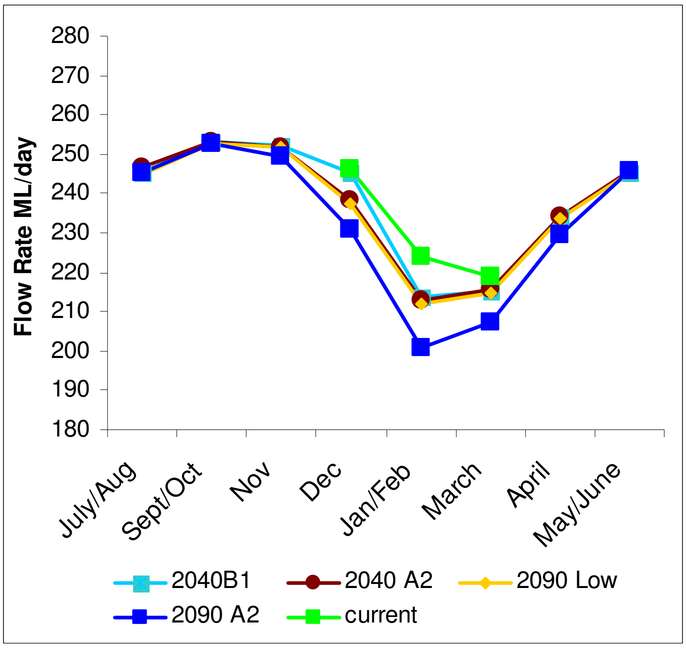
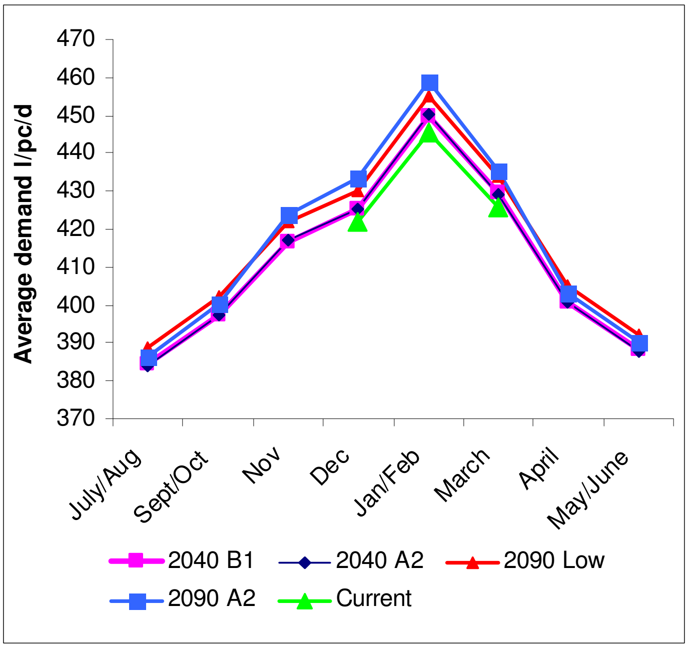
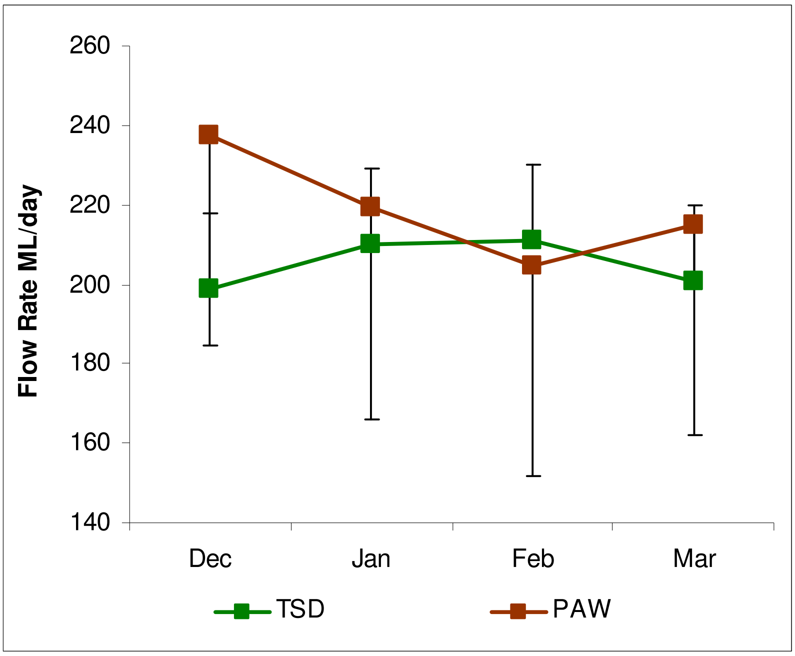


Figure 3.3. Average Per Capita Demand (PCD) 2040 and 2090 by month and IPCC A2, B1 and low-carbon scenarios (Mod 12).



As shown in Figure 3.4, when the projected population increase for 2040 is taken into account, average supply and average demand overlap in February, indicating that even in an average year, storage of surplus water from winter would become essential for supplying water in the summer.

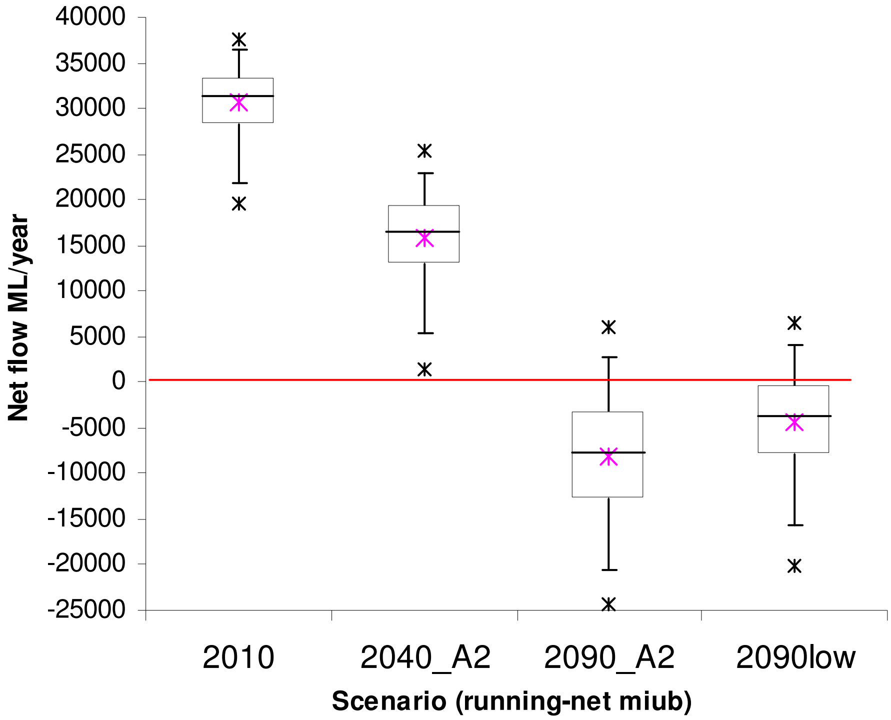
Figure 3.4. Average daily supply (PAW) -1 standard deviation, and average daily flow demanded (TSD) + 1 standard deviation in ML/day, from December to March under climate variability for the 2040 A2 projection with population growth (Mod 12).



3.2.2 Potential Effects due to Wider Considerations

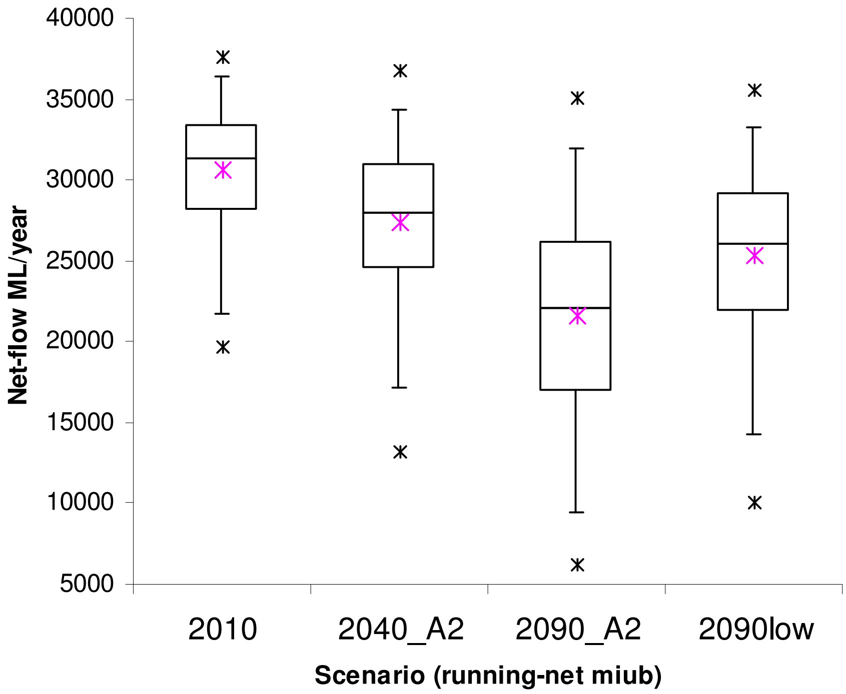
During a drier than average summer, daily demand may easily increase by more than one standard deviation from the mean with a concurrent decrease in supply. As a dry summer progresses, the deficit between demand and supply can grow considerably. Figure 3.5 shows the potential degree of annual variability for net-flow. As shown in Figure 3.5, with climate change, population growth and average PCD at 404 L/day, the mean running net-flow (supply less demand) is below zero for both the A2 and low-carbon scenarios by 2090. This indicates that even if balanced over a year and with large amounts of storage, the flow of water available to Wellington from current sources will be insufficient to meet projected demand. The minimum value for the 2040 box plot is close to zero, which indicates that even with as much as 20,000 ML of storage capacity to balance supply and demand flows over a year; there may not be enough water to meet projected demand in a particularly dry year by 2040.

Figure 3.5. Running net-flows for 2040 A2, and 2090 A2 and low-carbon scenarios, for projected population growth with average aggregate per capita demand equivalent to 404 L/day.



Assuming average PCD of 404 L/day; population growth coupled with climate change pushes the mean running net-flow down by 15,000 ML/year by 2040 and then by another 25,000 ML/year between 2040 and 2090 (Fig. 3.5). In Figure 3.6 the effect of population growth on the running net-flow has been removed by holding the population constant at 390,000. By holding population constant, the difference in net-flow shows the relative effect of climate change, with average PCD at 404 L/day. The mean annual net balance is 3144 ML/year less between 2010 and 2040, equivalent to the capacity of the Stuart Macaskill storage lakes, and there is a 5850 ML/year difference between the 2040 and 2090 A2 scenarios (Fig. 3.6). In percentage terms climate change alone decreases mean annual net-flow by 10% from 2010 to 2040, and by 21% from 2040 to 2090.

Figure 3.6. Running net-flows with no population increase for 2040 A2, and 2090 A2 and low-carbon scenarios.



PCD in the SYM model is based on average water consumption of the last 5 years, which is 404 ML/day. However daily per capita water consumption for Wellington has been decreasing steadily for both peak and base demand. The average rate of decline has been 3.3% per year over the last 4 years, or 1.5% per year averaged over the last 10 years (see Figure 2.12). While Wellington's population has been growing at an average of 1% over the last 10 years, total demand has been falling and in total PCD fell 25% between 1990 and 2010[11].

If the 1.5% average annual reduction in per capita demand continues to 2025, along with a 1% annual population increase, Wellington's aggregate consumption of 375 lpcd will shrink to a similar level to Auckland's (302 lpcd; Kenway 2008) by 2025. In addition, Wellington's average total daily demand will decrease from 146 ML/day to 135 ML/day (Table 3.1).

[11] Calculated from data for Fig. 1.3.

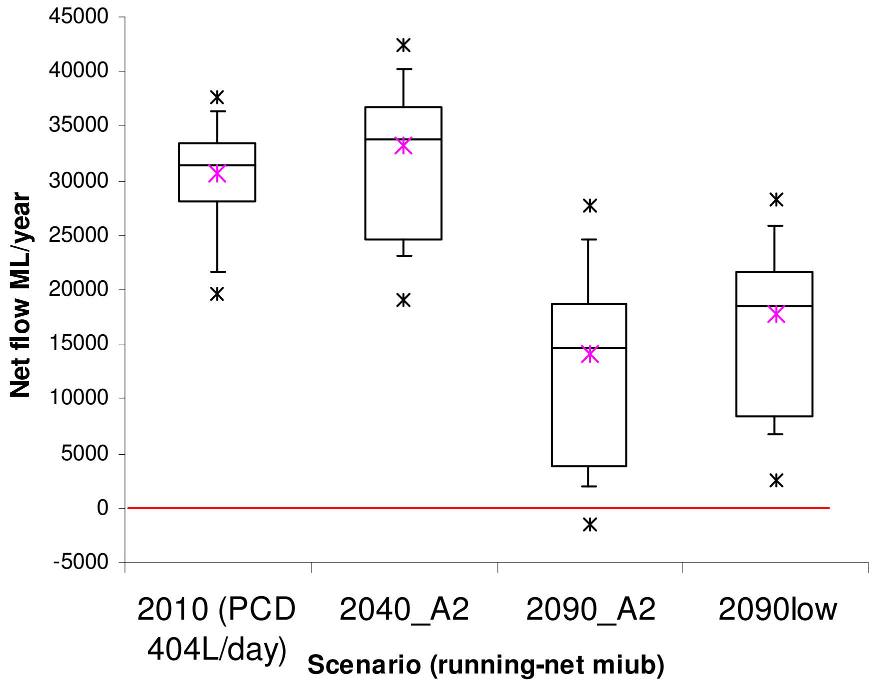
Table 3.1. Water savings and changes in consumption and population to 2025 with 1.5% annual demand reduction and 1% population growth. Projections for the '2040 scenario' column are shown in Figures 3.7 and 3.8.

Year	2010	2015	2020	2025	2040 Scenario
Aggregate PCD (L/day)	**374**	347	322	***298***	303
Domestic PCD[12] (L/day)	**235**	218	203	***189***	191
Population	**390,000**	410,000	431,000	***453,000***	467,500[13]
Annual Average Consumption (ML/day)	**146**	142	139	***135***	142
Water saving (Per Capita, 2010 baseline)	0%	7%	14%	**20%**	20%[14]

The calculations in table 3.1 show that a reduction to 300 L/day is theoretically feasible by 2025. Figure 3.7 presents a scenario where average PCD is reduced to 300 L/day by 2040. The data indicates that with this scenario there is sufficient water available for storage, enabling projected demand to be met in all but the most extreme summers under the 2090 A2 climate scenario. By 2040, with population growth, climate change and a reduction in average PCD to 300 L/day, the mean annual running net-flow *increases* relative to 2010 by 2700 ML/year, and then decreases by 19,000 ML/year between 2040 and 2090 for the A2 scenario (Fig. 3.7).

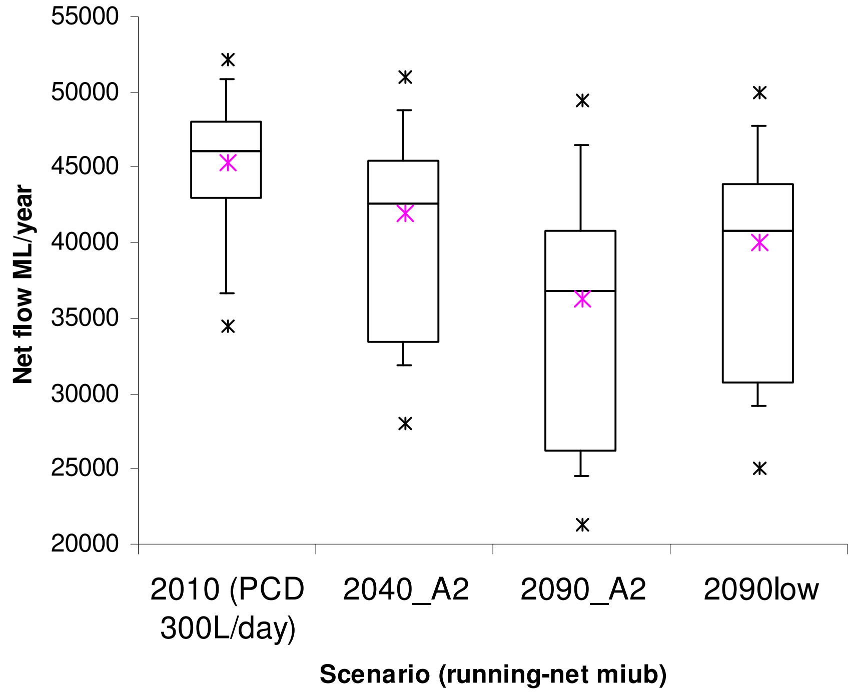
[12] 63% of Aggregate PCD, see table 4.1.
[13] Projected population used for the Wellington case study scenarios, equates to an average annual population increase of 0.6% from 2010.
[14] Includes 1% projected increase in PCD due to climate change.

Figure 3.7. Running net-flows for scenarios 2040 and 2090 using both the A2 and low-carbon scenarios, for projected population growth with average aggregate per capita demand equivalent to 300 L/day.



In Figure 3.8 population has been held constant at 390,000 and average PCD is 300 L/day to show the relative effect of climate change. There is a reduction in average net-flow of 3300 ML/day between 2010 and 2040, and 5,686 ML/day between 2040 and 2090. The relative contribution of climate change to the decrease between 2010 and 2040 is 7%, and between 2040 and 2090 it is 13.5%.

Figure 3.8. Running net-flows for 2040 A2, and 2090 A2 and low-carbon scenarios with average aggregate per capita demand equivalent to 300 L/day and no population growth.



3.3 Discussion

What net effects may arise from this confluence of factors and what are the key implications for water management in Wellington?

Population growth, per capita demand, and total system demand are key variables within the water supply system that Wellington's water managers must contend with and increased climate variability makes this job significantly more challenging.

On the basis of balancing water availability over the year with sufficient storage, current supply (PAW) is sufficient to meet per capita demand at 404 L/day to 2040, under the A2 scenario and with projected population growth. A reduction in net-flow due to climate change and population growth represents a reduction in the amount of water available to be stored so that the water system can cope with flow variability. This analysis shows that towards 2090 the average net-flow from current supply sources is below zero.

Per capita demand is relatively high in Wellington, but it is falling. With sufficient demand management efforts, average aggregate PCD could be reduced to 300 L/day by 2025 and maintained at that level to 2040. In which case, and with sufficient storage, reduction of PCD to 300 L/day could delay the need to augment supply until after 2090.

While increasing storage capacity is part of the solution, as TSD increases the surplus available for storage decreases to the point where the surplus flow is insufficient to fill reservoirs. However, once again reducing average PCD to 300 ML/day preserves the ability to use storage reservoirs to smooth out flow variability through to 2090, from present supply sources.

3.3.1 Managing for 'Extremes'

A scenario with average PCD of 300 L/ day was calculated for 2040 (A2 mod12)[15]. The net-flow over an 80 day period (80 day running-net, Fig. 3.9) gives the largest deficit for this scenario: a longer or shorter duration fails to capture the full extent of the deficit. The 12 model average projection for the A2 scenario was used in order to enable a more rigorous analysis of individual events within the data series.

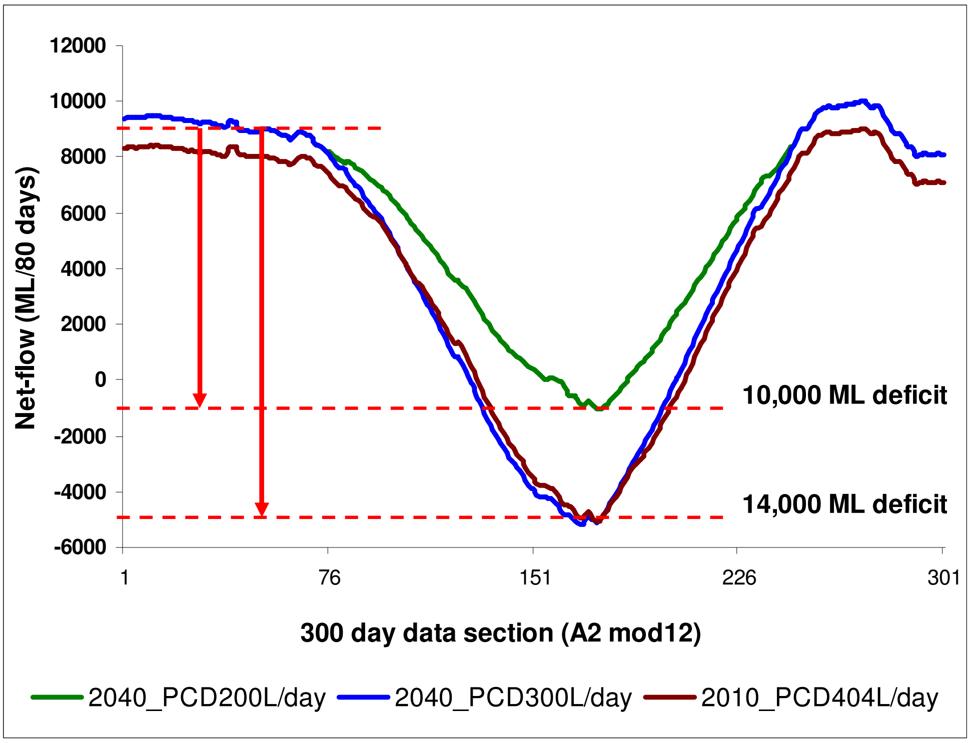
Two events with deficits of 14,000 to 15,000 ML appear in the data (one per 57.5 years), one of which is shown in Figure 3.9. In addition there were five events with deficits of 12,000 to 14, 000 ML (one per 23 years), and ten events with deficits of 10,000 to 12,000 ML (one per 11.5 years). In total there were 17 events (1 per 6.8 years) that with projected demand, and average PCD of 300 L/day could produce deficits of greater than 10,000 ML. Analysis of events occurring at an Annual Return Period of 1% or less

[15] i.e. using the IPCC A2 scenario projected by the 12 model average.

indicate that summer deficit events of this magnitude could occur once every 25 years by 2040, and once every seven years by 2090.

As illustrated in Figure 3.9, the results for the 2040 scenario with 300 L/day PCD are similar to the 2010 scenario with PCD 404 L/day, demonstrating the ability of reducing PCD to 300 L/day to 'offset' the effects of population growth and climate change on the water system. Figure 3.9 also shows a 200 L/day PCD scenario, which indicates a 'minimum bound' for a severe deficit event, such as might occur under optimal demand management conditions in 2040[16]. The actual average PCD for section of the 200 L/day scenario shown is 210 L/day, with PCD at 271 L for the maximum day.

Figure 3.9. 300 day sequence of the largest deficit event generated for 2010 with PCD of 404 L/day, and 2040 with PCD of 300 L/day scenarios. The green line indicates a 'minimum' with substantial and early demand management (A2 mod12, 80 day running-net).



[16] As seen in Auckland and in major Australian cities (Table 4.1), aggregate per capita demand of 300 L/day is currently achievable. In addition, as seen in Table 3.1, this level of demand can theoretically be achieved for Wellington by 2025, and greater demand reductions are possible. The 200 L/day scenario provides a lower bound as it requires a reduction in PCD of nearly 50% from 2010.

The deficits generated by the largest seven events within the 115 year series are within the range of 12,000 to 15,000 ML (2010 with PCD 404L/day and 2040 with 300 L/day), which suggests that up to 12000 ML of storage is required in order to meet Wellington's 2% or 1-in-50 year security of supply standard. This is potentially an upper bound, as the aquifer can be managed to provide short-term buffering capacity against a particularly dry month, and on average the Waiwhetu aquifer can provide 60% of current TSD. GWW can either reduce the rate of aquifer abstraction, if river flows are good, or increase aquifer abstraction if the river flow drops. This provides a buffering effect since abstraction from either storage lakes, the river or the aquifer can be varied pre-emptively or in response to emerging conditions. However, as yet not enough is known about the aquifer to be able to accurately quantify how much buffering ability it can provide or for how long (Williams 2011, pers comm.).

Auckland has adopted a 1-in-200 year security of supply standard, which also translates as 1-in-50 plus 25% (Watercare 2008, p.49). Water management generally centres on meeting demand to an 'acceptable' level of risk, based on engineering and financial parameters:

> *"The security of supply standard is a measure of the level of risk the community is prepared to accept between the cost of supplying water and the impact of restrictions from not supplying sufficient water"* (Shaw 2011, p.2).

A recent review of GWW's 2% standard by consultants MWH found that of 15 comparable local and international water providers surveyed, *"the most common level of service for an unrestricted water supply is a 1-in-50 year drought return period"* (Shaw 2011). Implicitly, this means that normally demand will not be 'managed', and restrictions in particular are ideally avoided:

> *"Real-time system management requires decisions to be made on demand restrictions looking forward, whereas the severity and length of a drought is never known until it is over. Therefore summer demand restrictions are likely to be imposed more frequently and be more onerous as the security of supply standard reduces, when in retrospect the level of restriction may have been unnecessary"* (Shaw 2011, p.2).

However this approach also gives the community the unrealistic expectation that flow variability can be managed to enable 'unrestricted' summer water use. Unrestricted summer water use is unrealistic since just as it is not possible to know whether summer demand restrictions might retrospectively be seen as excessive, it is also not possible to exclude the possibility of a 1-in-50 or 1-in-200 year drought event for any coming summer, and because managing for such an event requires a strategy to implement seasonal demand management as early as possible.

3.4 Conclusion

How might climate change trends interact with water supply and demand factors to create water security and management issues for Wellington?

3.4.1 Implications of General Trends

The primary concern regarding "water security and management" in Wellington and in many other cities is contending with the conflicting variability of supply and demand in summer. This can be achieved by increasing the supply flow, increasing storage capacity, managing demand, or by a combination of these options.

Climate change will exacerbate water variability in Wellington. The general effect of climate change projected by 2040 is for a 5% decrease in potentially available water (PAW) and a 1% increase in per capita demand (PCD), and a 5.5% decrease in PAW and 3% increase PCD for the 2090 A2 scenario (for PCD of 404 L/day). The net effect of population growth and PCD of 404 L/day is to reduce net-flow, or surplus flow available for storage to well below zero by 2090, in an average year. When the net-flow is below zero, increasing storage capacity is no longer an option, and new water supply sources are required. However reducing PCD to 300 L/day is sufficient to 'offset' both projected population growth and climate change sufficiently to defer the need to augment supply until beyond 2090.

3.4.1 Implications for Managing 'Extreme' Events

Presently a risk management approach is taken in managing the conflict in flow variability between PAW and total system demand (TSD). Water managers aim to provide a particular level of service based on supply variability and to the extent that the community has been prepared to save water (or not). Climate change is expected to increase the frequency and severity of droughts and floods, therefore increasing the size of the extremes that must be 'managed'. Managing the increasing size of potential deficits into the future requires more water storage capacity, additional supply sources, or demand management, or a combination of these three strategies. In addition, and as outlined in section 2.4.2, model projections tend to under-represent climate variability at the local level. This increases the level of uncertainty in the projections on which 'security of supply' decisions are based. An increased risk of extremes combined with the uncertainty regarding local level climate variability may compromise the rigor of risk management based planning (i.e. significantly increase the uncertainty of calculations for long-term infrastructure planning to meet a 1% or 2% water security standard).

Expect Surprises

From a resilience perspective, an informed community, who are aware that a drought is possible in any given summer, and know that therefore they need to use water sensibly in summer, would be in a better position to cope with a particularly dry summer. The level of disturbance resulting from an extreme event will be more severe for a community that generally expects unrestricted use of water. A resilience approach is essentially an 'expect surprises' approach.

The analysis above necessarily makes a number of assumptions, with greater than expected population growth being a key limitation, and the effect of sea level rise on water abstraction from the Waiwhetu aquifer a significant source of uncertainty. Nevertheless, a reasonable conclusion is that 10,000 ML of storage capacity may be required for managing flow variability in Wellington to 2040. This would require construction of approximately 7000 ML of storage to complement the existing Stuart Macaskill Lakes (3390 ML after current upgrades are complete). 10,000 ML is the equivalent of 63 days supply at 158 ML/day, or 50 days at 200ML/day. Current storage provides 15 days at 200ML/day. Auckland's storage capacity provides 197 days (1-in-200 year standard), and Nelson 80 days (1-in-60 year drought standard) (MWH 2011). An 'expect surprises' or resilience approach would require the same storage capacity, designed around 'engineeringly' feasible and financially viable parameters, however in the event of a severe drought, the community would be much more prepared and better able to cope, the system would be less likely to fail, and the consequences would be less severe.

4 Wellington's Response Context

This chapter addresses Objective Two by setting out Wellington's context for responding and adapting to drivers of change including climate change.

4.1 Introduction

Wellington's reticulated water system has evolved over time according to its particular context of internal and external drivers and agents. This context includes Wellington's physical geography, climate, technology, institutions, and the values, beliefs and norms of its citizens. It also includes the rich and complex ways that these parts interact.

> *"…adaptation is a continuous stream of activities, actions, decisions and attitudes that informs decisions about all aspects of life, and that reflects existing social norms and processes"* (Adger et al. 2005).

Adapting to climate change has become a necessity given the warming that we are committed to as a result of past emissions (IPCC 2007b). However despite our past emissions and that the general trend is for emissions to rise at an increasing rate, *"it is extremely unlikely for any type of adaptive action to be taken in light of climate change alone"* (Smit and Wandel 2006, p.285). A further consideration for adaptation, as highlighted by the Intergovernmental Panel on Climate Change (IPCC 2007b, p.19), is that "*effective adaptation measures are highly dependent on specific, geographical and climate risk factors as well as institutional, political and financial constraints."* It is therefore necessary to integrate climate change adaptation with other adaptive activities within the local context.

Wellington's response to climate change will therefore depend on how climate change adaptation can be integrated into adaptation work that is currently being undertaken in response to other drivers, as well as on Wellington's social, political, cultural and economic context. Dealing with climate change risks can, in principle, be successfully integrated into existing policies, programmes, and decision-making processes, and these can also be configured to improve adaptive capacity (Smit and Wandel 2006). In order to achieve such integration it is essential to gain an understanding of the local context for adaptation, including what can be done, how and by whom, in terms of adaptation or increasing adaptive capacity, or for overcoming barriers to such activities.

The purpose of this chapter is to outline Wellington's social, political and cultural context in terms of the integration and practical application of climate adaptation initiatives. The Results section presents the contextual insights that were gained from interviews and literature, and in the Analysis and Discussion section these insights are summarised and related to broader academic theory and research. The conclusion then highlights the emergent opportunities, issues and pitfalls for adaptive management of urban water in Wellington.

4.2 Results

4.2.1 The Local Context

What characteristics of Wellington's particular 'water context' might shape adaptation to water shocks, constraints, response measures or policy reforms?

4.2.1.1 Declining Per Capita Consumption

Alastair McCarthy is the Water Supply Development team leader for GWW and says that GWW has been quite surprised by the marked downward trend of the last few years. McCarthy attributes the general decline to an increase in water awareness through problems in other places, including Australia; water efficiency labelling of appliances, which also arises from having a common market with Australia; a general increase in awareness of environmental issues; as well as GWW summer promotional work and the gradual improvement in infrastructure through renewal (McCarthy, Interview 07.10.10).

Wellington City Council has recognised the potential from such efficiency gains and adopted an interim goal: *"To accommodate Wellington city's population growth through to 2025 with the same amount of water we have available to us now"* (WCC 2009, p.2). Wellington City Council has identified potential savings from the residential sector of greater than 10%, along with additional options for managing demand such as volumetric charging that could reduce demand by at least 15% (WCC 2009b, p.80).

4.2.1.2 Political Leadership and Policy Decisions

Bryan Smith, principal policy advisor for Wellington City Council (WCC) says that while WCC has decided to try to live within its current supply capacity to 2025, building an additional dam and metering are both considered "more onerous" options (Smith, interview, 12.10.10). Capacity strategic policy analyst Paul Glennie highlights that GWW's calculations that the security of supply standard has slipped is a key driver of Capacity's current demand management work, and that WCC's desire for fiscal prudence is a restraint on both augmentation and metering (Glennie, interview, 12.10.10). There are direct financial benefits to the council from deferring either a dam or metering; however a plan capable of balancing out population growth and meeting an acceptable security of supply standard will need to be in place in order to defer these more onerous options. Bryan Smith notes that the enforcement of restrictions also has a cost and people have a limit for tolerating restrictions (Smith, interview, 12.10.10). In addition to population and consumption trends, a key driver for GWW's emphasis on water efficiency is resource consent conditions. Water consent holders need to be able to demonstrate efficient use of the water they take in order to satisfy consent authorities at the time of consent renewal and this applies equally to Greater Wellington Water (McCarthy, interview 07.10.10).

4.2.1.3 Water Conservation

Information and education activities, particularly targeted at gardening during summer, have been run by GWW since 1997/1998 (GW 2004). Annual promotions in conjunction with local gardening retailers encourage water-efficient gardening through information and product discounts, including on mulching, timers and targeted irrigation (Samuel 2011, pers comm.). Water restrictions were introduced for the first time in 20 years during a dry summer in 2008 (WCC 2009). Greater Wellington Water (GWW) uses a probabilistic forecast model, the 'Karaka model', which forecasts the probability of storage shortfalls at the Stuart Macaskill Lakes as the basis of their Summer Water Demand Management Plan (Samuel, interview, 07.10.10). This plan is activated by an increased risk of summer water supply shortfalls, and has increased communications activity and water restrictions as responses. As the risk of a water shortfall increases, publicity and education campaigns and restrictions are stepped up in order to decrease consumption (Williams 2010b, Samuel, interview, 07.10.10).

> *The first stage of the plan is the advertising by the cities of the standard 'odds and evens' water restrictions[17]. If the summer situation got more serious then patrols would be used to check on compliance with the restrictions in parallel with an increase in publicity – to warn the public as the situation developed and provide advice – and advertising of the water restrictions. Tougher restrictions would also be used if needed.* (Samuel, interview, 07.10.10).

GWW worked closely with the City Councils as the dry summer of 2008 unfolded and this experience led to the development of the Summer Water Demand Management Plan (McCarthy, interview 07.10.10). This plan is a 'participation-limited' adaptive management strategy consisting of a hierarchy of triggers, and interventions that can be taken by the regional council and by the city councils in order to manage an emerging summer water deficit.

> *With a largely run-of-river system the situation can change quite quickly over summer and there was a concern that the general public wasn't being given enough time to take in what was happening, think about it, then do some things that would help in good time. We've been working on how to ramp up public awareness more effectively, so people don't feel that they've gone from no worries to the sky falling within a week.* (McCarthy, interview 07.10.10).

The promotion of the benefits of water-efficient showerheads is also planned after collaborative work between GWW and the Energy Efficiency and

[17] "Odds and evens" or 'alternate day restrictions' refers to restrictions permitting garden watering by even numbered houses on even numbered days, and odd numbered houses on odd numbered days of the month.

Conservation Authority and a product test by *Consumer* magazine (GW 2010). GW highlights the need to overcome *"unfavourable publicity due to the perception that a reduced flow rate must result in a lesser showering experience"* (GW 2010, p.24). Such unfavourable publicity may have arisen as a result of water efficient showerheads being labelled 'nanny state' during the 2008 general election. Then Opposition energy spokesperson Gerry Brownlee stated that a vote for the incumbent Labour Party was a "*vote for a nanny-state government spending your taxes to tell you what light bulbs to use, how much water can flow through your shower head, and how much hot water you can use"* (Brownlee 2008). Phil Goff, the post-election Labour Party leader, subsequently blamed the election loss on Labour having taken up issues such as energy efficiency, rather than on the party administration's own failure to quash political misinformation or to bring the public with them (Clifton, Rudman, 2009).

4.2.1.4 Information and Communication

Greater Wellington Regional Council (GW) was caught out by significant revisions to population projections for Wellington, made by Statistics New Zealand, which occurred between 2002 and 2005. These revisions brought forward the need to have augmented supply in 15 to 20 years (WCC 2009, Shaw 2008). The population able to be supported at 2008 levels of demand was subsequently revised downward following refinement of GWW's water supply model and updated climate data from NIWA (Shaw 2008). Andrew Samuel, senior marketing advisor for GW says that in the 1990s GWW felt it had a system that could supply to the 2% standard till about 2020, and that was reflected in the messages they were putting out.

Such messages could have contributed to the general perception amongst the public that Wellington is not typically affected by water shortages, which also coincides with most peoples experience (Samuel, interview 07.10.10). Furthermore the degree of importance people placed on responding to the messages that GWW were putting out may have been lower in the past as a result (Samuel, interview, 07.10.10). In the last couple of years the amount of local government activity and publicity on water issues has increased, largely concerning water supply options, but also on water saving following the dry spring and summer of 2007/08; leading to water issues receiving a higher profile (Samuel, interview, 07.10.10). Andrew Samuel says that with this higher profile people seem to be taking more notice of GWW's campaigns.

The raised profile of water issues is also a double-edged sword as discussion regarding options can quickly become polarised. Alastair McCarthy notes that in a polarised environment clear and rational debate is difficult as people and politicians tend to form strong views one way or another on the basis of incomplete information (McCarthy, interview 07.10.10).

4.2.1.5 Water Cost and Price

The cost of bulk water in Wellington for 2009/2010 was $0.47/kL, which is 24% less than the cost of bulk water in Auckland (GW 2010) and 18% less than in Melbourne (NWC 2010). Based on Wellington City Council's rates and water charges for 2009/10, the annual cost for water and wastewater for a three person household using the per capita domestic average would be $205 per person,[18] or $2.35/kL for non-metered, and $280 per person,[19] or $3.25/kL for metered domestic customers (WCC 2009c).

[18] This calculation assumes a rateable value of $450,000 per household and a 3 person household.
[19] Also based on a 3 person household.

Table 4.1. Water statistics and costs in Australia and New Zealand in New Zealand dollars (NZ$1.0 = AU$0.75).

	Sydney	Melbourne	Brisbane	Auckland	Wellington [20]
Aggregate L/PC/day	323[21]	312	308	302	374
Domestic L/PC/day	201 (State Average 205)[22]	194 (State average 172)	166 (State average 191)	185	235
% Domestic	62	62	54	61	63 (56% Wtn City)
Bulk Water $/kL[23]	$0.47	$0.75	-	$0.62	$0.47
Domestic Retail Water Price $/kL	$2.55 (State Average)	$1.60 (Yarra Valley Water Melbourne)	$3.02 (State Average)	$2.00 / $3.50 (central city / townships)	$1.28 (Wgtn City non-metered)
Average water bill[24] (per person/yr)	$191 (State Average)	$116 (Yarra Valley Water Melbourne)	$210 (State Average)	$136 / $238 (central city / townships)	$110 (Wgtn City non-metered)

The marginal cost of supplying a quantity of water is not a key consideration as only 18% of GWW's costs are volume related, with fixed costs comprising approximately 90% of the total cost of supplying water to consumers. However reducing demand in order to defer the costs of capital development is a significant driver (McCarthy, interview, 07.10.10). Alastair McCarthy says the decision on whether the approach should be to supply

[20] Includes Upper Hutt, Lower Hutt, Porirua and Wellington Cities – see Wellington water reticulation map (Fig. 1), data for 2009-10 year.
[21] City statistics for Sydney, Melbourne, Brisbane and Auckland for 2006/2007 year, Residential water use for any given city and year my be strongly influenced by restrictions (Kenway et al. 2008).
[22] State average statistics are for 2008-09 from the Australian Bureau of Statistics; Household water consumption decreased 11% in New South Wales, 16% in Victoria, and 38% in Queensland from 2004-05 (ABS 2010b).
[23] Australian bulk water prices calculated from NWC 2010, Wellington and Auckland from GW 2010.
[24] Excludes wastewater component, which can increase the actual bill significantly.

more water or increase efficiency is politically difficult and requires City Council ‘buy-in’. However attempts over the last two years to develop a regional water strategy have had limited success (McCarthy, interview, 07.10.10). In the absence of an agreed strategy, whether the pathway will be orientated more towards supply or efficiency remains uncertain (McCarthy, interview, 07.10.10).

4.2.1.6 Resistance to Universal Metering

Metering is a political ‘hot-potato’ and during the 2010 local body elections mayoral candidates distanced themselves from metering. The incumbent Hutt City Council Mayor even accused his rival of supporting metering (Edwards and Boyack 2010). Metering has been investigated for Wellington, and the estimated costs are $70 million (Sherlock 2008, GW 2008b). Political opposition to metering stems from a fear that universal metering is a key step towards the privatisation of water (MfE 2009, PCE 2001), as well as general opposition to the commoditisation of a basic necessity of life and a human right (Right to Water 2010, MfE 2009). The Parliamentary Commissioner for the Environment (PCE) investigated urban water systems in New Zealand, finding that there were considerable tensions between some local governments and their communities (PCE 2001). The PCE found that fear of water privatisation was the greatest issue of concern regarding water management and stated that this fear is “limiting vision and constraining dialogue.” The PCE also stated that until such tensions are addressed and stakeholders achieve some consensus on needs and options, progress towards the sustainable management of urban water systems will be constrained.

A key concern for Right to Water spokesperson Maria McMillan is a fundamental shift from treating water as a human right and basic necessity, and its supply as a public service, to its commoditisation through metering, private sector involvement, and the introduction of a profit motive. Maria is not opposed to charging for water when it is an economic input (McMillan, interview, 22.11.10). The opportunity cost of meters also concerns Maria and she would like to see money invested in devices that save water directly, rather than in meters which can only provide indirect savings. However her biggest concern is the social justice implications:

> *Charging for water has inequitable results; someone on $100,000 might use the same amount of water as someone on $20,000, but the water bill will be a much greater proportion of the lower income. Likewise someone on a higher income or who owns three cars won't mind paying a little bit more to wash them, or can continue to be wasteful if they want. However paying a bit more might really hurt someone on a low income who has kids to feed* (McMillan, interview, 22.11.10).

Andrew Samuel is a senior marketing advisor at GW. From his perspective, the absence of universal metering is a limitation both in terms of information about water use, and in the effectiveness of options that are available in order to manage demand in the event of a dry summer (Samuel, interview, 07.10.10). Metering provides the higher resolution information on water use necessary in order to provide more targeted demand reduction strategies and obtain feedback to evaluate and refine such strategies. (Samuel, interview, 07.10.10). The information that meters provide and the additional pricing tools that they enable have advantages in terms of providing water efficiency signals and information to households.

> *If you look at councils that have a broad offering of water conservation options to the public you'll tend to find councils that have universal metering and volume-based pricing. That's because they've got a means to have a conversation with individual households about their water use; both in terms of local norms, and financial benefits available to those consumers from using a bit less water* (Samuel, interview, 07.10.10).

4.2.1.7 Values, Beliefs and Trust

The Ministry for the Environment (MfE, 2009) summarised three pieces of New Zealand-based research, including research undertaken in Wellington. These studies indicated that while many New Zealanders have strong anti-waste attitudes and value water as a vital necessity of life, water is generally not a 'top-of-mind' issue and it tends to be taken for granted (MfE 2009). There was also evidence of tension, community disempowerment and mistrust, resulting in disengagement with water management:

> *"I haven't heard anything about it and I don't think I would go to the trouble of trying to find out about the infrastructure because I think that it will probably ... annoy me even more"* (MfE 2009).

Right to Water spokesperson Maria McMillan and her husband are both involved in Right to Water, "*water is a common good and it belongs to everybody, there's also a sense that it's a human right, and that's a big issue for me… My husband has been involved in environmental groups and he has more of an environmental focus"*. Maria notes that there has been a clash in New Zealand between people who are interested in water from a social justice perspective, and people who are interested in water from an environmental perspective. "*It's almost as if the environmentalists are saying 'if you don't accept meters then you want to waste water' – however we need to watch that the green approach to conserving water is not used as a tactic to introduce neo-liberal approaches to water management"* (McMillan, interview, 22.11.10).

In April 2009 Wellington resident and tertiary engineering teacher Frank Cook submitted a report to Wellington City Council (WCC) discrediting water use figures that WCC was using in its publications and on its website (Cook 2009). In particular Frank Cook asserted that WCC's discussion and consultation document for developing its Long Term Council Community

Plan *"contains serious errors of fact and uses these distortions to channel residents' responses in a particular direction"* (Cook 2009). In response WCC admitted that it had got its figures wrong (Chipp 2009). The comparison of aggregate and domestic metered water statistics was highlighted again in an editorial in The Wellingtonian[25] in October 2009, but this time in relation to Capacity. In addition former Capacity Chairman Brian Jackson was quoted as confidently stating *"that he expects to have control of the region's bulk water supply within a decade"* (The Wellingtonian 22.10.09). These events have reinforced the sense of distrust in the credibility and motives behind Wellington's water management. Maria McMillan states:

> *From the hype we have seen in the press it sounds like Wellingtonians are really wasteful with water. Wellington City Council made a lot of excessive claims – that we use three times as much as Nelson and twice as much as Auckland, when in fact their figures were wrong in that they were comparing our gross use with metered domestic use figures. Basically I think there was a campaign to make it sound like Wellingtonians are really wasteful. Wellington is a very wet city and if there is water shortage issues in Wellington they relate to inappropriate planning.*

Maria's distrust also extends to central government:

> *Under the Local Government Act ownership and control of water had to be in public hands, but the current Government has removed these controls; 414 submissions, 316 of them expressly opposed to the water privatisation bits of the bill, but still the Government thought that urgency was appropriate.*

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[25] A community newspaper delivered to an estimated 70,000 homes and businesses in Wellington City.

Adding to privatisation fears, the present National Party administration has announced plans to partially privatise state-owned power companies (Kay 2011).

4.2.1.8 Supply Augmentation Options

Centralised augmentation options being considered or initiated include increasing the storage capacity of the Stuart Macaskill Lakes from 3000 ML to 3390 ML, with capital costs of approximately $5 million; reducing the minimum flow of the Hutt River at the Kaitoke Weir (no capital cost)[26]; constructing a new reservoir in Wellington City ($5 million); and developing the Upper Hutt Aquifer as a standby source ($15-$20 million) (GW 2008b). A 9000 ML dam on the Whakatikei River (5000 ML 'usable' storage), a tributary of the Hutt River, was considered to be the best long-term augmentation option, with capital costs of $142 million in a 2008 study (GW 2008b). Subsequently a new option for a 5000 ML storage reservoir at Kaitoke has become a possibility and is also being assessed (GW 2010).

4.2.1.9 Earthquake Risk

A key consideration for Wellington is the resilience or robustness of the water supply system in terms of its vulnerability to damage from a large earthquake, and in particular how long it would take to get it back up and running after a major earthquake (Smith, interview, 12.10.10). The Wellington Fault bisects the region (Fig. 4.1) and it is estimated that in the event of a large earthquake it may take months to re-establish water services to some areas, rendering such areas uninhabitable (Cousins et al. 2010). A key benefit of the Whakatikei dam is that it would be on the western side of the Wellington fault, and would connect Porirua and Wellington with less exposure to movement of the Wellington Fault, whereas all other supply sources are on the eastern side (GW 2008b).

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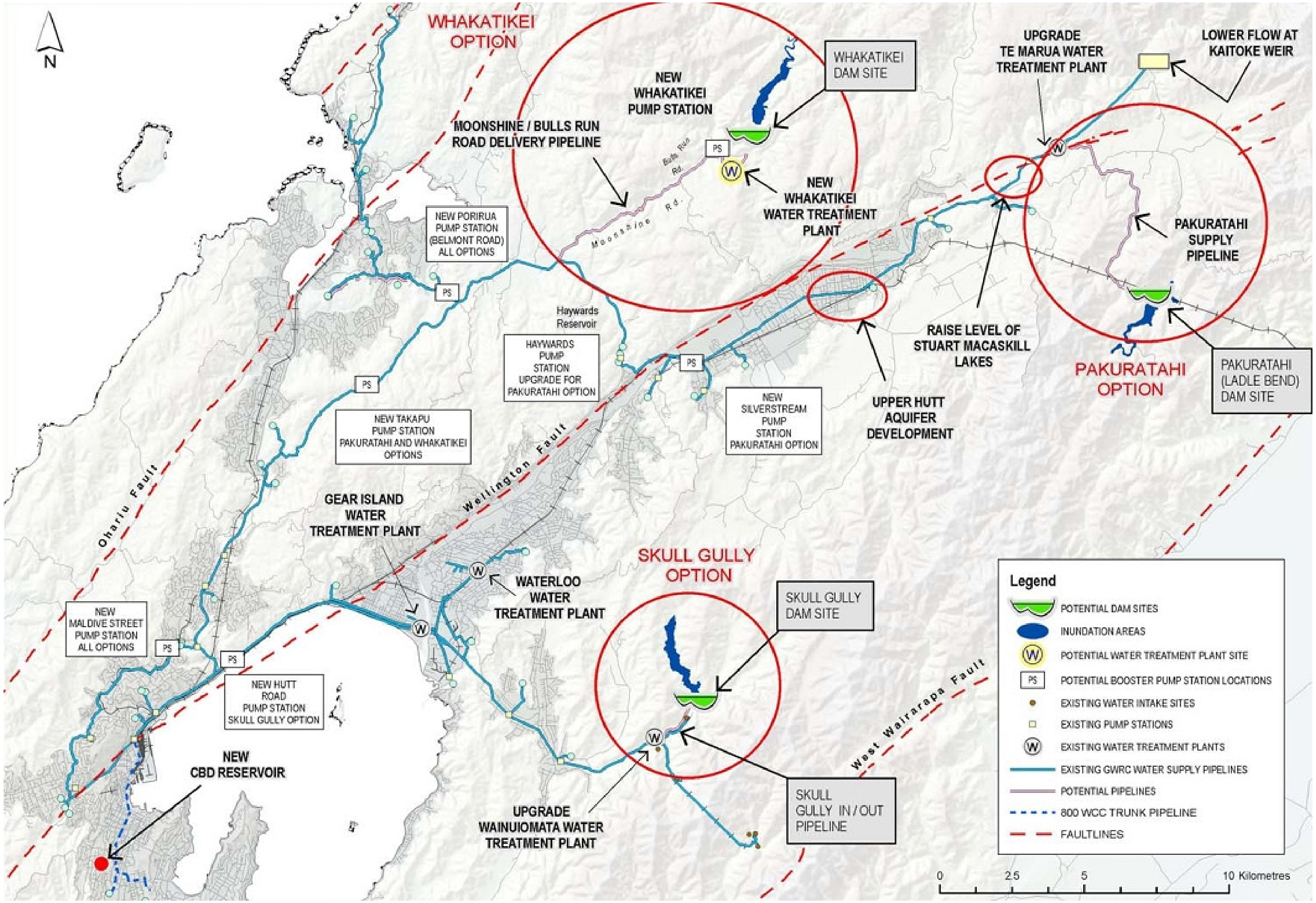
[26] There are no capital costs for this option since the infrastructure is already in place.

Figure 4.1. Augmentation and upgrade options, plus Wellington Fault location (GW 2008b).



4.2.1.10 Health of the Hutt River

The role of incorporating or balancing various values and issues relating to water use is largely entrusted to politicians. A key concern for Hutt Valley residents is the health of the Hutt River, which is the primary water source for the four cities. Cr Margaret Cousins of the Hutt City Council has noticed the increase in toxic algal blooms in the Hutt River in recent years. Many of her constituents have a view of the river, or interact with it in other ways on a daily basis, such as walking a dog, or crossing a bridge.

GWW applied for resource consent to reduce the minimum flow of the Hutt River, which may be necessary in order to avert a water shortage during planned upgrade works on the Stuart Macaskill Lakes. However there are fears that reducing the minimum flow could exacerbate toxic algal blooms, which significantly affect recreational use and enjoyment of the Hutt River (Kopp 2010). As advocates for their constituents, Local Government politicians respond when such conflicts arise in order to advocate for their constituents' values. In this case, Lower Hutt City Councillor Max Shierlaw used an Official Information Act request in order to obtain reports by the peer reviewer of GWW's Assessment of Environmental Effects for the consent application:

> *I was concerned that major political decisions on water capacity and supply were being requested of politicians, without being given any scientific evidence to back up [the GW] Officers' assertions. I therefore decided to request the scientific information to ascertain if it supported the claims being made by the Officers that reducing the flow would have no more than a minor effect; the peer reviews of GW's work did not support such a contention.*
>
> (Shierlaw 2011, pers comm.).

4.2.1.11 Water and Infrastructure Management Structure

Cr Cousins believes that in general, having the retail supply managed separately by the city councils, and the bulk supply handled by GWW for the regional council creates a *"healthy tension"*. The present dynamic enables the cities, as large and powerful customers, to question the bulk supplier, whereas if bulk and retail supply were amalgamated this dynamic would be lost (Cousins, interview, 15.12.10). As in the example above regarding environmental concerns, City Councils and Councilors can act as 'aggregators' for constituents, and when the City Council itself is the customer, this aggregator role is much more structural.

Dealing with the conflicting values of water is challenging and any structure is likely to have its drawbacks. For example Cr Cousins feels that GWW used the potential for a water shortage to leverage compliance from Hutt City with its application to reduce the minimum flow of the Hutt River:

> *Suddenly we're being told 'you've got to agree to this – and if you don't say yes to what we want you'll be the pariah of the region because you're going to affect the other cities to the point that they are going to have to face stronger restrictions'. Also, when we asked [GWW] for further information, [for Cr Shierlaw] to have to resort to the official information act wasn't exactly conducive to my idea of open governance or good relations"* (Cousins, interview, 15.12.10)[27].

[27] Hutt City Council supported the proposal at the consent hearing, requesting conditions including restoration of the current minimum flow if an algal bloom occurs, and no possibility for a renewal of the consent (Chipp 2011).

4.2.2 Responses to Change

How have people, institutions and communities responded or adapted to 'water shocks', shortages, or policy and trend changes in the past?

4.2.2.1 Auckland

In 1993/94 the North Island of New Zealand experienced a severe drought resulting in water shortages in Auckland, with the impact of this event being due to its duration rather than its magnitude (Clauson and Pearson 1996). Analysis suggests that this drought was a 1-in-50 year event in terms of its effect on rainfall in Auckland (Clauston and Pearson 1996). In response to the drought, a pipeline to transport water from the Waikato River was constructed, and the security of supply standard was increased to 1 in 200 years from the previous 1 in 50 year standard (Watercare 2008). Auckland has universal metering and per capita domestic water consumption is relatively low (Table 4.1). Auckland generally has low levels of leakage as much of its reticulation network is less than 50 years old (Taylor and Hodges 2008).

A range of demand management responses has been proposed or implemented in Auckland including monthly billing for high water users, sliding tariffs, mandatory water audits for high-use industries in order to identify inefficiencies, information and education campaigns (Water Wiseup, Every Drop Counts), regulation (e.g. restrictions on outdoor water use), pressure and leak management, rain tank subsidies, and the promotion of water efficient devices including a free water gizmo[28] (Watercare 2008). Waitakere City Council[29], widely regarded as a leader on sustainability achieved a 10% reduction in demand over ten years (from 1992/93 to 2003), primarily due to pressure management (Pilipovic and Taylor 2003). During

[28] A water gizmo is a device that makes it necessary to continue to hold down the toilet flush button in order for the toilet to flush).

[29] Waitakere City Council was one of six retailers supplied by Watercare, Auckland's bulk water supplier. These retailers were amalgamated on the 1st November 2010 and Watercare now provides all retail and supply services for Auckland.

the course of the pressure management programme (affecting 35,000 properties), 1% of affected customers contacted Waitakere City Council to complain about pressure issues. Half of these were due to internal plumbing with many simply requiring adjustments, and were resolved at the Council's expense. Some of the plumbing issues were also resolved at Council expense (Pilipovic and Taylor 2003). Managing customer relations was prioritised, and the programme was communicated as 'pressure standardisation' with the goal of 'standardising pressures across the city'. Prior notification and a prompt response to enquiries were considered essential. A specialist fire engineer assessed the impact of the programme on fire sprinklers, and the council covered the costs where changes were required (Pilipovic and Taylor 2003).

Prior to November 2010 the Auckland Region had vertical and horizontal separation of water services. Enthusiasm for demand management was variable due to considerable diversity between the six retailers, especially where a substitution option (such as greywater or rainwater as a 'fit-for-purpose' alternative to mainswater) would reduce revenue (Taylor and Hodges 2008). An issue created by this former structure was that if one retailer implemented successful demand management but others did not, and if wholesaler investment was still required, then the bulk supply price would still be increased (Taylor and Hodges 2008). The wholesaler was removed from the customer, and this was seen as a barrier to the promotion of water conservation measures (Taylor and Hodges 2008).

In 2005 a petition was presented to Parliament requesting an inquiry into the charging practices of Metrowater, a Council-Controlled Trading Organisation (CCTO) owned by Auckland City Council. Profits not reinvested in Metrowater were required to be paid as 'charitable payments' to Auckland City Council (Chadwick 2007). Between 2003 and 2006 payments ranging from $5 - $12 million per annum were made, and

Metrowater was advised by the council that it expected significantly larger payments in the future, totaling $324 million over the next 10 years. The Council told the Select Committee that it required these payments in order to upgrade the city's stormwater system (Chadwick 2007). The Committee noted that the price increases in water and sewerage services were significant, that the public of Auckland were not well informed about the process of the payment and its purpose, that information supplied by the Council had been misleading and that the Council's decision making lacked transparency. The Committee stated that it considered that both the method used by the Council and the extent of the payments were unacceptable and strongly advised the Council to reconsider (Chadwick 2007).

4.2.2.2 Australia

A key adaptation to water shortages for many Australian urban centres and regions is to build desalination plants (Chanan et al. 2009). From 1997 to 2009 inclusive, Melbourne's rainfall was below the long term average (BoM 2010), resulting in a 40% drop in average storage inflows in that period including a 70% drop in 2006 (Melbourne Water 2010). Such a decline in inflows had been indicated as a possibility under a 'high' climate change scenario by 2050 (Melbourne Water 2010). In 2007 storage levels dropped below 30% (Barnett and O'Neill 2010, Melbourne Water 2010b), and a water crisis was declared (Barnett and O'Neill 2010). The State Premier announced plans for two schemes: a desalination plant with a maximum capacity of 150 GL/year; and a pipeline to transport an additional 75GL/year to Melbourne (Barnett and O'Neill 2010, Abbot, Wang and Cohen 2010).

Australia's largest ever demand management programme was initiated in response to Sydney's water shortages (Turner et al. 2004). This initiative was largely based around subsidised retrofits of water-saving fixtures and achieved savings of 8% of average household demand (Turner et al. 2004).

The retrofits started in 2000 and by 2009 350,000 houses had been retrofitted (Turner et al. 2009). In 2006 the New South Wales Government produced a ‘Metropolitan Action Plan’ which outlined an ‘adaptive management’ approach to water security:

> *“Rather than prescribing now how water needs will be met over the next 25 years, adaptive management means having the capacity to respond to circumstances as they change, taking advantage of new information and technologies as they emerge, and avoiding costs by deferring investment until it is needed. The approach adopted in this Plan reflects this new thinking – particularly with respect to measures required to provide security of supply in deep drought”* (MWP 2006, p.121).

Preparations to build a desalination plant, if the drought conditions worsened, were framed as part of the adaptive management approach. In 2007 Sydney’s storage dams dropped to 34% of capacity after a gradual decline since 1998 (SCA 2010) resulting in the NSW Government triggering the construction of the Kurnell desalination plant (MWP 2010 p.11). This plant was completed in January 2010, and can produce 90 billion litres/year or 15% of Sydney’s water needs. Adaptive management was introduced as a new approach with the desalination plant given as an example, however adaptive management was not referred to in the 2010 water plan, with framing around diversification and security used instead (MWP 2010). The Kurnell plant has also been designed so that its capacity can be doubled if necessary (MWP 2010, p.35).

Restrictions have been used extensively in Australia and 80% of households are reported to have been affected by restrictions (NWC 2010). One household response to restrictions in Australia has been to install rainwater tanks. The Australian Bureau of Statistics (2010) found that 1.6 million Australian households installed rainwater tanks between 2007 and 2010.

Households reported that their primary motives for installing rainwater tanks were to avoid restrictions (24%) or to save water (47%). In 2010 26% of Australian households used rainwater tanks compared with 19% in 2007. Over the same period the use of rainwater tanks increased by 25% in Brisbane and 16% in Melbourne. The majority of households with rainwater tanks (57%) were residing in houses less than 1 year old (ABS 2010). Recycled water use is also increasing in Australia and the percentage of recycled water supplied by urban water utilities increased from 10% in 2007-08 to 12% in 2008-09 (NWC 2010).

4.2.2.3 Residential Water Users

The key theme that emerged from the interview with Janet[30] was the initial strong response to a price signal. However this signal was later attenuated by the landlord incorporating the water bill into Janet's rent. The shock of potentially having to pay the majority of a six monthly billed spurred action, while the weekly flat rate took away the price incentive.

Steve and Julie's price incentive to save water was attenuated by their incomes, and since the water bill is a minor consideration relative to other expenses. In addition the volumetric component makes up only 46% of their bill, and is averaged over their buildings eight apartments (17 residents). However their water use is moderated by strong moral and normative pro-conservation influences, along with 'sanctioning made easy', i.e. the couple and their neighbours can easily report any water use indiscretions they see to the local council, which could result in a fine being issued. They share the volumetric component of their bill with the other occupants of their building, and so they have an added incentive to keep an eye on each others' water use.

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[30] Interview summaries can be found in Appendix Three. The names of residential water users have in all cases been changed for anonymity.

Eila grew up in Pakistan and was strongly conditioned to use water carefully as a child, while Paul grew up in England and recalls that water was taken for granted. Eila's strongly 'water conservative' upbringing has had a big influence on her family's water use. Paul is now very conservative with water and the family notice when other people's water use habits conflict with their own. For example when they lived in Thorndon in Welliongton City they noted that water was taken for granted, and that their neighbours did not observe the 'odds and evens' water restrictions. In addition one of their two teenage daughters will encourage her peers not to waste water at art school. The family's attention to their water use has helped them to manage in their present home where they are dependant on rainwater. However one adaptation to their current situation is to shower at work.

4.3 Analysis and Discussion

How might individuals and key groups or institutions in Wellington adapt to water shocks, constraints, response measures or policy changes and what might impede or facilitate adaptation by these actors?

The following themes were identified through the literature analysis and interviews:

4.3.1 Political Leadership and Policy Decisions

At the local government level there is a range of incentives to manage demand and defer supply augmentation. However there is a fine political balance that is subject to fiscal costs, meeting the supply standard, and to community tolerance of restrictions. Leadership failure and uncertainty about water reform at central government level is adversely impacting water efficiency efforts at the local level (e.g. water efficient showers framed as 'nanny-state', fear of privatisation agenda). Political conflict is certain given the clash of paradigms – technical, social justice, environmental, neo-liberal, and the partial solutions that each generates (Holling, Gunderson and Ludwig 2002). Folke et al. (2005) highlight the central role of *adaptive governance* (where participation of the extended peer community is central) and *co-management* (where decision-making power is shared) in creating resilient socio-ecological systems. No such arrangements are evident in Wellington regarding water management. At the national level the Land and Water Forum is a recent 'collaborative governance' initiative of a range of stakeholders (industry, environment, recreation, iwi) tasked with providing 'advice' *"on how water should be managed in New Zealand"* (Land and Water Forum 2011), however this forum has no decision-making powers.

4.3.2 Water Conservation Activities

GWW have taken an adaptive-management approach in order to manage summer-shortage events within their run-of-river system including incorporating lessons from the 2008 summer. However New Zealand has no water efficiency standards other than a shared water-efficiency product-labelling standard with Australia, and in general Wellington lacks incentives to motivate uptake of water efficient devices. While restrictions and information/education are used to manage summer demand, Wellington and Lower Hutt City Council's have no enforcement policies in place to promote compliance with bylaws, while Upper Hutt contract a private security firm to do patrols (Glennie 2011, pers comm.). Porirua City Council targets high use areas with 'letter box drops' to remind people of bylaws, respond to calls from the public, and council officers keep watch during regular activities or conduct patrols if required (Scrimgeour 2011, pers com.).

In general, water users in Wellington perceive that water is plentiful, and this perception is reflected in their attitudes to water use (MfE 2009). While the overt waste of water is generally frowned upon, making a conscious effort to save water is not seen as a priority until a crisis is reached, and some people may in fact be unwilling to make voluntary efforts unless there is a crisis (MfE 2009). Therefore a focus on promoting structural water conservation measures and the use of water efficient devices should be prioritised, as unlike measures which require a sustained commitment from water users, once structures and devices are in place, they continue to save water. Failure to address the current legacy of inefficient water use creates future legacy problems.

4.3.3 Information, Communication, Framing and Community Expectations

GW's Summer Water Demand Management Plan, perceptions of copious water supplies and the water-efficient shower misinformation are examples that highlight the value and need for good communications strategies to smooth transition and change, manage times of crisis and to justify or defend policy and strategy. Effective political champions are required to bring the public along, and also to counter misinformation.

Water issues are given plenty of public attention during shortages and a period of social learning ensues as a result of a positive public response. On the other hand public attention can also be used to advance pathways which may lead to maladaptation. As the crisis dissipates, much of the extra effort is not sustained, which highlights the importance of encouraging structural initiatives during such periods to achieve lasting effects. When people have experience of conserving water, they are more able to respond with extra effort in the event of a water crisis. The recent spate of large destructive earthquakes and Wellington's own exposure could be used as an opportunity within which to frame resilience and adaptive capacity concepts and drive their integration.

4.3.4 Water Cost and Price

Water is relatively cheap in Wellington and domestic use is charged on the basis of property value rather than tied to consumption.

> *"How frugal would we be if the cost of fuel was bulked up in uniform annual charges against private property, oil companies were recompensed by territorial authorities and motorists filled up at the pump at no charge?"* (Gibb 2009).

Commercial use is metered yet significant inefficiencies remain (Bint, Issacs and Vale 2010) highlighting that effective demand management requires more than just price and volumetric charging policies and 'the market'. While 90% of the costs of supplying water are fixed, volumetric charging is a commonly used mechanism in other cities, sometimes in conjunction with sliding tariffs.

A regular water bill can provide incentives for high volume water users, while a less regular bill accumulates a more substantial sum to provide a better price incentive for lower volume users. Politicians, landlords, high incomes, and the cost of water in relation to other expenses can all attenuate the price signal, and removing up-front costs can also be used to the benefit of demand management[31]. For example, Waitakere's 'pressure standardisation' programme covered up-front costs in order to smooth the transition to lower water pressures

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[31] The Solar Saver Scheme, a nationwide initiative developed by Nelson City Council (NCC) and piloted in Nelson in 2010, is a potential model that could be adapted to facilitate the uptake of a range of retrofit upgrades. The scheme aims to facilitate the uptake of solar hot water systems by removing barriers such as up-front costs, while reducing the overall cost through bulk purchasing of both product and finance. The Council pays the up-front costs, and the households repay the loan with interest over 10 years along with their rates payments (NEC 2011).

One potential maladaptation to water charges is to take showers at work or the gym; the negative effects of this can be reduced through workplace water efficiency audits, water efficient device retrofits of commercial buildings, standards for new buildings, and bringing old buildings up to standard.

4.3.5 Resistance to Universal Metering

There is strong community opposition to metering from the viewpoints of efficacy, equity, and values; particularly as metering is seen as a step on the slippery slope to privatisation. From a water management perspective metering would provide better information and enable a greater range of policy tools and options to be used. A stalemate has emerged due to a lack of confidence and trust in governance, and a community wary of a privatisation agenda. Equity is the central goal of good governance (Lebel et al. 2006), and the current concerns manifest in the metering debate perhaps reflect local dissatisfaction with structural inequalities of power and circumstance.

4.3.6 Values, Trust, Social Learning and Self-Governance

Value conflicts and trust issues are present as can be expected for any complex socio-ecological problem. Wellington City Council was accused of inflating the water shortage situation to justify metering, while Hutt City Councillors felt they were being pressured to comply with GWW's bid to reduce the minimum flow of the Hutt River. Ostrom (2009) highlights the central role of trust in coping with social dilemmas, with increased levels of trust leading to greater co-operation and increased efficacy of social learning. Trust is often neglected or undermined in order to push through a particular agenda or 'solution'.

> *Trust makes social life predictable, it creates a sense of community, and it makes it easier for people to work together. Trust can be said to be the*

> *basis of all social institutions and is also integral to the idea of social influence, as it is easier to influence or persuade someone who is trusting*. (Folke et al. 2005).

Kahan (2006) highlights the role of *'cultural cognition'* in public policy debates such as climate change, abortion and gun-control laws, where debate is highly polarised across distinct social groups such as racial, sexual, religious, regional, and ideological. Kahan's research shows that cognitive filters also cause people to form beliefs based on preconceived cultural notions and in conformance with the norms of the culture or group that they identify, or wish to identify, with. The key implication of Kahan's theory of cultural cognition is that a trusted agent who is part of a given cultural community has the most influence on community perceptions (Kahan 2010, 2006).

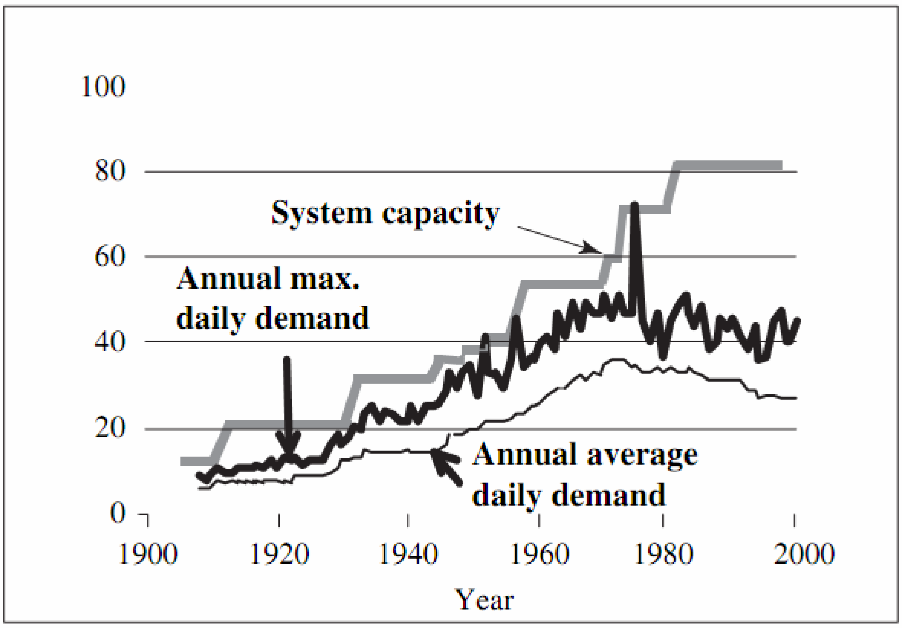
Families, schools, workplaces and neighbourhoods can be ideal environments for the transfer of conservation norms. For example, the presence of a strong moral and social obligation to save water in response to water stress is evident in a Melbourne neighbourhood. Sanctioning neighbours who flout restrictions is as easy as a 'raised eyebrow' or a phone call to the council. With the low transaction costs of sanctioning neighbours who flout restrictions, water use is moderated primarily through a sense of obligation combined with the threat of sanctions. Under such conditions powerlessness, i.e. an individual's perception that their actions can make no difference (Aitken, Chapman and McClure 2011), is mitigated by the extent of obvious collective behaviour.

4.3.7 Supply Augmentation Options

Generally water supply capacity in industrialised nations is designed to meet or respond to extremes, periodically requiring major investments in long-lived infrastructure (Pahl-Wostl 2005). Increasing supply or storage capacity is a common response to water shortages which can lead to maladaptation (Barnett and O'Neill 2010), and 'stranded assets', due to the 'lumpy' nature of system capacity increases (Fig 4.2). An evident form of maladaptation is when security of supply leads to increasingly casual attitudes to the use or wastage of the resource. However when supply is constrained, and where discretionary water use has been trimmed and efficiency options exhausted, managing events through increasing storage capacity or supply becomes attractive. A number of additional supply options are available for Wellington but, in the absence of comprehensive demand management incentives or signals, augmentation can have the undesirable effect of shifting the tackling of inefficient water use into the future, delaying structural and behavioural change and further entrenching inefficiencies. However if augmentation does occur yet per capita demand continues to fall, then the stranded assets[32] scenario emerges.

[32] For example as represented in Figure 4.2, system capacity is increased, representing significant capital and infrastructure expenditure, but is not required as annual average daily demand decreases.

Figure 4.2 Responding to an extreme event based on historical trends led to an increasing and expensive gap between capacity and consumption for a big city in Switzerland (Pahl-Wostl 2005).



Auckland and some Australian cities have outgrown the supply capacity of their water catchments. Additional water sourced from pipelines and desalination plants is considerably more expensive and creates additional issues and conflict. For example pipelines and desalination plants increase the energy intensity of water provision, while pipelines take water from other catchments, creating conflict with water users in that catchment. The energy use of the Melbourne and Sydney desalination plants is offset by wind energy which has provided stimulus for the renewable energy sector. However in general desalination can be characterised as ‘maladaptation’ (Barnett and O’Neill 2010). Moreover Barnett and O’Neill (2010) argue that Melbourne’s pipeline and desalination plant will reduce the incentives for Melbourne residents to adapt and it will undermine the current shift to a “responsible water conservation norm” from the previous “excessive consumptive norm”. Melbourne households have responded with a range of adaptations, including technologies and practices which recycle grey-water and capture rainfall, taking shorter showers, and planting drought tolerant natives in their gardens (Barnett and O’Neill 2010).

> *"These changes have been achieved with simple and cheap policy instruments such as rebates on the purchase of rainwater water tanks and public education. The potential further effectiveness of such instruments, which encourages millions of water users to take responsibility for action, saves water users money, and creates powerful new norms, will be undermined by the desalinisation and pipeline projects, which transfer responsibility for responses to government, and will stifle the water conservation norm"* (Barnett and O'Neill 2010, p.212).

4.3.8 Water and Infrastructure Management Structure

Vertical disaggregating of bulk supply and retail services, and City Councils as aggregated customers gives water users a collective voice against a large public utility. There is a need to be able to question the water supplier, and the current structure affords this ability. There is also horizontal separation in that there is diversity between the approaches taken by each of the four cities. There has been good collaboration between GW and the four cities on managing summer demand, but progress on an overall water management strategy has been slow.

Issues were identified with Auckland's retailing structure, where some of the city councils owned profit-motivated retailers, as the profit-motive conflicted with efficiency incentives and other values. With the recent Watercare amalgamation, Auckland now lacks a variety of aggregated customer advocates. Nobel Prize winning economist Elinor Ostrom highlights the role of 'polycentric' governance for 'complex economic systems' (Ostrom 2009). Polycentric governance achieves a balance between decentralisation and centralisation where institutions operate and overlap at different domains and scales, achieving economies of scale in some services and avoiding diseconomies of scale in others (Ostrom 2009). Resilience comes from "*the capacity to expect the unexpected and absorb it"* and therefore from an institutional resilience perspective diversity and overlap are required within institutional arrangements (Folke et al. 2005). However these pre-conditions for resilience are often seen as signs of waste and inefficiency within the present dominant paradigm (Ostrom 2009, Folke 2005). This paradigm sees management as 'control' and environmental and social systems as external boundary conditions rather than integral dimensions of the management and design process (Pahl-Wostl 2005). Ostrom's work demonstrates that current paradigms such as the market being the optimal institution for the production and exchange of private goods; hierarchical government the optimal institution for the production and exchange of nonprivate goods; and individuals as rational utility maximisers, are too simplistic for socio-ecological systems (Ostrom 2009).

> *Simple strategies for governing the world's resources that rely exclusively on imposed markets or one-level, centralized command and control and that eliminate apparent redundancies in the name of efficiency have been tried and have failed* (Dietz, Ostrom and Stern 2003, p.1920).

4.4 Conclusion

How might individuals and key groups or institutions in Wellington adapt to water shocks, constraints, response measures or policy changes and what might impede or facilitate adaptation by these actors?

Key opportunities, issues and pitfalls that emerge for adaptive management of urban water in Wellington are:

- Trust – can be built or eroded.
- Equity – social justice is a central goal of good governance
- Structural measures – for example there is considerable capacity to increase water efficiency, but currently little incentive to do so.
- Providing a range of incentives and signals, including metering and volumetric charging.
- Summer demand management – use the dry summer policy window for structural as well as outdoor water use changes.
- Earthquake resilience – a complimentary resilience driver.
- Political leadership – clear vision and goals required at both local and central government levels.
- Paradigms and cultural cognition – matching interventions with particular worldviews .
- Polycentric governance, co-management and enabling self governance.

This chapter has presented a snapshot of some of the context in which climate change adaptation in Wellington will occur. This context is a "*continuous stream of activities, actions, decisions and attitudes that informs decisions about all aspects of life, and that reflects existing social norms and processes"* (Adger, Arnell and Tompkins 2005). This snapshot indicates that from a resilience perspective Wellington has the following advantages:

- Vertical and horizontal separation of water services.
- Sophisticated adaptive management systems are in place for managing the run-of-river system.
- Declining per-capita consumption indicates that the community is responding positively to water constraints.
- Wellington could supply greater than expected population growth by 2025, with current supply capacity.
- The exposure of the centralised water supply to fault movement is a significant opportunity for concurrent resilience adaptations.

Given the following issues, Wellington could easily maladapt, or adaptation could be inadequate;

- A lack of trust; perhaps resulting from failure to acknowledge urban water management as a post-normal problem, requiring processes to fully involve the extended peer community.
- 'Lumpy' augmentation opportunities; there are multiple options available to significantly increase bulk supply or storage. Augmentation will shift the problem into the future and when consumption again catches up with capacity, the problem will be bigger, more complex, and more expensive.
- Lack of signals; Commercial water users have a price signal too weak to incentivise the uptake of water efficient devices, and no legislative signals. Domestic water users have only restrictions and their own moral and cultural motivations.
- The tendancy for the dominant paradigm to assume hierarchical governance, centralisation and rationalisation, and market economic solutions, coupled with political manoeuverings that pose significant barriers to retaining or implementing resilience precursors.

5 Analysis and Integration

This chapter addresses Objective Three by integrating key insights from Objectives One and Two with analysis of the systems dynamics workshops which were conducted into considerations for selecting options, taking into account relevant literature, including theory and concepts regarding resource management and governance.

5.1 Introduction

As an adaptive socio-ecological system Wellington has the ability to absorb a disturbance, and 'bounce back,' or reorganise after a disturbance. However a system that fails to respond sufficiently to resist or cope with change will undergo a forced shift in state. Disturbances to socio-ecological systems can vary from minor and regular shifts to severe sudden shifts, or may be in the form of more gradual processes. A disturbance to an urban water system might be long-term climate change, manifest in a particularly dry summer resulting in water shortages, or even the policy interventions devised as a response to or in preparation for change itself.

We can explore and understand systems by focusing on the interactions of their parts and agents, identifying emergent properties such as tipping points, and understanding system dynamics over time (Duit et al. 2010). In focusing on these interactions we take a complexity perspective in order to understand the world as the complex, dynamic system that it is. Governance, institutions, policies and networks all become systems in which adaptive agents respond to internal and external drivers (Duit et al. 2010).

Complex systems tend to be counterintuitive and intervening in systems can have unintended consequences. For example interventions can drive the system in the opposite direction than that intended (Meadows 1999), or an intervention may provoke an affected group to rally to oppose it (Ormerod 2010). A systems perspective attempts to develop a rich and integrated picture of the issue which includes the context, drivers, interactions, and feedbacks. Such a rich picture is necessary in order to devise better and more effective policy interventions, and also to understand how the system might react to proposed interventions.

The aim of this chapter is to integrate and analyse the key insights of this study. Section 5.2 first presents and discusses key adaptive options for Wellington in relation to analysis of the systems modelling workshop and relevant literature, and then a framework for effective commons governance is outlined based on resource management and governance literature. In Section 5.3, *Synthesis,* key insights from Objectives One and Two and from Section 5.2 are used, in conjunction with the commons governance framework, to derive a set of principles for designing a water management strategy and demand management package for Wellington.

5.2 Adaptive Capacity, Resilience, and Options for Wellington

Looking at a range of key options for Wellington including changes to institutional arrangements for governance and management, what are the implications of these options for community resilience?

5.2.1 Supply and Demand Management Dynamics

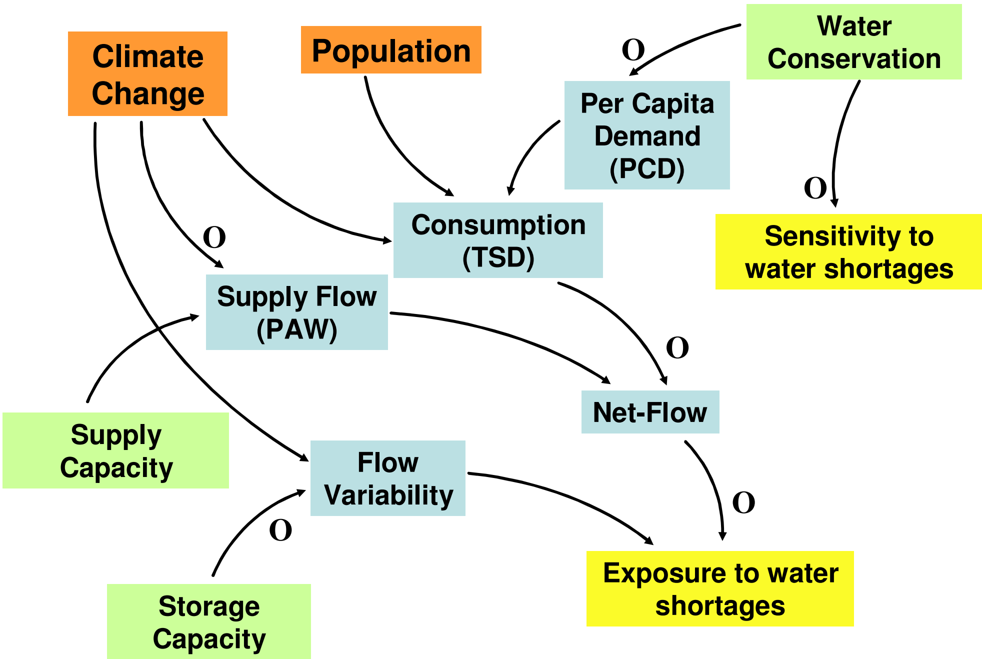
Greater Wellington Water (GWW), as the region's bulk water supplier has identified a range of short-term possibilities that will enable the reinstatement of its 2% security of supply standard at current levels of consumption, and with population growth projections till 2030 (GW 2008b). Building a dam on the Whakatikei River has been identified as a key option that may need to be initiated soon (Shaw 2011), and two other potential dam sites (Skull Gully and Pakuratahi) and a storage reservoir site (Kaitoke) have also been identified.

> *Development of the Whakatikei dam is likely to take up to 8 years or a storage lake 5 years. With design commencing in 2012, the actual security of supply could fall to a 1-in-25 year drought return period (4% ASP)*[33] *by completion, or lower if the decision to develop is delayed. Completion of the Whakatikei dam or a storage lake will immediately raise the actual security of supply well above a 1-in-50 year drought level* (Shaw 2011, p.4).

Exposure, sensitivity and adaptive capacity are key elements of vulnerability (Adger 2006). Figure 5.1 shows how the primary response pathways of supply or storage augmentation and demand management act on system variables in order to reduce community exposure and sensitivity to water shortages. On the supply side, exposure to water shortages is reduced by increasing storage capacity in order to reduce flow variability, or by increasing supply capacity to increase the supply flow and net-flow. From the demand side an increase in water conservation activities reduces consumption to increase net-flow (surplus water available for storage).

[33] Annual Shortfall Probability, also referred to as the security of supply standard.

Figure 5.1. Response pathway diagram: showing influence of key responses (green) on system variables (blue) to reduce community exposure and sensitivity (yellow) to water shortages due to increasing climate change and population[34].



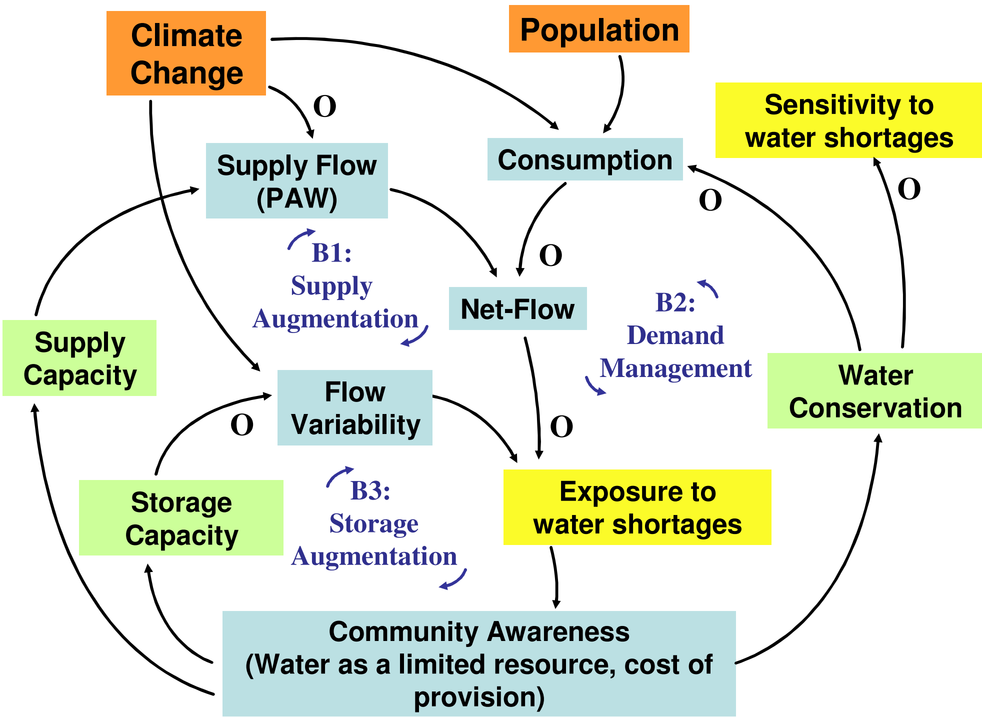
Starting with a community with an increasing exposure to water shortages (highlighted yellow, near the bottom of fig 5.2); the increasing exposure leads to an increasing awareness of an impending or actual shortage problem. From here the community has three primary response pathways (or a combination of these three).

1. Increase the storage capacity to reduce flow variability, which decreases the exposure to shortages, which reduces the community's concern (Storage Augmentation loop - B3). This loop thus tends to 'balance' increased community awareness and concern.

[34] Guidance for interpreting structure diagrams is in Appendix Two. Feedbacks and system dynamics are illustrated in following figures.

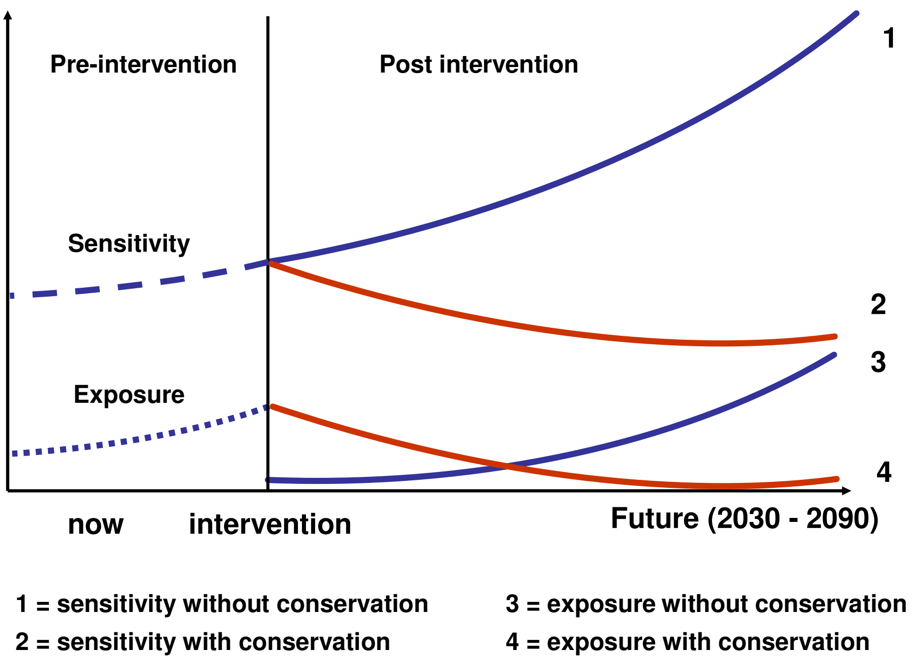
2. Increase the supply capacity to increase the supply and net flows, which decreases the exposure to shortages, which again reduces the community's concern (Supply Augmentation loop - B1).
3. Increase water conservation activities to reduce consumption, which increases the net flow, alleviating the exposure, which again reduces the community's concern as the crisis passes (Demand Management loop - B2).

Figure 5.2. Structure diagram demonstrating socio-ecological system feedbacks resulting from response pathways (green) with regard to exposure and sensitivity to water shortages. 'Capacity' is a measure of consumption to supply, e.g. number of days of storage or percentage of supply consumed at peak consumption.



Over time and with decreasing community awareness, plus population growth and climate change, the ratio of storage and supply to consumption falls to the point where exposure to shortages again becomes a problem (Fig. 5.3). The sudden drop in exposure due to the intervention, as illustrated in Figure 5.3 relates to the 'lumpiness' of supply and storage augmentations, which tend to occur in large increments (see also Fig.4.2). However without demand management as the primary response option, sensitivity continues to increase since the community continues to grow in a water-intensive manner. As noted in Chapter Three, the occurrence of drought that exceeds the design capacity of the water supply system cannot be ruled out. Therefore the higher the community's water dependence, the more sensitive it is to a water shortage caused by an 'extreme' event.

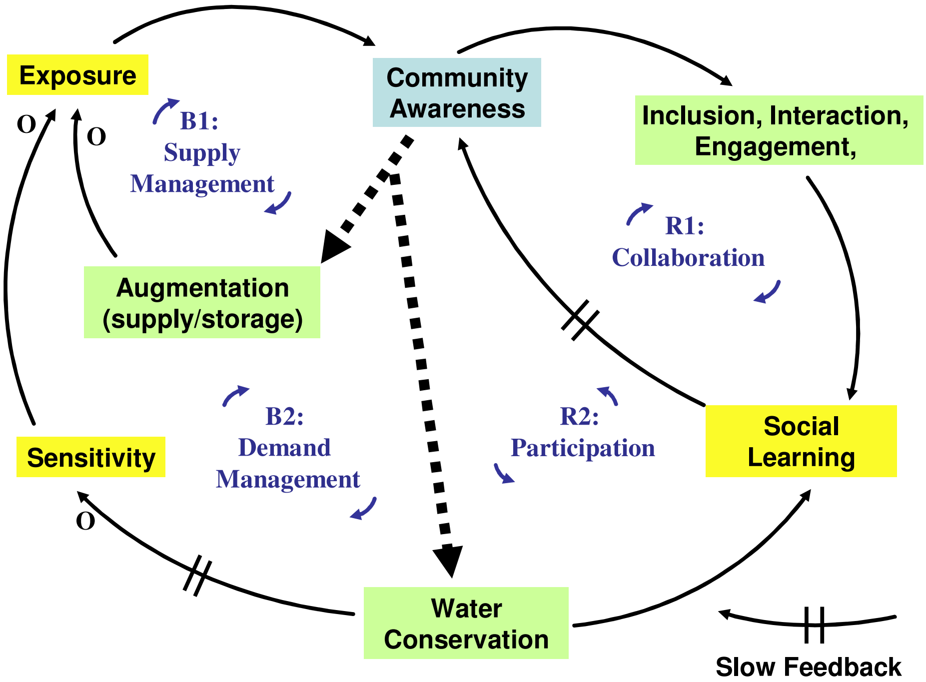
Figure 5.3. 'Behaviour over time' graph demonstrating implications for exposure and sensitivity to water shortages with and without water conservation as the primary response pathway.



If the water conservation response pathway is taken in response to community concerns, the benefits are three-fold. Firstly exposure is reduced and future exposure delayed due to a reduction in consumption, which increases the net-flow (surplus flow available for storage); secondly future sensitivity to shortages is reduced due to the structural changes that are implemented; thirdly, the costs of this pathway are, at least initially, likely to be lower than the costs of the supply or storage augmentation. However, implementation of such a pathway is not likely to be cost-free, either in resource or political terms.

An approach orientated toward supply and storage augmentation enables a community to “retain the same basic structure, ways of functioning and self-organisation”, by reducing exposure to water shortages. However exposure is decreased only within the ‘engineeringly’ feasible and financially affordable parameters of the system, and exposure to larger magnitude events remains. As illustrated in Figure 5.4, the Supply Management loop (B1) forms a tight feedback that can quickly satiate the need to reduce exposure, whereas demand management increases water security less directly, and through longer-term or ‘slow feedbacks’. Broadly, a community’s water-intensity is indicated by its ‘per-capita demand’, and the ‘security of supply standard’ or ‘Annual Shortfall Probability’ indicates the range of variability that the bulk system is designed to manage exposure to. The variables ‘inclusion, interaction, engagement’, and ‘social learning’ in Figure 5.4 are discussed in the following sections.

Figure 5.4. Structure diagram demonstrating feedback differences between 'supply management' (B1) and 'demand management' B2. The water security standard serves as a proxy for exposure, while Per Capita Demand (PCD) could be used as a proxy measure of sensitivity.

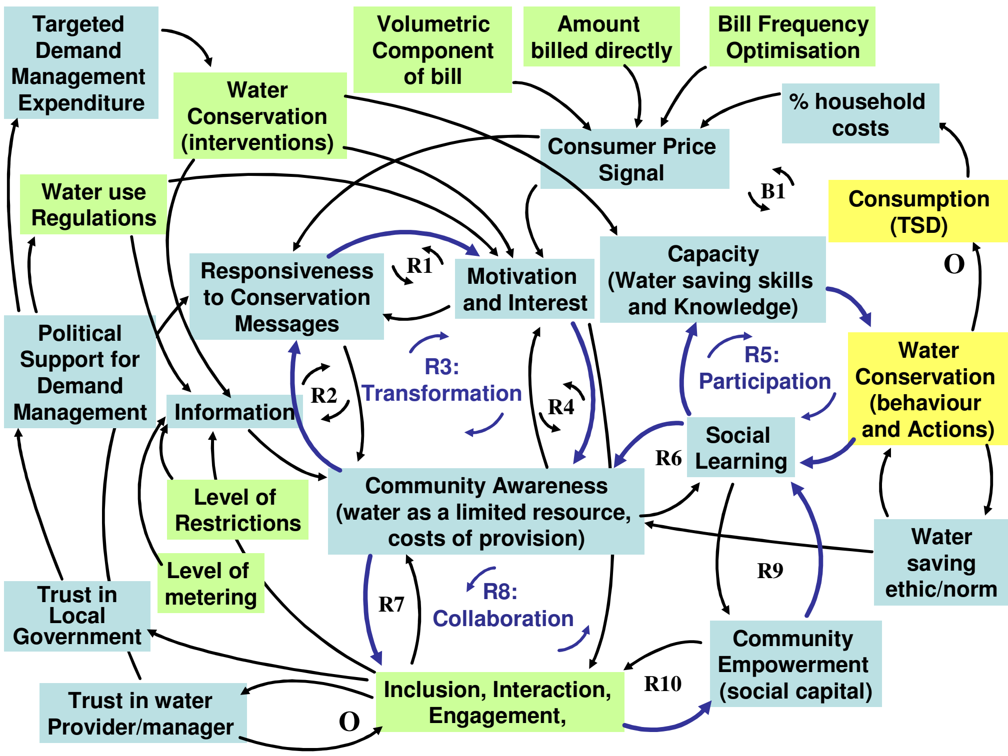


5.2.2 Demand Management Options

As discussed in Chapter 4, Wellington lacks an effective combination of incentives to motivate the uptake of water efficient devices and encourage sustained shifts in water use norms. Water conservation can be behavioural or structural. Structural strategies address the contextual and external barriers to water conservation (Steg and Vlek 2009), such as rigid legislation, prevailing habits of consumers and dominant technologies (Pahl-Wostl 2007), to facilitate the uptake of water efficient technology and practices. Structural strategies include pricing, regulation, and bulk purchasing and finance initiatives. Structural changes tend to reduce sensitivity to water shortages if they decrease the community's water dependence (Fig. 5.2). Behavioural changes tend to be made in the short term in response to present conditions, while structural changes provide ongoing water savings. Related to both is a shift in the underlying mental models from which the behaviour or actions emerge.

Water conservation interventions aim to provide motivation and knowledge and to change perceptions and norms within an existing external context in which choices are made (Steg and Vlek 2009). A range of factors act to increase interest or to motivate pro-environmental behaviour. These factors include the weighing of costs and benefits, values and beliefs, social norms, affective or emotive, and symbolic motivators. Most importantly, actual behaviour is the result of multiple motivators, contextual factors, habits and mental processes (Grist 2010, Steg and Vlek 2009). Figure 5.5 was derived from analysis of the workshop data, interviews and literature and gives some indication of the complexity of the social, cultural and economic interactions that influence behaviour in order to increase water conservation. Key insights from Figure 5.5 will be discussed in following sections.

Figure 5.5. Structure diagram showing feedback structures and system interactions between demand side intervention options (green) and the target variables ' Water Conservation' and 'Consumption' (yellow). R3, R5 and R8 indicate key structures that influence adaptive capacity.



5.2.2.1 Information

Information can be used strategically, such as with framing, commitment strategies, social marketing and role models, or in combination with retrofit programmes to increase the effectiveness of the information itself, as well as the effectiveness and acceptance of associated measures (Syme et al. 2000; Steg and Vlek; Turner et al. 2009). Individuals need to first accept and understand structural options, adopt or purchase them, and also use them properly (Steg and Vlek 2009). Information alone is generally ineffective, except where pro-environmental behaviour is relatively convenient, not very costly (in terms of money, time, effort and/or social disapproval), and when individuals do not face severe external constraints on behaviour (Steg and Vlek 2009). Figure 5.5 therefore does not show direct links between 'information' and 'water conservation; rather, 'information' links to 'water conservation' through 'social learning' and 'capacity'. In addition to marketing or promotional work, specific demand management interventions such as metering, restrictions and regulation contribute to the 'flow' of information that can raise 'community awareness'.

5.2.2.2 Water Pricing, Charging and Billing

Residential water use can be viewed in two distinct categories: outdoor use tends to be discretionary, while water used indoors is required for more essential purposes. Discretionary water use is more price elastic than indoor use, with studies finding that aggregate demand was 25% more sensitive to price during summer (Renwick and Green 2000) and 50% more sensitive to price during a drought (Kenney et al. 2008). Therefore incorporating a volumetric component into the water bill can assist summer demand management efforts, particularly during a drought.

By contrast, water used indoors for essential uses such as cooking, cleaning and personal hygiene tends to be highly inelastic, and water used jointly with complementary goods such as washing machines is highly inelastic in the short term (Martínez-Espiñeira and Nauges 2004). Income differences also need to be considered with regard to water pricing, since people on low incomes may not have the ability to purchase water efficient appliances in order to save water, while for those on higher incomes, the water bill may not be a significant proportion of their income or expenses. In effect, since water demand for essential use is highly inelastic, price increases for low-income groups work like a tax (Jansen and Shultz 2006). Impacts on those low income households who are large water users for reasons such as family size are a key consideration when using price as a demand management mechanism. However such issues can be resolved equitably with tariff design mechanisms (Chapman et al. 2003, PCE 2001).

The structure diagram in Figure 5.5 shows that increasing the 'consumer price signal' increases 'water conservation behaviour' through 'motivation and interest' and 'responsiveness to conservation messages', which drives a subsystem of virtuous reinforcing feedbacks (R1 to R4), the principal structure of this subsystem being R3, 'Transformation'. There is also a balancing feedback, since when households reduce their water consumption, the contribution of their water bill to the 'percentage of household costs' decreases, which decreases the 'consumer price signal' (B1), and thereby reduces the stimulus it provides.

5.2.2.3 'Green Plumber' and Retrofit programmes

Porirua City Council (PCC) employs a plumber to visit householders in order to find and fix any external leaks as part of their demand management strategy. The plumber offers advice and distributes free tap-washers. PCC also has short instructional videos on its website on how to fix tap and toilet cistern washers. PCC's recent investment of $84,000 in demand management produced immediate annual water savings worth $100,000

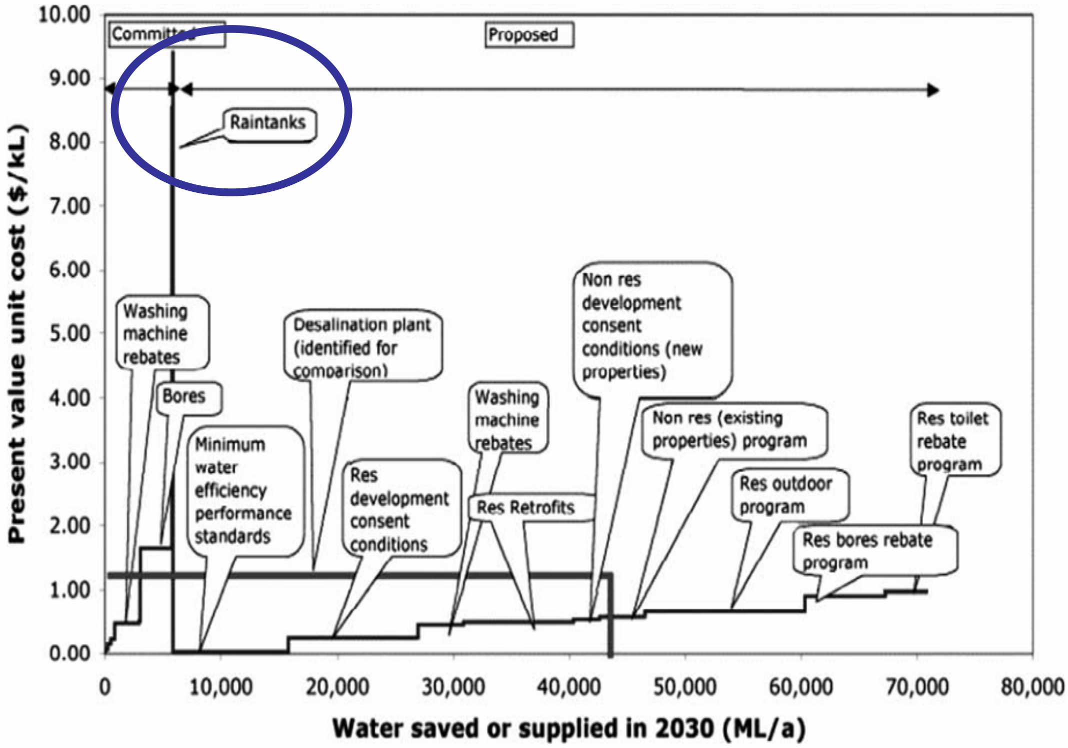
(PCC 2011). The Kapiti Coast District Council (KCDC) offers both 'green gardener' and 'green plumber' services, fixing leaking taps, showers and toilet cisterns and providing free advice to residents, community groups and schools.

As seen in Figure 5.5, increasing the capacity of the community to save water through skills and knowledge directly drives R5 'Participation', a virtuous reinforcing cycle directly connected to 'water conservation' and 'social learning'. Social learning in turn connects with 'community awareness' producing R6 'Collaboration', and also contributing to the R1 to R4 subsystem.

5.2.2.4 Rainwater

Some supply and storage options are in a grey area where they can be viewed as either supply side or demand side measures (i.e. they reduce demand for mains water by supplying a 'fit-for-purpose' substitute). Mains water substitutes include rainwater, greywater and recycled water. Rainwater is most commonly used as a substitute for garden irrigation, flushing toilets and laundry washing (Roebuck, Oltean-Dumbrava and Tait 2010). However as seen in Figure 5.6, household rainwater systems ('tanks') are an expensive option from a demand management perspective (see also Roebuck et al. 2010, and Mithraratne and Vale 2007).

Figure 5.6. Comparison of unit costs for various demand management options including rainwater (blue circle) in an Australian context (Turner et al. 2009, p.209)[35].



While an expensive option from a more narrow demand management perspective, rainwater tanks provide a number of benefits within integrated water management portfolios including:

- Rainwater tanks reduce demand on mains water, deferring the need for supply and storage augmentation (Coombes and Kuczera 2003).
- Urban roof water collection is not affected by catchment recharge; rainwater collection can therefore increase water resilience during dry periods (Coombes and Barry, 2007).
- Rainwater tanks with mains water 'trickle top-up' mitigate daily mains supply demand peaks, enabling the reduction of capacity

[35] The abbreviation "Res" in Fig. 5.6 is short for residential.

requirements and associated infrastructure expenses (Lucas et al. 2010).

- Modelling shows that rainwater tanks with trickle-top-up provide stormwater retention capacity, reducing urban runoff and stormwater peaks (Coombes and Kuczera 2003).

Most significantly, in the context of this study, rainwater systems increase system resilience through 'modularity': *"in resilient systems everything is not necessarily connected to everything else"* (Walker and Salt 2006, p.146). For example it would take at least 30 days to restore the mains supply to Wellington City following a significant movement of the Wellington fault (GW 2008b, p.18)[36]. Rainwater systems can also provide an alternative source of water should a toxic algal bloom or water-borne pathogens compromise the mains supply (NRC 2010, Chapman et al. 2003). In addition climate change adds to the confluence of factors which can promote the growth of harmful algae (Paerl et al. 2011).

Lindsay (2011) modelled the performance and climate change effects of a range of rainwater tank sizes (5,000, 10,000, and 50,000 litre tanks), for two person households with 170 square meters of roof area, and for 70 L of rainwater used as a substitute for outdoor irrigation and flushing toilets. A 51 year rainfall data series from Wellington Airport was used. On average 5,000 and 10,000 litre tanks can provide 94% of annual outdoor irrigation and toilet flushing needs at 70 L per person per day. A climate projection for the 12 model average of the A1F1 scenario indicates that climate change has very little influence on rainwater tank performance by 2100 at this site (Lindsay 2011).

[36] GW's current estimate for the restoration of bulk water to a partial supply is 46 days and to a full supply is 66 days with the existing system (median time for restoration of service) (Shaw 2011, pers. comm.)

5.2.2.5 Standardising 'Sensible Water Use' - Local Government-Level Regulation

Under the Resource Management Act (RMA) central government can issue a National Policy Statement (NPS) in order to state objectives and policies for matters of national significance that are relevant to achieving the purpose of the RMA (RMA 1991, section 45). Local Government can also make bylaws affecting water supply under Part 8 of the Local Government Act (LGA) (section 146 (b)), and wilfully wasting water is an offence under the LGA (section 192). Environment Waikato requires that demand management plans are submitted with consent applications for all water takes, while Horizons (Manawatu and Wanganui Regional Council), has a draft plan that would limit 'reasonable' domestic water use to an allocation of 300 L/capita/day (MWH 2011).

As part of its response to a 1-in-25 year drought in 2002/2003 and to population pressures, Kapiti Coast District Council introduced new residential zone rules requiring grey-water and/or rainwater systems for new dwellings (The new rules became operative on 9.05.2011[37]). The regulations specify *"all new or relocated dwelling units"* install either a rainwater tank with a minimum capacity of 10,000 L or a 4,500 L rainwater tank and a greywater system (Ammundsen et al. 2009). Rainwater will be used for flushing toilets and for outdoor use, and grey-water for subsurface garden irrigation (Ammundsen et al. 2009). Co-benefits of the rainwater/greywater regulation, such as a water supply in the event of a natural disaster, and reductions in stormwater and waste water flows are also expected (Ammundsen et al. 2009).

The rainwater and greywater tank capacity specifications were based on modelling work which indicated household water savings of 30% were

[37] See Kapiti Coast District Councl's schedule of changes, available from www.kapiticoast.govt.nz.

achievable from these options, and that best performance occurs when a grey-water system is installed (Ammundsen et al. 2009). The rainwater and grey-water regulations were in addition to existing regulations which applied to new developments requiring the installation of 'water saving devices', and specifying that potable water would be supplied to a maximum of 1000 L/day per dwelling (Ammundsen et al. 2009). Notably KCDC also has a policy *"to design any future supply within the water consumption targets and not simply build for an unconstrained average"* (Ammundsen et al. 2009, p.22).

Kapiti Coast's summer water use had been up to 40% higher than winter, with peak water use increasing, and research by KCDC found that water use was strongly correlated with socio-economic status, rather than property or household size, i.e. wealthier households were using more water to irrigate their gardens (Ammundsen et al. 2009). Modelling work showed that substituting 'fit-for-purpose' water for potable water where appropriate would reduce the summer water use peak by 30% (Ammundsen et al. 2009). KCDC expect an increase in the building stock of one third from 2008 to 2050 and the regulations are to ensure that these homes are built to maximise water efficiency (Ammundsen et al. 2009).

The Water Services Association of Australia (WSAA) regards permanent outdoor water use regulations as *"fundamental to any effective suite of demand management options… to ensure sensible watering practices"* (Turner et al. 2008, p.12). The WSAA also recommends the inclusion of regulations to prohibit the watering of hard surfaces (Turner et al. 2008). Porirua's restrictions apply only during daylight savings, while restrictions for Wellington City, Upper Hutt and Lower Hutt apply throughout the year. Restrictions in all four cities apply only to garden irrigation.

Figure 5.5 shows water use regulations providing 'information' and driving 'motivation and interest', which then drives the subsystem of virtuous reinforcing cycles (R1 to R4).

5.2.2.6 National Policy Statement and Water Efficiency Standards - Central Government Level Regulation

A National Policy Statement (NPS) on freshwater management takes effect on the 1st of July 2011. Local government is required to amend regional policy statements and regional and district plans to 'give effect' to the objectives and policies of an NPS within specified time frames. While the proposed NPS specified objectives and policies relating to demand management, conservation, efficiency, and resilience to climate change, the recently gazetted version has none of these features. This is despite the recommended version of the Board of Inquiry (which reviewed the proposed NPS) including policies that specifically referred to managing demand, avoiding wastage, and water conservation (Sheppard et al. 2010).

Central Government has legislated for water efficiency labelling of washing machines, dishwashers, taps, toilets and showers, *"in line with trans-Tasman single economic market initiatives"* (Roy 2010), but stopped short of applying minimum water efficiency standards such as have been legislated for in Australia (WELS 2010). Legislating for minimum efficiency performance standards is one of the lowest per unit cost water conservation mechanisms available (Turner et al. 2009).

An amendment[38] in 2010 to the Residential Tenancies Act (1986) substituted a new section 39 which specifies that the tenant is responsible for all outgoings *"that are exclusively attributable to the tenant's occupation of the premises or to the tenant's use of the facilities"*. Such outgoings include the

[38] Amended through the Residential Tenancies Amendment Act 2010 (2010 No 95).

"supply of water if the water supplier charges for water provided to the premises on the basis of consumption". The implication of this in terms of demand management is that there is no legal reason for the landlord to receiving a tenant's water bill to charge the tenant a flat rate, thereby attenuating the tenant's price incentive to conserve water. However if the landlord receives the bill, then it is he or she who has the price incentive to make structural changes to the property such as installing water-efficient showerheads.

5.2.2.7 Social Capital, Social Networks and Social Learning – Facilitating Community Innovation

Of particular interest to the present study is the potential for interventions or options to concurrently decrease exposure and sensitivity, and increase adaptive capacity. Adaptive capacity is the community's capacity to adapt or respond to change, and in the present study, to improve institutions, systems, structures, behaviours and practices in order to increase resilience to water shortages.

Social capital is a prerequisite of adaptive capacity (Adger 2003), since community adaptation requires "*the collective action of communities of place and communities of practice"* (organisations) (Pelling and High 2005, p.309), in order for the community as a system to adapt. Social capital is defined as *"the features of social life, networks, norms, and trust that enable participants to act together more effectively to pursue shared objectives"* (Putnam, 1995, pp. 664–665). Key elements of strong social capital are high levels of education, social trust and civic participation (Putnam 1995). A community with strong social capital is an empowered community, and as such has considerable ability to determine its own future. However strong social capital and self determination can also perpetuate vulnerability (Wolf et al. 2010), and a community with strong social capital can implement a maladaptive response pathway.

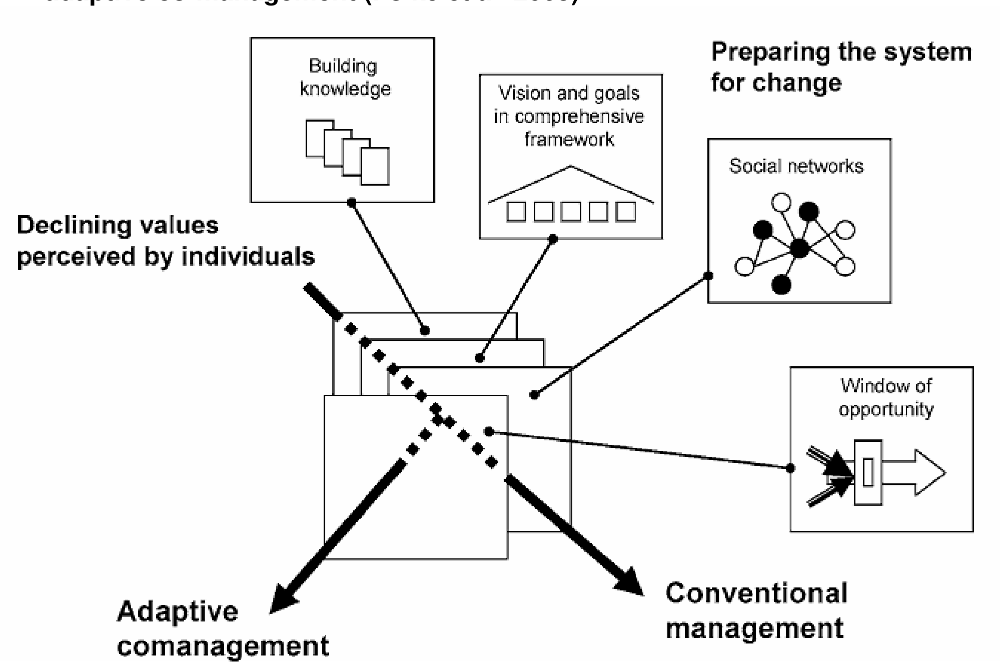
If social capital is a prerequisite of adaptive capacity, and collective action is the desired product of social capital, social networks are the engine of collective action. Social networks that influence demand management adaptation in a community will include those of the water users, plus the networks of the demand management practitioners, as well as the social networks of any actors opposing demand management. These may include those who see supply-side options as more cost-effective. Political will and resources, as well as the social capital and networks of water managers and users, and their ability to initiate *and* sustain a water demand management plan are all elements that determine the effectiveness of demand management programmes (Wolfe 2008).

Social learning is the 'flow' or diffusion of knowledge into the wider community, including through social networks. Reed et al. (2010, online) define social learning as *"a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks"*. Social learning occurs over multiple time scales; in the short-term, through direct interaction and collaboration between actors; in the medium to long-term through actor networks; and on longer time scales through changes in governance structures, informal and formal institutions, and cultural values and norms (Pahl-Wostl et al. 2007).

In order for social networks to spark collective action, the network must be 'primed' or prepared for change. A 'primed' state requires that the 'stock' of social knowledge or awareness of a particular issue, including both the 'problem' and 'solution' is sufficient for a proposed change to be successful (Fig. 5.7). For example the community's awareness of the issues surrounding present water use must give it sufficient ‘sense’ that collective action to reduce consumption is needed, and the vision and goals of a pathway to do this must have sufficient support within the social networks required to achieve the desired goals (Folke et al. 2005).

> *“The transformation was orchestrated by leaders providing vision and meaning, learning and knowledge generation, and gluing and expanding social networks, thereby preparing the social-ecological system for change when the opportunity opened”* (Folke et al. 2005, p.458).

Figure 5.7. Schematic of a successful example of transformation towards adaptive co-management (Folke et al. 2005).



As seen in Figure 5.7, once the community is primed for change, the window of opportunity could result in either adaptive co-management or the choice of a conventional management pathway. Which pathway is taken depends on the extent to which the goals, vision, values and principles underpinning resilience are admitted to the community’s stock of knowledge regarding the issue in question. In relation to urban water management, the pathway is likely to be determined by the 'ecology' of the structures and subsystems that include 'participation', 'collaboration' and 'transformation', as shown in Figure 5.5.

Kapiti District Council's policy to *"design any future supply within the water consumption targets and not simply build for an unconstrained average and average summer water use"* (Ammundsen et al. 2009, p.22), is a good indicator that Kapiti has not taken a conventional management pathway, but has given consideration to sustainable consumption levels as a critical target.

5.2.3 Resource Management and Governance Strategies

As a natural resource system, water consists of a core resource or stock variable, which provides a limited extractable quantity for resource users. This type of resource is known as a common-pool or common property resource (CPR), with issues such as overuse common to this type of resource. Ostrom (2009) has studied CPRs throughout the world, noting that in many cases, users do a better job than governments at managing such resources. Bakker (2008) notes that a key limitation of public water ownership models is that an emphasis on consensus leads to politically workable outcomes in preference to long-term environmentally and economically sustainable outcomes, particularly where unequal power relations and inequitable representation of consumers and other stakeholders guide decision-making. Ioris (2008) asserts that conflicts of interest between government agencies and lobby groups, and an uneven balance of power and policy inertia often distort water management outcomes. Ostrom (2009) argues that rather than designing institutions to force or 'nudge' people, in order to achieve desired outcomes, the goal should be to "*facilitate the development of institutions that bring out the best in humans"* (Ostrom 2009, p.435).

Bakker (2008) found that common-pool water management regimes have proven to be successful when certain conditions exist:

- A small geographical area with well-defined boundaries
- Low levels of mobility (migration and immigration)
- A small community with a high degree of social capital
- An overlap between residential and resource-use location.

Bakker (2008) also cites Welsh Water, a non-profit water utility company supplying 3 million customers in Wales, as an example of a successful large scale public water management model. The conditions attributed to the success of large-scale cooperatives are:

- Aligning the incentives of customers and owners (owners are members)
- Reducing risk (and thereby the cost of capital and consumers' bills)
- Creating efficiency incentives through the link between lower bills and cost reduction (rather than lower cost and profit maximisation).

The ability to manage resilience relies on actors, social networks and institutions (Lebel et al. 2006). Dietz, Ostrom and Stern (2003, p.1908) highlight that *"no single broad type of ownership uniformly succeeds or fails to halt major resource deterioration"*, and that governance structures and institutions can help, hinder, authorise or override local control. Dietz et al. (2003) provide the following points for devising effective commons governance strategies:

- **Institutions:** Design adaptive institutions prepared for change as some current understanding is likely to be wrong. Provide mixtures of institutional types including hierarchies, markets and community self governance, that employ a variety of decision rules to change incentives.

- **Rules:** Fixed rules are likely to fail as they place too much emphasis on current knowledge. Humans find ways of evading rules, therefore rules must evolve. A multiplicity of rules will be more effective than a single type of rule.
- **Sanctions:** Sanctioning must be seen as effective and legitimate or resistance and evasion will undermine the strategy. Use modest sanctions for first offenders and for modest violations.
- **Style:** Regulatory approaches are more effective when requiring or prohibiting familiar behaviours and technologies, and sufficient resources are made available for monitoring and enforcement; but less effective at encouraging innovation in behaviours and technology. Command and control approaches are often economically inefficient. Informal communication and sanctioning within user networks can have a significant impact.
- **Dialogue:** Well-informed and structured dialogue involving scientists, resource users and interested publics is critical. Conflict can spark learning and change if used constructively.
- **Design interventions to facilitate experimentation, learning, and change[39].**

5.3 Synthesis: Six Principles for Urban Water Management

How might key options for responding to water shortages be utilised in order to optimise community resilience?

The last section outlined some key points for governance strategies, and previous sections set out a number of demand side options and discussed the dynamics of supply and demand side options in relation to exposure and

[39] For example Kapiti Coast District Council run a 'sustainable home and garden' show, a platform to get local suppliers and residents together (Ammundsen, Pomare and Lane 2009).

sensitivity to water shortages. Chapter Three of this study indicated that Wellington's supply flow is sufficient to meet current levels of demand (PCD 404 L/day) and projected population growth to 2040, and sufficient to 2090 if PCD is reduced to 300 L/day, a reduction that could be achieved by 2025 (Table 3.1). This reduction would also align levels of water use in Wellington with current water use in Auckland and major Australian cities (Table 4.1). Chapter Four indicated that while trending downwards, Wellington's PCD is high, and Wellington lacks signals to encourage efficient water use. Moreover, despite metering and volumetric charging being in place for the commercial sector, Wellington's CBD water use appears to be affected by large inefficiencies (Bint et al. 2010).

Renwick and Green (2000) highlight that achieving greater than 'moderate' savings (5-15%) requires stringent regulation, relatively large price increases, or a package of policy instruments. A package of policy instruments seems the most politically acceptable of these options, since both large price increases and stringent regulation are likely to attract concentrated opposition. The following are six principles for designing a water management strategy and compiling a package of options for Wellington, which incorporates adaptive capacity and resilience considerations. The evaluation of these options draws heavily on the framework set out in the previous section (i.e. insights from Bakker 2008 and Dietz et al. 2003).

5.3.1 Prioritise Structural Demand Management measures

Since a reduction in both sensitivity and exposure to water shortages can be achieved through increased water conservation, and achieved at low cost it would make sense for a demand management strategy to be given priority. Storage options would then follow since current storage capacity is likely to be insufficient to cope with the degree of current and expected flow variability over the next 30 years (Chapter 3). The location of the

Whakatikei dam, closer to Wellington and Porirua and on the north-western side of the faultline, may still make this option attractive (Chapter 4). However, as per the resource consent requirements noted in Chapter 4, efficiency of water use needs to be demonstrated before supply capacity is increased. Moreover as shown in Figures 5.2 and 5.3, while a dam will reduce exposure in the short term, sensitivity to water shortages will continue to increase. Critically, the Whakatikei dam is a combined supply and storage augmention option and building a large dam will weaken incentives to conserve water. Therefore from a resilience perspective, and given the potential for reducing current levels of water consumption, building the Whakatikei dam would be an example of maladaptation.

From the perspective of increasing earthquake resilience, there may be bulk water storage or smaller dam options on the north-western side of the fault. Moreover, in the event of a large earthquake, mains water could be disrupted for some time, even with a supply source on the north-western side of the fault. Therefore the integration of (distributed) rainwater systems is required for community resilience in the event of a large earthquake.

Short-term restrictions in response to a crisis are an inadequate response on their own and can be politically costly in terms of support for further demand management. While restrictions are currently used reluctantly, they are also used in a context where they are the primary demand management measure encountered by residential water users in Wellington. Wellington City Council's initiative to create sensible water use bylaws should effectively counter the expectation of 'unrestricted' water use, and be consistent with the use of a light regulatory approach to discourage familiar behaviours (Dietz et al. 2003). A primary requirement for sufficient rule compliance is that sanctions and those doing the sanctioning need to be seen as legitimate and effective (Dietz et al. 2003). While the use of enforcement patrols by 'water police' may be seen by some as the council 'telling them what to do', anonymous neighbours are much more difficult to oppose. Moreover, rather than build the trust needed to secure long-term support for demand management, the use of 'water police' patrols to enforce bylaws may reduce trust between the council and the community, eroding social capital. An alternative approach would be to give the community responsibility for reinforcing water-use norms. Within any community there is very likely to be 'strong reciprocators' (Gintis 2000), who may be inclined to sanction non-cooperation, particularly were a good relationship exists between the local council and the community. These strong reciprocators can be assisted by making sanctioning as easy as a phone call to the council. Infringers would receive little more than a friendly visit from an innocuous council officer bearing information about the bylaws, and stronger sanctions may be unnecessary and undesirable.

5.3.2 Rainwater and Mains Water are Complementary – Water Security AND Water Resilience

"Complicating the Far North District Counncil's woes is that the normal alternate source of town supply, the Kauri dam, has once again fallen victim to a toxic algal bloom rendering the many millions of litres of water in it useless for town supply" (Northland Regional Council [NRC] 2010, online).

Rainwater collection offers benefits for the wider water system such as reduced demand on mains supply. While a life-cycle analysis and economic comparisons with centralised storage both favour mains supply, from a resilience perspective there are strong arguments to support the inclusion of rainwater systems within the overall urban water system. As shown in the aftermath of the recent earthquakes in Christchurch, and Kaitaia's drought and reservoir contamination as a result of a toxic algal bloom (NRC 2010), over-reliance on the centralised approach leaves communities vulnerable. Distributed rainwater collection should not be expected to compete with the economies of scale offered by centralised bulk storage, just as the reticulated system should not be expected to compete with rainwater systems in terms of resilience. Instead, the two systems, rainwater and centralised reticulation, should be regarded as complementary.

5.3.3 Provide all Water Users with a Price Signal Linked to Consumption

Water management is inherently political; outcomes such as price are determined by climatic variables together with the political economy rather than economic efficiency or even monopoly power (Hoffman 2006; Hall 2009). Acknowledgement and understanding of the "profound influence" of the socio-political backdrop on policy architecture and management outcomes is crucial (Ioris 2008). The PCE (2001) highlighted that the community fear of privatisation and commercialisation is a "major impediment to flow-based charging systems". However volumetric pricing by water utilities is in place both in parts of New Zealand and overseas and the vast majority of these water utilities remain in public ownership (PCE 2001). Additionally privatisation is neither inevitable nor probable following the introduction of volumetric charging (PCE 2001) and pricing can be overseen by regulators and specialist bodies (Hall 2009, IPART 2010).

As discussed in Chapter four, the use of universal metering and volumetric charging do not guarantee that a price signal will get to the actual water user, nor that price will be sufficient in itself to motivate water conservation. The main implication for policy makers is that using price as a demand management mechanism can be effective to a point, with that point depending on income, season, outdoor and indoor use, and the time and ability of consumers to change complementary goods. However, like information, price alone is not enough. This underlines that a broad package of measures is likely to be most effective if it includes a price signal linked to the volume of water used.

5.3.4 Meter only to the required information needs

Water meters in and of themselves are simply an instrument by which to measure the quantity of water used. Metering provides information to increase community awareness, which can be used to inform and evaluate intervention strategies, and can also be used as the basis of volumetric charging and pricing strategies. Metering also has a considerable cost: in addition to the estimated high capital cost ($70 million initial cost of universal metering for Wellington (Sherlock 2008), water meters lose accuracy over time due to wear and need to be replaced after about 10 years (Girard and Stewart 2007).

The variable used with regard to metering in Figure 5.5 is *"level of metering"*. This framing arose from the workshop sessions conducted for this study and reflects that Wellington's commercial water use is metered, that there is considerable opposition to universal water metering in Wellington, and that some information objectives are not dependent on 'universal' metering. For example information at increasing levels of resolution (and expense) can be attained by metering suburbs, demand zones (approximately 1000 homes), streets and neighbourhoods, or individual households. Interventions such as consumption target campaigns would be possible using such information. For example a 'target 150' (L per capita/day) campaign, to appeal to people's ability to make an extra effort in response to a drought, could be pitched at the street level, with competition between streets encouraged.

5.3.5 Regulate old and undesirable behaviours and habits

Like smoking, some existing water use behaviours can no longer be considered sensible, as costs and population rise. Also like smoking, the behaviour of others regarding water use impacts on everyone, since water is a common-pool resource. The following are suggestions (with examples) for identifying where water use might be considered 'wastage' under the RMA and LGA[40].

- Where a fit-for-purpose substitute such as grey water is readily available and the water use is clearly a discretionary decision - for example, keeping lawns green during summer (as regulated for new developments by Kapiti District Council).
- Where a new efficient technology becomes available, for example cyclic flushing urinals are wasteful now that waterless urinals and sensor flushing urinals are readily available ("water efficient devices" are required for new developments by Kapiti District Council).
- Where daily per capita water use exceeds a 'reasonable needs' threshold (peak and/or average) (Kapiti: 1000 L/day per dwelling; Horizons: 300 L/capita/day)

If trickle-top-up rainwater systems are to be scattered throughout the community, rainwater use will also need to be subject to the same outdoor irrigation regulations as mains water. Trickle-top-up systems use mains water, and it would be difficult to differentiate between systems that do or do not incorporate trickle-top-up. Only greywater irrigation systems would avoid outdoor irrigation regulations.

5.3.6 Utilise Commons Governance and Common-pool Resource Management-Based Strategies

Water management is inherently an environmental or commons governance issue, and in assessing impacts and formulating solutions the socio-political dimensions are as relevant as scientific and engineering assessments or management techniques (Ioris 2008). Many of the conditions listed by

[40] These suggestions are additional to the proposed 'odds and evens' and 'morning and evening' outdoor irrigation regulations proposed by Wellington City Council.

Bakker (2008) for successful common-pool resource management and large-scale cooperatives are evident in Wellington, as well as some 'polycentricity' (Ostrom 2009) and institutional variety (Dietz et al. 2003). For example responsibility for water supply is delegated to GW, a democratic entity with a jurisdiction based on water catchment boundaries; Wellington and Lower Hutt City Councils are collective customers of GWW and owners of water retailer, Capacity; Upper Hutt contracts water services to Capacity; while Porirua City manages its own water needs and infrastructure. In principle, this enables different management options to be explored concurrently and their effectiveness to be compared.

Wellington's current governance structure provides a good base from which to increase urban water resilience; however its future is uncertain. This uncertainty arises from the recent amalgamation of the former Auckland councils into a unitary authority, and talk of doing the same in Wellington. As discussed in Chapter 4, simple governance strategies for managing complex economic systems "*that eliminate apparent redundancies in the name of efficiency have been tried and have failed*" (Dietz, Ostrom and Stern 2003, p.1910). Yet, as is evident from a statement by the Minister of Local Government, Auckland's amalgamation was based on simplistic thinking:

> *"It seemed to me that as Auckland is one region, the simple solution is to have one council, one Mayor, and one plan"*
> (Hide 2009).

Auckland's amalgamation was preceded by a Royal Commission of Inquiry into Auckland's governance. The Commission recommended a two tier approach with an overarching unitary authority, six elected local councils within it, plus community boards for each of Waiheke and Great Barrier Islands, and the Auckland CBD and waterfront (Salmon, Bazley and Shand 2009). This would have provided a balance between decentralisation and centralisation and created a more polycentric model which is a pre-condition for resilience, and would also provide economies of scale in some areas and avoid diseconomies of scale in others (Ostrom 2009). However despite the Commission's findings and recommendations, a centralised single tier unitary structure was mandated by central Government. The guiding principles that led to the Commission's structural recommendations included:

> **Responsiveness** - *The structure should respect and accommodate diversity and be responsive to the needs and preferences of different groups and local communities. It should be inclusive and promote meaningful public participation. It must be nimble in responding to change* (Salmon et al. 2009, p.313).

The Commission's report looked at resilience in the context of responding to climate change and civil emergencies, but not explicitly in the context of institutional and governance structures. However, as seen under the principle of 'responsiveness', resilience was implicitly incorporated through the accommodation of diversity, inclusion and participation of multiple legitimate perspectives; as was adaptive capacity, in being *"nimble in responding to change"* (Salmon et al. 2009, p.313).

Wellington's Mayors proactively commissioned a governance review to explore governance issues and opportunities (PWC 2010). One of the options put forward as a result of this review is a two tier local government. In addition "resilience into the future" was an explicit "Good Governance and Practice Principle" while climate change is recognised as part of "The Changing Landscape" that the Wellington Region needs to be planning for (PWC 2010). However, just as local government can help, hinder, authorise or override lower tier institutions, as seen in the example of Auckland's amalgamation; central government can hinder and override local governance.

6 Discussion and Conclusions

This chapter identifies the incorporation of resilience concepts into policy and practice as a critical factor for increasing adaptive capacity. It then presents a framework that incorporates resilience and adaptive management, and presents a way forward for Wellington.

6.1 Incorporating Resilience into Urban Water Management

> *"The assumptions of representative democracy have been progressively undermined by the scale and complexity of contemporary societies and their rate of change. Elected representatives can rarely capture the diverse values and social and economic interests of their constituents, while the uncertainties generated by novel threats argue for the inclusion of a wider range of knowledges in decision-making"* (Dryzek 1990, in Stagl 2003, p.3).

Climate change is one of these novel threats, with attendant uncertainties. As identified above by Dryzek (1990) and in a more positive sense in the opening quote to this thesis by Mike Hulme (2009), the addition of climate change to the mosaic of issues faced by communities forces us to confront many assumptions. For example many authors writing from adaptive management, resilience and systems perspectives highlight contrasts between their views and 'traditional', 'hierarchical' and 'command and control', or 'market-based' management approaches. The command and control approach, for example, is an overly simplistic and partial view that is focused on efficiency, control and stability, and sees humanity and 'nature' as separate entities (e.g. Walker 2005, Folke et al. 2002, Holling et al. 2002). In contrast an adaptive management, systems and resilience perspective promotes an approach that takes into account complexity and system dynamics, is integrative and collaborative, and is focused on addressing the issues of a dynamic and changing world, where humanity and nature exist within a coupled system.

The challenge of incorporating resilience and systems thinking into the mental models of resource users and decision-makers, sufficiently to shift course from a 'conventional' and potentially maladaptive path, is non-trivial. In addition to confronting a range of embedded assumptions, the task of promoting systems and resilience approaches is complicated by human cognitive tendencies which are averse to complexity and change (Kahan 2006, Klayman and Ha 1989, Doerner, 1980). Yet an adaptive management and resilience based strategy *must* provoke dissonance with existing mental models, since it *must* challenge embedded assumptions to achieve change. A further complicating factor is the uneven distribution of power in society, and that incumbent regimes tend to form *"strongly embedded, self-reinforcing systems"* (Smith and Stirling 2010, p.11).

> *When power is unevenly distributed, more powerful actors can tilt the playing field such that information and knowledge are further skewed in their favor* (Adger et al. 2006, p.9).

6.1.1 An Overarching Framework for Urban Water Management

Figure 6.1 synthesises insights gained from the present study and from the literature into an overarching water management framework showing both governance and management elements and process elements. The 'windows' represent governance and management preconditions from which resilience-optimising water management strategies can emerge. 'Inclusion, Interaction and Engagement' is shown as a fundamental cross-scale component, consistent with Ravetz's (2006, p.277) assertion that *"an extended peer community is at the heart of post-normal science"*. This component influences system principles and design through participatory adaptive management, thereby influencing system variables and the efficacy of utilising virtuous cycles to achieve multiple desirable outputs. Presently, the majority of the components of the 'tiles' in Figure 6.1 are either missing or require substantial development.

Figure 6.2 uses the iceberg model to illustrate the features and requirements of key components of the Urban Water Resilience Framework as they relate to the iceberg analogy. A key point is that the framework is not 'top down' or 'bottom up'. From a systems perspective the framework components are part of a whole, and all contribute to the nature of the emergent features. Participatory adaptive management is the 'key ingredient', as this feature coordinates and drives the dynamic and knowledge-intensive socio-ecological system.

Figure 6.1. Urban Water Resilience Framework with 'Inclusion, Interaction and Engagement' as a key cross-scale input and 'intervention' ('tile' format adapted from Folke et al. 2005).

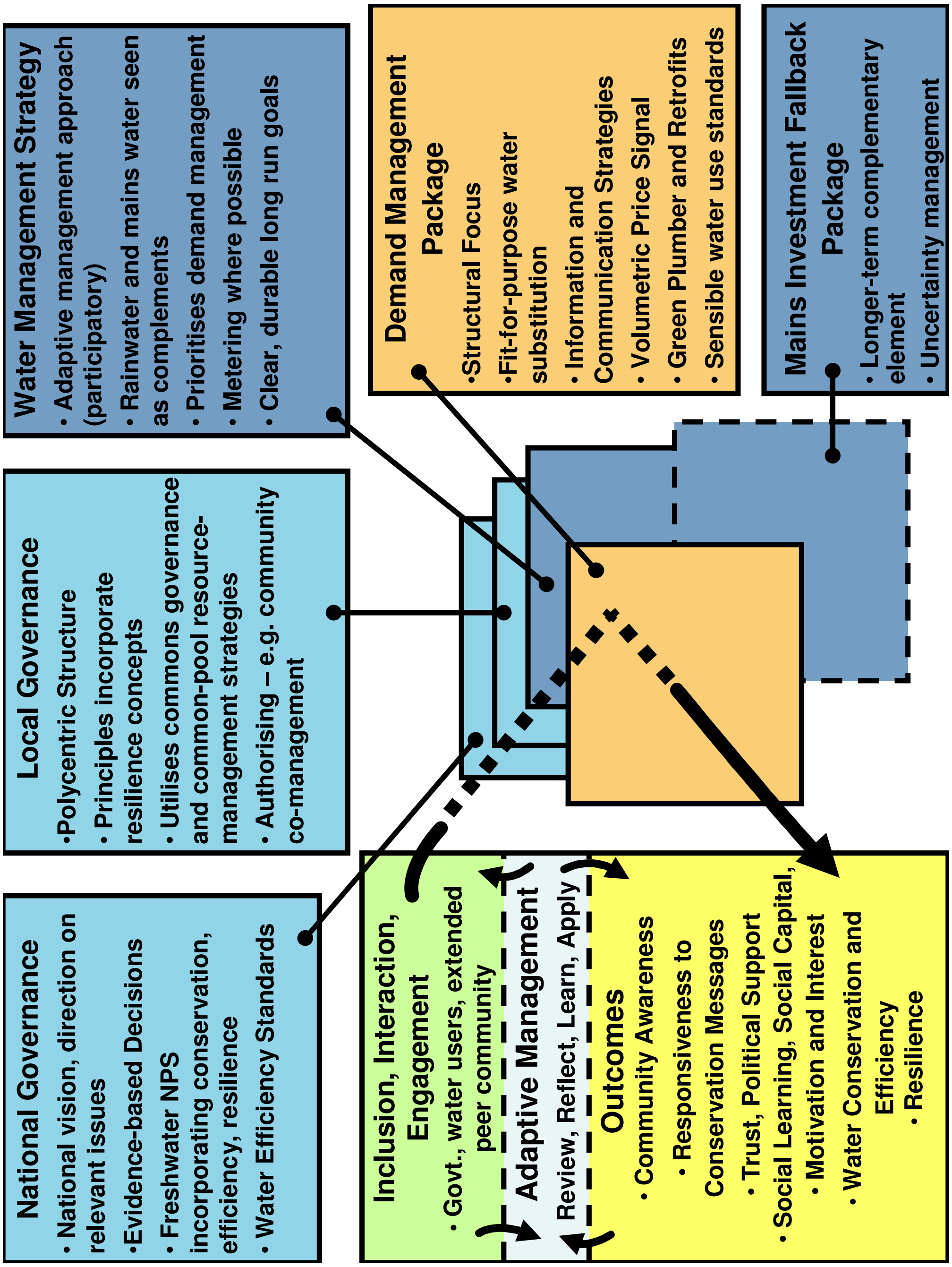
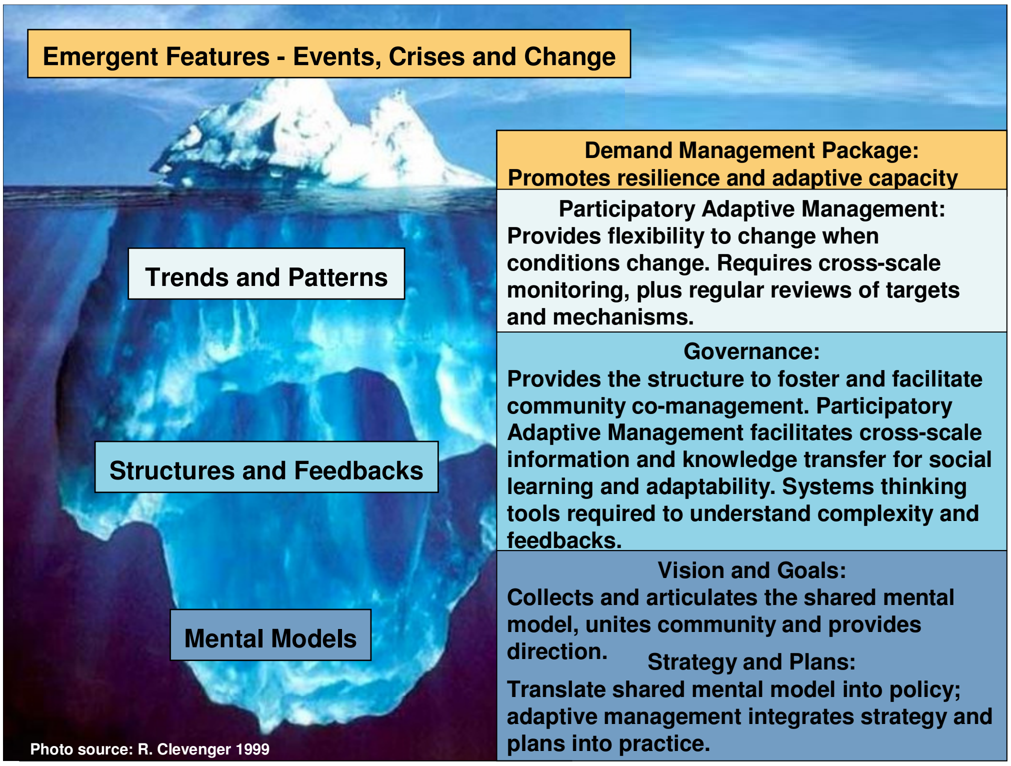


Figure 6.2. Key features and requirements of the Urban Water Resilience Framework as they relate to the Iceberg Model. The emergent feature of the framework is the adopted demand management package.



6.1.2 A Way Forward

Turning to Wellington, whether the water management pathway taken is adaptive or maladaptive could be decided by the relative success or failure to incorporate resilience and adaptive management into policy and practice. The community has a shared stake in the management and governance of water, as a common-pool resource subject to increased pressure over time. They also have a shared interest in keeping the costs of its provision down and reducing any adverse effects of water extraction. From water users, a resilience approach requires a shift from risk-complacent or disengaged 'consumers', to cooperative, risk-aware communities. From current decision-makers, adaptive management requires a shift to a more collaborative and facilitative approach, in order to foster and facilitate innovation and knowledge transfer. The challenge of transforming from a ‘conventional’ direction to an adaptive management and resilience pathway should not be underestimated. The transition of resilience and adaptive management into both policy and practice will need to be managed based on sound principles, and also be adaptively managed:

> *An alternative adaptation model is to pursue resilience-informed approaches. However, we have no evidence that these will perform better than the ‘bridging institution’ model, in the face of reluctance by those who would prefer to see a continuation of the status quo. Whichever approach is adopted, learning mechanisms are central to long-term effective adaptation* (Tompkins et al. 2010, p.629).

Making the price of water provision transparent, rather than hiding it in the rates bill, needs to be a key part of a demand management package for Wellington. However the Wellington community is strongly opposed to universal metering due to privatisation fears. Concern that the water services may be privatised could be particularly acute at present with the Government’s proposal to partially privatise state-owned power companies. In addition metering every property is an expensive option with ongoing costs to replace meters, and additional administrative costs for individualised water bills. Moreover in many cases an individualised water bill alone does not provide sufficient incentive to motivate a desirable level of water conservation.

One way forward for the residential sector is to meter at a small suburb or ‘demand zone’ level of resolution, and charge households a volumetric component based on average consumption for that community. The volumetric component needs to be balanced between incentivising conservation and provoking excessive concern. A further measure to reduce concern is to provide an option of individualised metering and billing, at a charge reflecting its greater capital and administrative costs. Demand-zone charging will save money and water, foster the development of community co-management, facilitate innovation and social learning, provide additional community-based motivation to sanction by-law infringers, including informally; and help establish community-level adaptive capacity, including motivating greater engagement that can be drawn on in the event of a shortage. Co-management of the water resource can enhance resilience and adaptive capacity through the development and enhancement of networks through which social learning can occur (including with and within central and local government). It can also significantly reduce enforcement costs (Adger, Brown and Tompkins 2006).

6.2 Conclusion

This research project used a complex systems science approach, modelled climate data, systems-modelling tools and a resilience perspective in order to address the following question:

What adaptive capacity and resilience features could different options or combinations of options provide for managing Wellington's water? What factors or conditions might lead to greater adaptive capacity and resilience, and what vulnerabilities might lead to insufficient adaptation or even maladaptation?

Key components of resilience are diversity, modularity and redundancy. In general, with regard to providing adaptive capacity and resilience to water management, these components of resilience are enhanced by the following factors and options:

- Mental models able to navigate complexity
- Polycentric governance and management structure
- Particpatory adaptive management

- Water management strategies incorporating resilience
- A demand management package that promotes resilience and adaptive capacity.

The primary source of adaptive capacity is participatory adaptive management, since instituting this management option provides a format for the ongoing participation and collaboration which are required for social learning and collective action, as well as the flexibility to change when conditions change. By contrast, hierarchical, command and control regimes have a tendency to rigidly hold on, steering the system down undesirable pathways. A further vulnerability is evident in the much tighter feedback between augmentation and the reduction of community concern, in contrast to the adaptiveness-increasing demand management feedback (Fig. 5.4). The process of augmentation is therefore more simple and certain than demand management, making augmentation an attractive short-term option, but being at odds with longer-term goals of building resilience.

This case study was centered on Wellington, though the conceptual framework and research methods, as well as insights from literature and theory such as common-pool resource management could be applied to any local context. What matters is that there is sufficient understanding of the local context, and of the extent to which theory and research can be applied within the local context. On the part of a researcher, understanding of the local context can only come from participating in and collaborating with local water users and managers, as part of the extended peer community.

Within the diversity provided by Wellington's disaggregated water management structure, it should be possible to establish a pilot study based on sound adaptive management principles, but which challenges the embedded assumptions of both resource users and managers. A way forward has been proposed based on the mental model developed by the researcher throughout this project. However this mental model is necessarily partial, the reasoning behind it limited by the time and resource limitations of the research project, and by the cognitive tendencies and limitations of the researcher. Ideally, the workshop-modelling process that was initiated for this research would be continued until the participants were able to generate their own broadly supported response pathway.

As seen by the example of the Royal Commission on Auckland Governance, in a hierarchical governance situation, there are no guarantees that the recommended options from even a very well resourced participatory process will be adopted. The increased diffusion of knowledge and information through participatory adaptive management may be able to engender a more collaborative approach from a hierarchical regime. However power dynamics and transition management were beyond the scope of this research project.

A focus on resilience may help to shift policy responses from a 'control-orientated' to an adaptive and collaborative process (Folke et al. 2002). If so, then the challenge of instituting resilience thinking and adaptive management could be a crux of addressing climate change as a 'super-wicked problem', but with no guarantee that reshaping the way that humanity thinks will be enough to counter the adverse effects of the "*progressive expansion of the scale of human influences on the planet"* (Walters and Holling 1990, p.2067), or of the novel problems that our expansion creates. An investigation into options and processes for embedding adaptive management and resilience concepts into the governance and management approaches could therefore provide further invaluable insights for increasing adaptive capacity.

What matters about climate change is not whether we can predict the future with some desired level of certainty and accuracy; it is whether we have sufficient foresight, supported by wisdom, to allow our perspective about the future, and our responsibility for it, to be altered. All of us alive today have a stake in the future, and so we should all play a role in generating sufficient, inclusive and imposing knowledge about the future.

Mike Hulme, 2009

References

Abbott, M, W.C. Wang and B. Cohen. 2010. The long-term reform of the water and wastewater industry: The case of Melbourne in Australia. *Utilities Policy*, in Press.

ABS (Australian Bureau of Stastistics) 2010. Water use and Conservation, Mar 2010, Summary of findings. Viewed 17.12.10. http://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/4602.0.55.003Main%20Features2Mar%202010?opendocument&tabname=Summary&prodno=4602.0.55.003&issue=Mar%202010&num=&view=

ABS 2010b. Water Account Australia 2008-09. Viewed 31.12.10. http://www.abs.gov.au/AUSSTATS/abs@.nsf/ProductsbyCatalogue/517E56D3E26FA357CA2577E700158AC7?OpenDocument#NSW

ADB (Asian Development Bank) 2011. Migration Due to Climate Change Demands Attention. News Release, 07 February 2011, viewed 27.02.11. http://www.adb.org/Media/Articles/2011/13473-asian-climates-changes/

Adger, N. 2003. Social Capital, Collective Action, and Adaptation to Climate Change. *Economic Geography*, Vol. 79, No. 4 (Oct., 2003), pp. 387-404.

Adger, W.N., N.W. Arnell, and E.L. Tompkins. 2005. Successful adaptation to climate change across scales. *Global Environmental Change* 15 (2005) 77–86.

Adger, W. N., K. Brown and E. L. Tompkins. 2005. The political economy of cross-scale networks in resource co-management. *Ecology and Society* 10(2): 9.

Adger, W. N. 2006 Vulnerability. *Global Environmental Change* 16(3) 268-281.

Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit and K. Takahashi, 2007. Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 717-743.

Aitken, C., R. Chapman and J. McClure. 2011. Climate change, powerlessness and the commons dilemma: Assessing New Zealanders' preparedness to act. *Global Environmental Change*, article in press.

Allen Consulting Group, 2005. Climate Change Risk and Vulnerability Promoting an efficient adaptation response in Australia. Report to the Australian Greenhouse Office, Department of the Environment and Heritage. Published by the Australian Greenhouse Office, in the Department of the Environment and Heritage.

Ammundsen, D., M. Pomare and R. Lane. 2009. Proposed Plan Change 75 to the Kapiti Coast District Council District Plan – Water Demand Management. Commissioners Report and Recommendation.

Bakker, K. 2008. The Ambiguity of Community: Debating Alternatives to Private-Sector Provision of Urban Water Supply. *Water Alternatives,* 1 (2):236-252.

Barnett, J. and S. O'Neill. 2010. Maladaptation. *Global Environmental Change,* Volume 20, Issue 2, May 2010, Pages 211-213.

Beavan, J., R. Bell, R. Bindschadler, J. Church, J. Hannah, K. Hunter, P. Kench, A. Mackintosh, M. Manning, T. Naish, D. Ramsay, R. Reinen-Hamill, A. Reisinger, J. Renwick, Z. Rissel, C. Saunders, D. Wratt and D. Zwartz. 2010. Sea-level Rise Emerging Issues. The Royal Society of New Zealand.

Bint, L., N. Issacs and R. Vale. 2010. Water Performance Benchmarks for New Zealand: an approach to understanding water consumption in commercial office buildings. Victoria University of Wellington.

BoM (Bureau of Meterology) 2010. Graphical Climate Statistics for Australian Locations. http://www.bom.gov.au/jsp/ncc/cdio/cvg/av accessed 06.12.10.

Brownlee, G. 2008. $3.5 million PR campaign on light-bulb ban. Press Release: New Zealand National Party. *Scoop*, 22 October 2008, viewed 24.06.11. http://www.scoop.co.nz/stories/PA0810/S00513.htm

Capacity 2010. Annual Report 2009 – 2010. Capacity Infrastructure Services, Petone, Lower Hutt.

Chadwick, S. 2007. Petition 2005/106 of Penelope Bright and 40 others Report of the Local Government and Environment Committee. Chadwick, S. (Chairperson), House of Representatives, Wellington.

Chanan, A., J. Kandasamy, S. Vigneswaran and D. Sharma 2009. A gradualist approach to address Australia's urban water challenge. *Desalination* 249 (2009) 1012–1016.

Chapman, R., E. Goldberg, G. Salmon and J. Sinner. 2003. Sustainable Development and Infrastructure. Report for the Ministry of Economic Development. Maarama Consulting.

Chipp, J. 2009. Council's water-use figures discredited. *The Wellingtonian* 08 March 2009, viewed 05.01.11. http://www.stuff.co.nz/dominion-post/news/local-papers/the-wellingtonian/2323541/Councils-water-use-figures-discredited

Chipp, J. 2011. Council argues minimum flow reduction won't increase algal blooms. *Hutt News,* 15 June 2011, viewed 22.06.2011. http://www.stuff.co.nz/dominion-post/news/local-papers/hutt-news/5144992/Council-argues-minimum-flow-reduction-won-t-increase-algal-blooms

Clauson, B. and Pearson, C.P.1997. How Extreme was the Drought? *Nordic Hydrology*, 28 (4/5), 297-306.

Clifton, J. 2009. Labour might be saying sorry, but does it really mean it? *New Zealand Listener*, September 26-October 2 2009 Vol 220 No 3620.

Climate Commission. 2011. The Critical Decade: Climate science, risks and responses. Commonwealth of Australia (Department of Climate Change and Energy Efficiency) 2011.

Conlisk, J. 1996. Why Bounded Rationality? *Journal of Economic Literature*, 34 (2), 669-700.

Cook, F. 2009. Wellington City Water Usage. http://www.righttowater.org.nz/Cook.doc

Coombes P.J. and G. Kuczera. 2003 Analysis of the Performance of Rainwater Tanks in Australian Capital Cities. The Institution of Engineers, Australia 28th International Hydrology and Water Resources Symposium 10 – 14 November 2003 Wollongong NSW.

Coombes P.J. and M.E. Barry 2007. Climate change, efficiency of water supply catchments and integrated water cycle management in Australia. Rainwater and Urban Design Conference. Engineers Australia.

Corral-Verdugo, V., G. Carrus, M. Bonnes, G. Moser and J.B.P Sinha. 2008. Environmental Beliefs and Endorsement of Sustainable Development Principles in Water Conservation: Toward a New Human Interdependence Paradigm Scale. *Environment and Behavior* 2008 40: 703.

Cousins, J., N. Perrin, G. Hancox, B. Lukovic, A. King, W. Smith, A. McCarthy and T. Shaw. 2010. Bulk water supply – Impacts of a Wellington Fault Earthquake. New Zealand Society for Earthquake Engineering Conference.

Dietz, T., E. Ostrom and P.C. Stern. 2003. The Struggle to Govern the Commons. *Science* 302: 1907 (2003).

Doerner, D. 1980. On the difficulties people have in dealing with complexity. *Simulation and Gaming,* 11: 87-106.

Dryzek, J. 1990 Discursive Democracy: Politics, Policy and Political Science, Cambridge: Cambridge University Press.

Duit, A., V. Galaz, K. Ekerberg and J. Ebbesson. 2010. Governance, complexity, and resilience. *Global Environmental Change* 20 (2010) 363–368.

EcoClimate, 2008. Costs and Benefits of Climate Change and Adaptation to Climate Change in New Zealand Agriculture: What Do We Know so Far? Contract report by EcoClimate Consortium: Integrated Research on the Economics of Climate Change Impacts Adaptation and Mitigation. Wellington: Ministry of Agriculture and Forestry.

Edwards, S. and N. Boyack. 2010. Wallace claims 'dirty politics' in Hutt advertising insert. *Hutt News*, 28.09.10.

Festinger, L. 1957. A Theory of Cognitive Dissonance. Stanford, CA: Stanford University Press.

Folke, C., T. Hahn, P. Olsson and J. Norberg. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environmental Resources* 30:8.1-8.33.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C.S. Holling, B. Walker,

J. Bengtsson, F. Berkes, J. Colding, K. Danell, M. Falkenmark, L. Gordon, R. Kasperson, N. Kautsky, A. Kinzig, S. Levin, K.. Mäler, F. Moberg, L. Ohlsson, P. Olsson, E.Ostrom, W.Reid, J. Rockström, H. Savenije and U. Svedin. 2002. Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. Scientific Background Paper on Resilience for the process of The World Summit on Sustainable Development on behalf of the Environmental Advisory Council to the Swedish Government.

Frame, B. 2009. Sustainability Technologies 101: Wicked Problems and other such technical terms. Chapter 19 in Hatched: The Capacity for Sustainable Development. Frame, B., R. Gordon and C. Mortimer (eds). Landcare Research New Zealand Ltd.

Funtowicz, S.O. and J.R. Ravetz. 1991. A new scientific methodology for global environmental issues. In: Costanza, R. (Ed.), *Ecological Economics*. Columbia, New York, pp.137–152.

Funtowicz, S.O. and J.R. Ravetz. 1993. Science for the Post-Normal Age. *Futures* 25 (7), pp. 739-755.

Gibb, M. 2009. Case for water meters is too strong to resist. *Dominion Post*, 19 October 2009, viewed 13.03.11. http://www.stuff.co.nz/blogs/opinion/2979189/Case-for-water-meters-is-too-strong-to-resist

Gintis, H. 2000. Strong Reciprocity and Human Sociality. *Journal of theoretical Biology*, 206, 169-179.

Girard, M. and R. A. Stewart. 2007. Implementation of pressure and leakage management strategies on the Gold Coast, Australia: Case study. *Journal of Water Resources Planning and Management* 133 (3):210-217.

Global Carbon Project 2011. Carbon Budget 2009. http://www.globalcarbonproject.org/carbonbudget/09/files/GCP2010_CarbonBudget2009.pdf accessed 25.2.11.

Grist, M. 2010. Steer: Mastering our behaviour through instinct, environment and reason. RSA London.

Gunderson L, C.S. Holling and S. Light. 1995. Barriers and Bridges to the Renewal of Ecosystems and Institutions. New York: Columbia Univ. Press.

GW 2004. Greater Wellington Water Asset Management Plan November 2004. Greater Wellington Regional Council. Wellington.

GW 2008. Wellington Water Management Plan Technical Document. Version 5.4 Updated April-May 2008. Greater Wellington Regional Council.

GW 2008b. Wellington Metropolitan Water Supply Development. Greater Wellington Regional Council. Wellington.

GW 2008c. Technical Information: Waterloo Water Treatment Plant. Greater Wellington Regional Council.

GW 2010. Water Supply Annual Report 2010. Greater Wellington Regional Council.

Hall, D. C. 2009. Prescriptive public choice: application to residential water rate reform. *Contemporary Economic Policy* 27 (4):555-565.

Hennessy, K., B. Fitzharris, B.C. Bates, N. Harvey, S.M. Howden, L. Hughes, J. Salinger and R. Warrick. 2007: Australia and New Zealand. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Hide, R. 2009. Rodney Hide Speech To Rotary Club Of Pakuranga 15 June 2009. http://www.scoop.co.nz/stories/PA0906/S00192.htm accessed 27.04.11.

Hodgson, A.M. 1992. Hexagons for systems thinking. *European Journal of Systems Dynamics* Volume 59, No 1, 1992.

Hoffmann, M., A. Worthington and H. Higgs. 2006. Urban water demand with fixed volumetric charging in a large municipality: the case of Brisbane, Australia. *Australian Journal of Agricultural and Resource Economics* 50 (3):347-359.

Holling CS. 1973. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* 4:1–21.

Holling, C.S. 1996. Engineering Resilience versus Ecological Resilience. In Engineering within Ecological Limits, Peter C. Schulze (ed.). National Academies Press, pp31-43.

Holling, C.S., L.H. Gunderson and D. Ludwig, 2002. In Search of a Theory of Adaptive Change. Chapter 1 in Panarchy: Understanding Transformations in Human and Natural Systems, Holling, C.S., Gunderson, L.H (eds). Island Press, Washington.

Hulme, M. 1990. Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity. Cambridge University Press.

Ibbitt, R. 2010. Development of separate demand sequences for the SYM and Karaka Model. NIWA Client Report. National Institute of Water & Atmospheric Research Ltd. Christchurch.

Ibbitt, R. 2007. Demand File Verification. NIWA Client Report. National Institute of Water & Atmospheric Research Ltd. Christchurch.

Ibbitt, R. and B. Mullan. 2007. Potential effects of Climate Change on Sustainable Yield Model (SYM) outputs. NIWA Client Report. National Institute of Water & Atmospheric Research Ltd. Christchurch.

Ioris, A. 2008. Water Institutional Reforms in Scotland: Contested Objectives and Hidden Disputes. *Water Alternatives* 1 (2):253-270.

IPART. 2010. About us. http://www.ipart.nsw.gov.au/about_us/about_us.asp accessed 02.04.10.

IPCC 2007. Climate change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report. [Core Writing Team, Pachauri RK, and A. Reisinger (ed)] Intergovernmental Panel on Climate Change, Geneva, Switzerland, pp104.

IPCC 2007b. Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

Jansen, A. and C. Shultz. 2006. Water Demand and the Urban Poor: A case study of the factors influencing water consumption amoung households in Cape Town, South Africa. In Working Paper Series in Economics and Management No. 02/06.

Johnson, B. L. 1999. Introduction to the special feature: adaptive management - scientifically sound, socially challenged?

Conservation Ecology **3**(1): 10. [online] URL: http://www.consecol.org/vol3/iss1/art10/.

Johnson-Laird, P.N. 2010. Mental models and human reasoning. *PNAS* 2010 107 (43) 18243-18250; published ahead of print October 18, 2010.

Johnson-Laird, P. N. 1995. Mental Models, Deductive Reasoning, and the Brain. In M.S. Gazzaniga (Ed.), The Cognitive Neurosciences (pp. 999-1008). Cambridge, MA: MIT Press.

Jones, R. 2010. A risk management approach to climate change adaptation. Chapter 1 in Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage, R.A.C., Wratt, D.S., Bornman, J.F., Jones, K. (eds), Wellington.

Kahan, D.M. 2010. Fixing the Communications Failure. *Nature* Vol 463|21 January 2010.

Kahan, D.M. 2006. Cultural Cognition and Public Policy. Faculty Scholarship Series. Paper 103.

Kay 2011. Partial asset sales a tough sell. *Dominion Post* 29 January 2011, viewed 17.06.11. http://www.stuff.co.nz/national/politics/4596129/Partial-asset-sales-a-tough-sell

Kenney, D. S., C. Goemans, R. Klein, J. Lowrey and K. Reidy. 2008. Residential water demand management: lessons from Aurora, Colorado. *Journal of the American Water Resources Association* 44 (1):192-207.

Kenway, S.J., A. Priestley, S. Cook, S. Seo, M. Inman, A. Gregory and M. Hall. 2008. Energy use in the provision and consumption of urban water in Australia and New Zealand. CSIRO: Water for a Healthy Country National Research Flagship.

Klayman, J. and Y.W. Ha. (1989) Hypothesis testing in rule discovery: strategy, structure and content. *Journal of Experimental Psychology,* 5: 596-604.

Kopp, M. 2010. Hutt River lower flow bid comes under fire. *Hutt News,* 02 November, viewed 22.06.11. http://www.stuff.co.nz/dominion-post/news/local-papers/hutt-news/4297928/Hutt-River-lower-flow-bid-comes-under-fire

Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov, 2007: Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 173-210.

Kusel, J., S.C. Doak, S. Carpenter and V.E. Sturtevant. 1996. The role of the Public in Adaptive Ecosystem Management. In: Sierra Nevada ecosystem project: final report to Congress. Vol. II, assessments and scientific basis for management options. Davis, CA: University of California, Centers for Water and Wildland Resources: 611–624.

Land and Water Forum. 2011. Homepage. http://www.landandwater.org.nz/ accessed 30.05.11.

Lazarova, V., S. Hills and R. Birks. 2003. Using recycled water for non-potable, urban uses: a review with particular reference to toilet flushing. *Water Science and Technology: Water Supply* Vol 3 No 4 pp 69–77.

Levin K., S. Bernstein, B. Cashore, G. Auld. 2007. Playing it forward: Path dependency, Progressive Incrementalism, and the 'Super Wicked' Problem of Global Climate Change. Unpublished manuscript.

Lindsay, G. 2011. Wellington Rainwater Performance. New Zealand Climate Change Research Institute. Wellington (unpublished data).

Lucas, S,A., P. J. Coombes and A. K. Sharma. 2010. The impact of diurnal water use patterns, demand management and rainwater tanks on water supply network design. *Water Science & Technology: Water Supply*—WSTWS Vol 10 No 1 pp 69–80.

Maani, K. and Cavana, R. 2007. Systems Thinking and Modelling – Managing Change and Complexity. 2nd edition, Pearson Education, Prentice Hall.

Manning, M.R., J. Edmonds, S. Emori, A. Grubler, K. Hibbard, F. Joos, M. Kainuma, R. F. Keeling, T. Kram, A. C. Manning, M. Meinshausen, R. Moss, N. Nakicenovic, K. Riahi, S. K. Rose, S. Smith, R. Swart & D. P. van Vuuren. 2010. Misrepresentation of the IPCC CO_2 emission scenarios. *Nature Geoscience* 3, 376 – 377.

Martínez-Espiñeira, R. and C. Nauges. 2004. Is all domestic water consumption sensitive to price control? *Applied Economics* 36 (15):1697-1703.

Meadows, D. 1999. Leverage Points, Places to Intervene in a System. The Sustainability Institute, Hartland, Vermont, USA.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.C. Zhao. 2007. Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Melbourne Water 2010. Water System Storage Interactive Graph. http://www.melbournewater.com.au/content/water_storages/water_report/water_report.asp accessed 6.12.10.

Melbourne Water 2010b. Water Storage Graph. http://www.melbournewater.com.au/content/water_storages/water_report/zoom_graph.asp accessed 6.12.10.

MfE. 2009. On Tap? Attitudes, behaviours, and perceptions of household water use – informing demand management. Wellington: Ministry for the Environment.

Miller, G.A. 1956. The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *The Psychological Review,* 63, pp81-97.

Min, S.K., X. Zhang, F.W. Zwiers, and G.C. Hegerl. 2011. Human contribution to more-intense precipitation extremes. *Nature* 470: 378-381.

Mithraratne, N. and Vale, R. 2007. Rain Tanks or Reticulated Water Supply? Rainwater and Urban Design 2007. Sydney, 21st-23rd August 2007.

Mortimer, C. 2010. Urban Resilience presentation, Resilience Workshop No.3: Unity in Diversity? Structuring Complex Problems using a Systems Approach. July 15 2010. Ministry of Civil Defence and Emergency Management. Wellington.

Munda, G. 2004. Social multi-criteria evaluation: Methodological foundations and operational consequences. *European Journal of Operational Research* 158 (2004) 662–677.

MWH 2011. Wellington Metropolitan Bulk Water Supply Review of Security of Supply Standard. Prepared for Greater Wellington Regional Council.

MWP (Metropolitan Water Plan) 2006. Water for Life. NSW Government.

MWP (Metropolitan Water Plan) 2010. Water for Life. NSW Government.

NEC (Nelson Environment Center) 2011. Solar Saver. http://www.nec.org.nz/SolarSaver accessed 14.04.11.

Nelson, D.R., N.W. Adger and K. Brown. 2007. Adaptation to Environmental Change: Contributions of a Resilience Framework. *Annu. Rev. Environ. Resour.* 2007. 32:395–419.

Nicholls, R.J., A. Cazenave. 2010. "Sea-Level Rise and Its Impact on Coastal Zones". *Science*, 328: 1517.

NIWA 2010. South Western North Island Climate Zone. http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview/map_sw_north accessed 19.08.10.

NRC (Northland Regional Council) 2010. Kaitaia's water situation – the facts. Posted 15 March 2010, viewed 29 April 2011. http://www.nrc.govt.nz/News-Archive/2010/Kaitaias-water-situation--the-facts-/

NWC (National Water Commission) 2010. National Performance Report 2008-2009, Urban Water Utilities. Australian Government National Water Commission. Canberra.

Ormerod, P. 2010. N Squared: Public policy and the power of networks. RSA, London.

Ostrom, E. 2009. Beyond Markets and states: Polycentric Governance of Complex Economic Systems. Nobel Prize lecture, December 8, 2009.

Paerl, H.W., N.S. Hall and E.S.Calandrino. 2011. Controlling harmful cyanobacterial blooms in a world experiencing anthropogenic and climatic-induced change. *Science of the Total Environment* 409: 1739–1745.

Pahl-Wostl, C. 2005. Information, public empowerment, and the management of urban watersheds. *Environmental Modelling & Software* 20: 457–467.

Pahl-Wostl, C., M. Craps, A. Dewulf, E. Mostert, D. Tabara and T. Taillieu. 2007. Social learning and water resources management. *Ecology and Society* 12(2): 5. [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art5/

PCC (Porirua City Council) 2011. Porirua City Water Savings No "Drop in the Bucket". Scoop, Tuesday, 22 March 2011, Press Release: Porirua City Council, viewed 29 April 2011. http://www.scoop.co.nz/stories/AK1103/S00818/porirua-city-water-savings-no-drop-in-the-bucket.htm

PCE (Parliamentary Commissioner for the Environment). 2001. Beyond Ageing Pipes. Urban water system issues for the 21st century. Wellington: Parliamentary Commissioner for the Environment. April 2001.

Pelling, M. and C. High. 2005. Understanding adaptation: What can social capital offer assessments of adaptive capacity? *Global Environmental* Change 15 (2005) 308–319.

Pilipovic, Z. and Taylor, R. 2003. Pressure management in Waitakere New Zealand: A Case Study. *Water Science and Technology*: *Water Supply* Vol 3 No 1-2 pp 135-141.

Putnam, R., 1995. Tuning in, tuning out: the strange disappearance of social capital in America. *Political Science and Politics* 28, 667–683.

PWC (PriceWaterhouseCoopers) 2010. Wellington Region Councils Governance Review. October 2010.

Ravetz, J.R. 2006. Post-Normal Science and the Complexity of Transitions Towards Sustainability. *Ecological Complexity*, 3, 275-284.

Rayner S 2006. Wicked problems: clumsy solutions – diagnoses and prescriptions for environmental ills. Jack Beale Memorial Lecture on Global Environment. ANSW Sydney, Australia, July 2006.

Reed, M. S., A. C. Evely, G. Cundill, I. Fazey, J. Glass, A. Laing, J. Newig, B. Parrish, C. Prell, C. Raymond and L. C. Stringer. 2010. What is Social Learning?. *Ecology and Society* 15 (4) [online] URL: http://www.ecologyandsociety.org/vol15/iss4/resp1/

Reisinger, A., B. Mullan, M. Manning, D. Wratt and R. Nottage. 2010. Global & local climate change scenarios to support adaptation in New Zealand. Chapter 2 in Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage, R.A.C., Wratt, D.S., Bornman, J.F., Jones, K. (eds), Wellington.

Renwick, M.E. and Green, R.D. 2000. Do Residential Water Demand Side Management Policies Measure Up? An Analysis of Eight California Water Agencies'. *Journal of Environmental Economics and Management* 40,37-55

Riebeek, H. 2010. Global Warming: How much more will the Earth warm? http://earthobservatory.nasa.gov/Features/GlobalWarming/page5.php accessed 01.03.11

Rittel, H. and Webber, M. 1973. Dilemmas in a General Theory of Planning. *Policy Sciences*, 4 (1973), 155-169.

Right to Water. 2010. Home Page. http://www.righttowater.org.nz/ accessed 03.04.10.

Roebuck, R. M., C. Oltean-Dumbrava and S. Tait. 2010. Whole life cost performance of domestic rainwater harvesting systems in the United Kingdom. *Water and Environment Journal*, Article published online: 5 MAY 2010.

Roy, H. 2010. Water Efficiency labels help consumers make better choices. Government Press Release 01 April 2010, Viewed 23.06.11. http://www.beehive.govt.nz/release/water-efficiency-labels-help-consumers-make-better-choices

Rudman, B. 2009. Apologetic Goff has fallen into Nats' trap. *The New Zealand Herald*. 16 September 2009. Viewed 23.06.2011. http://www.nzherald.co.nz/opinion/news/article.cfm?c_id=466&objectid=10597507

Salmon, P., M. Bazley and D Shand. 2009. Royal Commission on Auckland Governance. Report of the Royal Commission, March 2009.

Saloranta, T.M. 2001. Post-Normal Science and the Global Climate Change Issue. *Climatic Change* 50: 395–404, 2001.

SCA (Sydney Catchment Authority) 2010. Water Security and Supply Report 9 December 2010. Viewed 13.2.10

http://www.sca.nsw.gov.au/dams-and-water/weekly-storage-and-supply-reports/2010/9-december-2010

Schiermeier, Q. 2011. Increased Flood Risk Linked to Global Warming. *Nature* 470, 316.

Shaw, T. 2008. Bulk Water Supply Development Strategy 2008. Greater Wellington Regional Council. Wellington

Shaw, T. 2011. Wholesale water supply - security of supply standard. Greater Wellington Regional Council. Wellington

Shaw, T. and A. McCarthy. 2009. Stuart Macaskill Lakes seismic security upgrade. Greater Wellington Regional Council. Wellington

Sheppard, D., D. Harding, K. Prime and J. Vernon. 2010. Board Report and Recommendations NPS Freshwater Management.

Sherlock, B. 2008. Bulk Water Supply - Development Options. Report to Hutt City Strategy and Policy Committee. Hutt City Council.

Simon, H.A. 1978. Rational Decision-making in Business Organizations. Nobel Memorial Lecture, 8 December, 1978.

Smit, B. and J. Wandel. 2006. 'Adaptation, adaptive capacity and vulnerability', *Global Environmental Change* 16 (3): 282-292.

Smith, A. and A. Stirling. 2010. The politics of social-ecological resilience and sustainable socio-technical transitions. *Ecology and Society* 15(1): 11. [online] URL: http://www.ecologyandsociety.org/vol15/iss1/art11/

Stagl, S. 2003. Multicriteria Evaluation and Public Participation: In Search for Theoretical Foundations. Frontiers 2: European Applications in Ecological Economics, Tenerife, Spain, 12 - 15 February 2003. http://www.euroecolecon.org/old/frontiers/Contributions/F2papers/PL2-FPaper.pdf

Stankey, G.H., R.N. Clark and B.T. Bormann 2005. Adaptive Management of Natural Resources: Theory, Concepts, and Management Institutions. Washington: United States Department of Agriculture (USDA).

Steg, L. and C. Vlek. 2009. Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology* 29 (3):309-317.

Stern, P., T. Dietz, T. Abel, G.A. Guagnano and L. Kalof. 1999. A Value-Belief-Norm Theory of Support for Social Movements: The Case of Environmentalism. *Human Ecology Review*, Vol. 6, No. 2.

Syme, G.J, B.E. Nancarrow and C. Seligman. 2000. The Evaluation of Information Campaigns to Promote Voluntary Household Water Conservation. *Evaluation Review* 2000. 24(6), 539-578

Taylor, S. and Hodges, J. 2008. Water Supplies for Auckland – Predict and Provide or Conserve and Contain? 4th IWA Specialist Conference on Efficient Use and Management of Urban Water Supply, Jeju Island, South Korea, 21st May 2007. pp 409 – 417.

The Wellingtonian. 2009. Editorial: Lack Of Rigour in Water report, 22 October 2009, viewed 06.12.10 http://www.stuff.co.nz/dominion-post/news/local-papers/the-wellingtonian/2985461/Editorial-Lack-of-rigour-in-water-report

Tompkins, E.L., N.W. Adger, E. Boyd, S. Nicholson-Cole, K. Weatherhead and N. Arnell. 2010. Observed adaptation to climate change: UK evidence of transition to a well-adapting society. *Global Environmental Change* 20 (2010) 627–635.

Turner, A., S. White, A. Kazaglis and S. Simard. 2009. Have we achieved the savings? The importance of evaluations when implementing demand management. *Water Science & Technology: Water Supply* 7 (5-6):203-210.

Turner, A., J. Willetts, S. Fane, D. Giurco, A. Kazaglis and S. White. 2008. Guide to Demand Management. Institute for Sustainable Futures University of Technology Sydney, Water Services Association, Australia.

Turner, A., S. White, K. Beatty and A. Gregory. 2004. Results of the Largest Residential Demand Management Program in Australia. In *Biennial World Water Congress*. Marrakech, Morocco.

Vatn, Arild. 2005. Institutions: coordination and conflict. Chapter 3 in Institutions and the Environment, Elgar, Cheltenham, pp. 60-85.

Vermeer, M. and S. Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences* (USA) 106: 21527–21532.

Walker, B.H. 2005. A Resilience Approach to Integrated Assessment. *Bridging Sciences and Policy,* Vol. 5: No. 1, pp. 77–97.

Walker, B.H. 2009. Specified and General Resilience. Resillence Alliance. http://wiki.resalliance.org/index.php/1.5_Specified_and_General_Resilience accessed 15.06.11.

Walker, B.H. and D.A. Salt, 2006. Resilience Thinking: Sustaining Ecosystems and People in a Changing World. Island Press.

Walters, C.J. and C. S. Holling. 1990. Large-Scale Management Experiments and Learning by Doing. *Ecology*, Vol. 71, No. 6. pp. 2060-2068.

Watercare 2008. Three Waters Final 2008 Strategic Plan. Watercare, Auckland.

Wengraf, T. (2001). Qualitative Research Interviewing: Biographic, narrative, and semi-structured methods. London, United Kingdom: Sage Publications.

WCC 2009. Water Conservation and Efficiency Plan. Strategy and Policy Committee. Wellington City Council.

WCC 2009b. Draft Water Supply Demand Management Strategy.

WCC 2009c. Seting of Rates for 2009/10. Wellington City Council.

WCC. undated. The Wellington Water Charter. Wellington City Council.

WELS. 2010. Water Efficiency Labelling and Standards (WELS) Scheme. http://www.waterrating.gov.au/ accessed 06.04.10.

Williams, G. 2010. Climate Change Study 2010, SYM Data Output. Greater Wellington Regional Council.

Williams, G. 2010b. Karaka Model Probabilistic Forecast. Greater Wellington Regional Council internal Memo. 5 March 2010.

Wolfe, S. 2008. Capacity, Capability, Collaboration, and Commitment: How Social Networks Influence Practitioners of Municipal Water Demand Management Policy in Ontario, Canada. *Environmental Practice* 10:42–52 (2008).

Wolf, J. W. N. Adger, I. Lorenzoni, V. Abrahamson and R. Raine. 2010. Social capital, individual responses to heat waves and climate change adaptation: An empirical study of two UK cities. *Global Environmental Change* 20 (2010) 44–52.

Appendix 1: Climate Change Scenarios and Models

The IPCC emissions scenarios were developed for the Third Assessment Report (TAR) in 2001, and also used for the Fourth Assessment Report (AR4) of 2007.

The **low-carbon scenario** depicts a mitigation strategy that aims to limit the increase in global average temperatures to about 2°C relative to pre-industrial levels (about 1.5°C relative to 1980-1999) (Reisinger et al 2010). This scenario represents a rapidly decarbonising world with almost zero global emissions of CO2 by 2100 and significant reductions in non-CO2 greenhouse gas emissions in order to stabilise total greenhouse gas concentrations at about 450 ppm CO2-equivalent (Reisinger et al 2010).

The B1 scenario represents an integrated and ecologically friendly world, characterised by rapid economic growth concentrated on service, information, resource efficiency and clean technology. Population rises to 9 billion by 2050, but then declines, and there is an emphasis on global solutions to environmental, economic and social security.

The A1B scenario represents a similarly integrated world to the B1 scenario, but with a ‘balanced’ emphasis on all energy sources.

The A2 scenario depicts a more divided world than The B1 and A1B scenarios, with a continuously increasing human population and slower, more fragmented technological change.

The General Circulation Model set contains the following models, with name abbreviations shown:

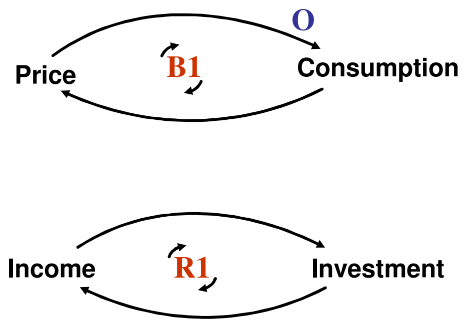
- cccma Canadian cccma_cgcm3
- cnrm French cnrm_cm3
- csiro Australian csiro_mk30
- gfd20 USA GFDL gfdl_cm20
- gfd21 USA GFDL gfdl_cm21
- mirhi Japanese miroc32_hires
- miub German/Korean miub_echog
- mpi German mpi_echam5
- mri CGCM2.3.2 Japan
- ncarc USA NCAR ncar_ccsm30
- ukhad UKMO ukmo_hadcm3
- ukgem UKMO ukmo_hadgem1
- mod12 12-model average

Appendix 2: Structure Diagrams and Behaviour Over Time

The conventions used for the structure diagrams in this study are shown below. **Causal influence** between system variables is indicated by the direction of the arrows. The influence between the originating variable and destination variable can be in the same direction, i.e. an increase or decrease in the originating variable will generally lead to a respective increase or decrease in the destination variable. Otherwise, an 'O' beside the point of an arrow is used to indicate that the influence is in the *opposite* direction, i.e. an increase in the originating variable will lead to a decrease in the destination variable. The absence of an 'O' implies a change in the destination variable in the *same* direction.

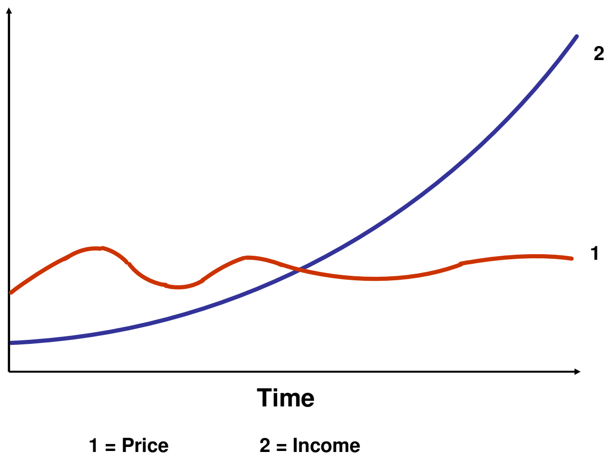
If there is a **balancing or negative feedback effect** in a loop, the loop is labeled with a 'B'. An 'R' indicates that there is a **reinforcing or positive feedback effect**. A reinforcing structure or cycle that produces a desired outcome is referred to as a **virtuous cycle**, while a structure producing an undesirable outcome is a **vicious cycle**. A virtuous cycle can easily become a vicious cycle if a variable is being pushed in the wrong direction.

Simple structure diagrams showing balancing and reinforcing feedback structures. In general, an increase in price leads to a decrease in consumption, which leads to a decrease in price, and an increase in consumption (Loop B1). Loop R1 indicates that an increase in income enables an increase in investment, thereby providing an increase in income, therefore allowing an increase in investment.



Another systems thinking tool is the **behaviour over time** (BOT) graph (below). The BOT graph is often used in conjunction with structure diagrams, and indicates the trend over time (x axis) for a variable of interest according to a performance measure on the y axis. The important elements of the BOT graph are the trend and direction of the trend, and any pattern to this trend, rather than numerical values. Therefore BOT graphs are drawn in a rough sense without exact numerical values (Maani and Cavana 2007).

Behaviour over time graph for the variables 'Price' and 'Income' above.



Appendix 3: Residential Water User Interview Summary's

All of the participants interviewed had university graduate or post-graduate level educations, and their household incomes were approximately $100,000 or more. Key characteristics of each household interviewed are summarised the table below.

		Janet	Steve and Julie	Eila and Paul
Location Moved to		**Auckland**	**Melbourne**	**Rural+ Rainwater**
Housing Tenure	Rent	**X**		
	Own		**X**	**X**
Water Billing Type	Volumetric	**X**	**X**	
	Indirect	**X**	**X**	**X**
Household Size		**4**	**2**	**4**

<u>Janet</u>

Janet is a former Wellington resident who moved to Auckland at the end of 2009. Janet is a mum, works part-time, has a post-graduate education and is renting her home. Her four person household (3 adults) has an income of approximately $100,000 dollars. Janet says that while she considers she has a strong sense of connection with water, she and her family do take water for granted. She does not recall any specific influences regarding water when she was growing up. Janet recently moved from Wellington to a semi-rural township in Auckland.

Janet's landlord receives the water bill for her residence. Water is charged at \$3.50/kL[41], with an additional 80% charged for wastewater. The water bill comes 6-monthly and the previous bill for Janet's residence was \$1000 which was 15% more than the average in Auckland for 4 people (217 L/day each, whereas Auckland's residential average is 185 L per capita/day). Janet's landlord passes on some of the cost for water used, which had been \$5 per week (\$250/year) as a component of the rent. However with the addition of the wastewater charge in 2009 the landlord had discussed passing on more of the cost of the bill to Janet, including passing on the water bill.

> *"This year [the bill] has made a huge difference and I am absolutely more conscious of the way that I use water now. I have become more conscious over the years as I became more aware of the environmental pressure from our use of water, but the increase in cost that's happened recently has made a huge difference to how I'm using water."*

Janet was shocked into action and adopted a range of measures to conserve water, such as recycling water from the sink or child's bath for watering plants, minimising clothes washing and dirtying dishes so there is less to wash, and only doing full loads, as well as minimising toilet flushing.

During the 2009/10 drought Janet's landlord asked her to water some newly planted native trees on the property, in order to get them established. Auckland suffered a drought in 2009/2010. Janet watered the trees, although some did not survive. The landlord did not pass the additional costs onto Janet from the \$1000 bill, but did put up the rent by \$15 per week to \$20 per week in total (\$1000/year) for the water component. Janet says that now that she knows that the water bill is covered in her rent she is no longer motivated to conserve water:

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[41] Different rates are charged in different areas of Auckland. Rural areas and townships pay \$3.50kl, while central areas pay \$2.00kl (Watercare 2010)

> *"The pressure I felt to conserve water has completely gone away, and my behavior is much more relaxed in terms of water conservation. Even as a 'greenie' at heart my behavior is much less conservation focused now I know that I will not be charged above what I'm already paying each week towards water, which is now $20 per week".*

<u>Steve and Julie</u>

Steve and Julie live in an apartment in Melbourne. Julie has been in Melbourne 8 years and previously lived in Dunedin and in Marlborough. Steve has lived in Wellington and in the Wairarapa and has been in Melbourne for 5 years. They are 'thirtyish dinkies'[42] with postgraduate and university graduate level educations and a household income of approximately $AU130k. The couple is acutely aware of Melbourne's water issues and the restrictions that apply to them, such as not being able to wash their car; except using "one bucket", or by going to a carwash that uses recycled water. While they are not aware of regular 'water-police' type patrols, they are aware that if they were to attempt to wash their car with a hose they would be reported by a neighbour and fined, and they would also be inclined to report indiscretions of others. The bottom four units in their building all have gardens, which can only be watered on alternate days and only in the evening. Julie says she doesn't see the occupants watering their gardens excessively, and that water conservation has become the norm *"especially in the last four years"* although she notes that as with every issue, some people just don't care. Publicity and tension about water issues are hard to miss and weather reports include updates on dam levels:

> *It's constantly in the news, they're digging a huge pipe from the river system to bring water to Melbourne, farmers are trying to stop the pipes being dug through their property; they're saying it's their water; that the*

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[42] Double Income No Kids

> *city is taking water from the farmers. The city is paying to redo the whole irrigation system because there's a huge amount lost to leakage and therefore wants some of the water that will be saved: and then they're building a desalination plant and everyone's protesting about that too".*

As the water levels in the dams have been gradually increasing, Steve and Julie have noticed that the amount of news coverage devoted to water has been decreasing, *"18 months ago there* was *something about water in every paper and on every news channel, but now we've had a bit of rain for the last four months the restrictions have gone down a level and it's not being reported as much".*

Steve and Julie receive a quarterly water bill, their building is metered and each of the eight apartments is billed directly by the water company for equal portions of the water used. For example each apartment was billed for the equivalent of 314 litres per day in the March to June quarter. The building has 17 occupants in total; therefore the occupants use an average of 148 litres per day each. Their bill is $AU150 per quarter and includes a significant service charge, as well as water and sewerage use (sewerage is based on a proportion of water used). This equates to $AU300 per year each, or $AU5.20/kL. Steve does not consider this to be a considerable amount, and while Julie considers that the bill is substantial, saving money on water is not a priority for them relative to other expenses: *"Proportionately there are other things we could do that would save a lot more money, so saving money on water would not be my top priority".*

The couple's last flat had its own meter and a water-saving initiative that they adopted then was to shower with a bucket. The bucket filled during the shower and was then used when the toilet needed flushing or they were doing a load of washing. However with the water bill now shared with 7 other units, and with a 56% service charge, they see less incentive to take extra steps to save water. Steve and Julie have short showers: *"four minutes is supposed to be the aim for everyone, but all the water companies gave out 2 minute shower timers to stick to the side of your shower"*. Other than when they were catching water with a bucket in the shower, Julie considers that there is probably not anything different that she does now due to her water conscious upbringing:

> *"My mum's just very conservative about everything, she always shouted on at us for having long showers, even though we were in New Zealand and I don't remember there being any droughts… But it is a big deal, and certainly if you have a garden, because you can only water between midnight and 5am so you would have to buy timers and set them up and have a sprinkling system. Also if you have a swimming pool you're not allowed to fill it off mains water, so people use rainwater and put covers on… I'm always joking that if they run out of water I'm going home [to New Zealand].*

Likewise Steve considers that living in Melbourne doesn't push him too far outside his parameters of experience. Steve's water consciousness stems from direct experiences of shortages growing up in rural Wairarapa where the well sometimes ran dry, or the waterpump broke down:

> *We had short showers because there were heaps of kids and there was not enough hot water. I've always been water conscious, though I imagine I had longer showers when I was in Wellington than I do here. But you feel like you have a moral obligation in Melbourne; so I have become even more conscious, and when we bought a new washing machine I got one that uses only 15 litres per cycle.*

Eila and Paul

Eila grew up in Pakistan and has lived in England and in Wellington City. Eila and her husband Paul are in their forties with two teenage daughters. Their home in rural Wellington is dependent on rainwater and they have 50,000 litres of storage. Eila and Paul have postgraduate and university graduate level educations and their household income is approximately $100k. Eila was strongly conditioned to use water carefully as a child due to her experiences of water as a scarce resource.

> *…where I grew up you either had to go outside to a tap in the street somewhere with a bucket, or get water delivered. A boy would come to our house with a calf-skin filled with water, and tip it into a concrete tank in our bathroom; he'd do several trips to fill it up from a tap out in the street.*

Growing up in the UK, Paul's water culture was quite the opposite to Eila's and looking back he sees many of the habits and behaviours he was once accustomed to as wasteful. "*When you wash your hands, 99% of the water goes straight past and doesn't touch them, so you can do things like turn the tap on less. It's the mechanical scrubbing that actually does the cleaning, and you only need a gentle flow of water".* Paul's transition to becoming very water conscious began after he met Eila. They did not have water meters, and were only occasionally subjected to water restrictions. If there was an exceptionally dry summer, "*there would be hosing restrictions and you wouldn't be allowed to wash your car. It wasn't a big deal. There wasn't much difference coming to Wellington, except we had a newer house with dual-flush toilets."*

Paul says that as a family their water use is now much less than when he was growing up. Eila's childhood conditioning to use water very carefully has strongly influenced the way the family views and uses water and they notice when the habits and behaviours of other people contrast with their own.

> *The guy next door used to go out and wash his car every morning before he went to work, it was black and sleek so I guess it needed to stay shiny. Supposedly there were water restrictions on, and if you were [in an] odd numbered house you are supposed to use your hose only on odd numbered days, but I don't think anyone actually does it.*

> Daughter - *When I go to school I get annoyed when I see people turn the water on full blast to wash the paint out – it's like, there's a brush right there, turn the water down and use it! I'm reaching over everyone to turn their taps down.*

Eila and Paul also consider that water is tied to the level of development, *"When we came to Wellington, we thought it odd that there seemed to be a problem with water, since New Zealand is a developed country"*. However Eila's experiences and the resulting water use culture that she has passed onto her family has helped the family to learn to live within the constraints of being dependent on rainwater.

> *In Thorndon we had free-flowing water whenever we needed it, but coming here, everyone had to learn to conserve it. I put labels everywhere, notices, especially for when we have guests stay over. If I make enough fuss about it hopefully they will realise that we have a problem with water.*

The family has a range of water efficient devices including dual flush toilets, efficient showerheads and tap aerators and are *"constantly conscious"* with their water use. *"When we have a shower, we wet ourselves, turn off the shower, soap, and then turn on the shower to wash the soap off… We don't* *wash our car, it just gets to the point where the dirt on and dirt off balances out. If anything the rain washes the dirt off.* Eila also shifts her water use to her workplace in Wellington, "*I go to the gym at work and have showers there, so that saves me five or six showers at home – but the water's coming from somewhere, so even at work I'm careful*".

Appendix 4: Workshop Participants

Local Government and Water Management
Murray McLea – GW (Initial workshop only)
David Lee – GW
Tony Shaw – GW (Follow-up only)
Cr Paul Bruce – GW (Follow-up only)
Cr Ngaire Best – WCC, Three Waters Portfolio Leader (Initial workshop only)
Cr Max Shierlaw – HCC, Hutt River Advisory Committee (Initial workshop only)
Ben Thompson – KCDC (Initial workshop only)
Phillip Stroud – KCDC (Follow-up only)
Paul Glennie – Capacity

Regional Public Health
Jill McKenzie Medical Officer of Health (Initial workshop only)
Chris Edmonds – Health Protection Officer

Environment Sector
Kris Ericksen – Department of Conservation (Initial workshop only)
Corina Jordan – Fish and Game (Initial workshop only)
Pat Van Berkel – Friends of the Hutt River

Community and NGO
Seth Hickling – Sustainability Trust
Joe Bucannan – Right to Water (Initial workshop only)
Frank Cook – Community Water Advocate
Nicholas Flaws – Student (Initial workshop only)

Research Sector
Andrew Tait – NIWA (Initial workshop only)
Robyn Moore – Water Researcher
Shabana Khan – CCRI
Martin Payne – Massey University Master's Student (Follow-up only)

Appendix 5: Issues and Factors from Workshop

Overarching Themes - Mauri and Sustainability				
	Variable used for Model	**Theme (grey hexagons)**	**Strongly held (orange hexagons)**	**General (yellow hexagons)**
1	Cultural River Health	**Values**	Conservation Estate	Consumption; consumer orientation vs community orientation
2	Recreational User Satisfaction		Enjoyment of our rivers – swim, fish, picnic, look, walk dog	Skepticism of climate change
3	Angler Days		Non-market	Private ownership
4	Individualism		Provision for recreational values of water in its natural state (in river)	Devine providence
5			Community (business and households) identification with water resource and issues/challenges	Treaty of Waitangi
6			Cultural values of water resource	Mauri, intrinsic values of water
7			Inequity is damaging for society	
8			Individualism vs society	
9			Whole of life cost of water	
10	Hydrological Flow	**Ecological Integrity**	Protection of ecological integrity of natural waters	Recreational Fisheries
11	Biodiversity		Earth is finite – there are limits to our land and water resources (water as a limited resource)	Ability of environment to pay (or vote)
12	Breaches of Consent		Maintenance of instream natural flow regime (Hydrological Variability)	Wader bird (indicator species)

13	River Water Quality			Native fish (strongly held? E.g. taonga - tangata whenua)
14				Habitat
15	Potable Water Quality	**Public Health**	Protect catchment quality, e.g. Wainuomata, Kaitoke, Hutt Aquifer	Fluoride debate
16	Compliance with Standards		Toxic algal bloom	Equitable access to potable water – especially smaller communities
17	Toxic Algal Blooms			Maintain drinking water standards compliance
18				Cost of future drinking water standards compliance
19				Assess health impact of water management decisions
20				Health issues
21				Quality of water
22				Heavy metals
23				Acceptable level of risk vs. compliance costs e.g. of regulatory standards
24	Supply Security	**Activity Management**	Non revenue water	Level of service
25	Level of Metering		Targeted monitoring investment (incl. meters)	Green plumbers
26	Modular Storage		Supply management	Keeping infrastructure well maintained (leaks)
27	Proportion of Valley Storage		Demand management	Transparency and efficiency in system processes of network (incl. decision making)
28	Bulk Storage			Transparent statistics communicated timely

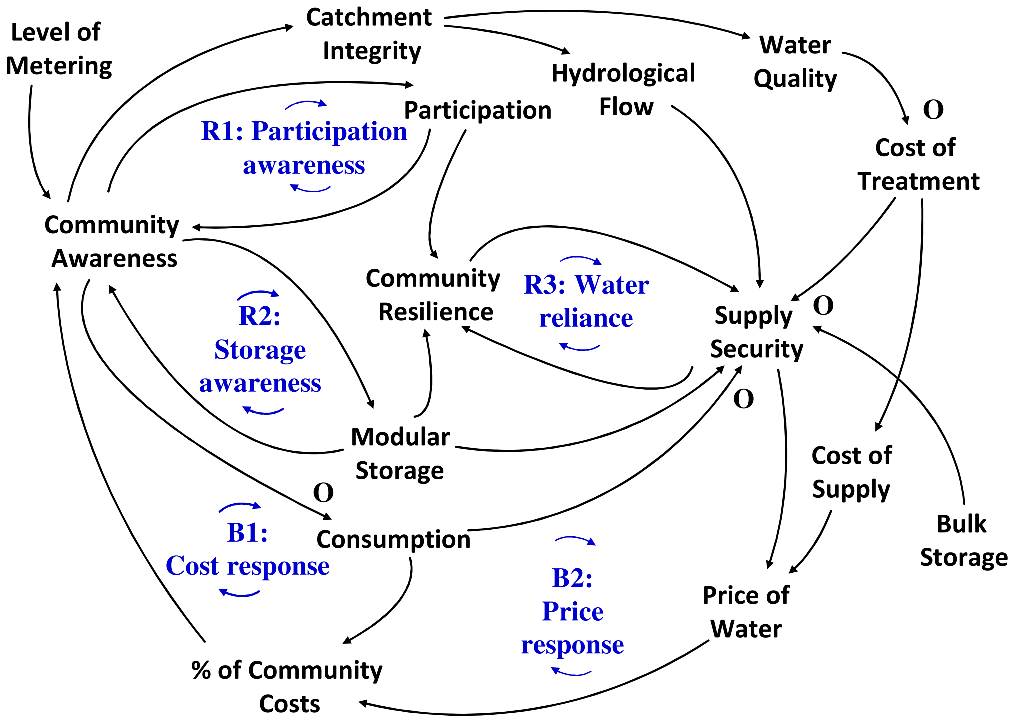
				with communities
29	Supply Security			Reliable data for good decision making (incl. from meters)
30	Rainfall			Fire fighting water supplies
31	Abstraction			Leakage (real/percieved)
32	Level of Restrictions			
33	Supply			
34	Demand			
35	Connections with Alternate suppilies			
36	Consumption			
37	% Business consumption			
38	Non Revenue Water			
39	Targeted Conservation Expenditure			
40	% in Public ownership	**Empowered Communities (incl. businesses)**	Community has empowered understanding of role of water management	Process of informing, engaging and empowering communities
41	Community Satisfaction		Democratic control of our resources	Engaged community
42	Community Awareness		Who manages water demand (Who not who?)	Community apathy
43	Participation (inclusion, interaction, engagement)		Targeted education on water conservation – businesses too (put in CLD as education)	Lifestyle choices
44	Monitoring		Clear goal, shared by community – healthy water, meet reasonable needs and expectations	Waste of water

			now and in the future	
45	Reporting			Community expectations
46				Understanding of costs (in widest sense incl non-market) vs risks vs benefits
47				Disregard of 'cheap' water resource
48				Individual behaviour
49				Public ownership of infrastructure assets
50				Water audit by large users
51				Trust in water provider
52				Expand 'water guy' role – Porirua example
53				Public participation in water conservation
54				Display water use of major water users
55	Speed of Recovery	**Vulnerability**	Learn how to save water from extreme flooding	Infrastructure security to natural events – resilience
56	Community Resilience		Infrastructure security to natural events – resilience	Learn how to save water from extreme flooding
57	Interaction with neighbours		Too much reliance on Hutt River for supply	Multiple pressures on water supply and demand (now and in the future)
58			for civil defence	Existing infrastructure (historical 'accidents') – legacy effects
59			Act for post earthquake response and recovery – accessible rainwater tanks in communities for civil defence	Earthquakes/extreme events
60				Modular systems for resilience
61				Danger – implications of saltwater intrusion

				into Hutt aquifer
62	Price of Water	**Economic Value** (broad sense)	How community pays for water infrastructure	Cost of treating discharge of clean water
63	Cost of Supply		Profit seeking	Ageing population and ability to pay
64	Cost as % of Household Income		The value of water	Inequity – i.e. in a non-metered system
65			(no) universal metering (none in present system, plus undesired)	Pareto optimality
66			The price of water?	Cost of water
67				Water as a commodity
68				How we pay for water e.g. rates or metering
69	Planning Horizon	**Planning**	Working as one (region)	Local Government Act
70	Number of Dammed Valleys		Prosperity without growth	Political process
71	Population		Gradual destruction of valleys for water supply dams	Region specific focus
72			Demonstration projects – case studies (social/technological learning)	Tragedy of the commons (lack of signals, structures and norms to ensure continued integrity of resource)
73			Start with the best water (then compliance/treatment costs reduced)	Population growth through high density housing
74			Adapting to climate change impacts is not hard – integration is key	Urban form
75			Avoid dams	Limits to growth
76			The regional council hasn't planned properly for growth	Supply augmentation (Bulk)
77			Low impact urban design	Water sensitive design investment
78			Social needs should be met by political organisations (Public ownership and	Population limits

			provision of public goods and services e.g. education)	

Key feedbacks and structures as identified within the shared mental model from the second workshop session.



Appendix 7: VUW Ethics Committee Approvals

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

MEMORANDUM

Phone 0-4-463 5676
Fax 0-4-463 5209
Email Allison.kirkman@vuw.ac.nz

TO	Nigel Taptiklis
COPY TO	Ralph Chapman and Andy Reisinger
FROM	Dr Allison Kirkman, Convener, Human Ethics Committee

DATE	08 October 2010
PAGES	1

SUBJECT	**Ethics Approval: No 17691 Urban Water Management and Climate change Adaption: Socio-Economic Impacts and Responses**

Thank you for your applications for ethical approval, which have now been considered by the Standing Committee of the Human Ethics Committee.

Your applications have been approved from the above date and this approval continues until 28 February 2011. If your data collection is not completed by this date you should apply to the Human Ethics Committee for an extension to this approval.

Best wishes with the research.

Allison Kirkman
Convener

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

Phone 0-4-463 5676
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MEMORANDUM

TO	Nigel Taptiklis
COPY TO	Ralph Chapman
FROM	Dr Allison Kirkman, Convener, Human Ethics Committee
DATE	10 January 2011
PAGES	1
SUBJECT	**Ethics Approval: No 18191 Water Resilience or Water Security? Climate change Adaptation and Reticulated Water Management in Wellington New Zealand**

Thank you for your application for ethical approval, which have now been considered by the Standing Committee of the Human Ethics Committee.

Your application has been approved from the above date and this approval continues until 31 March 2011. If your data collection is not completed by this date you should apply to the Human Ethics Committee for an extension to this approval.

Best wishes with the research.

Allison Kirkman
Human Ethics Committee