New Zealand Climate Change Research Institute
Te Pūtahi Hurihanga Taiao

Climate resilient water management in Wellington, New Zealand

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List of acronyms

ASP	Annual shortfall probability
BOT	Behaviour over time
CLD	Causal loop diagram
CO_2	Carbon dioxide
CPR	Common property resource
GWRC	Greater Wellington Regional Council
GWW	Greater Wellington Water
HCC	Hutt City Council
IPCC	Intergovernmental Panel on Climate Change
ML	Million litres
NGO	Non-governmental organisation
PAW	Potentially available water
PCC	Porirua City Council
PCD	Per capita demand
PCE	Parliamentary Commission for the Environment
RMA	Resource Management Act 1991
SYM	Sustainable yield model
TSD	Total system demand
WCC	Wellington City Council

Executive summary

A confluence of factors, including population growth and climate change, poses significant challenges to the sustainability of cities worldwide. In addition, climate change adaptation is now a necessity since past and present carbon dioxide (CO_2) emissions represent a commitment to further warming for the next few decades (Jones 2010, IPCC 2007b).

Research purpose

This report sets out the findings of the Wellington case study on urban water supply management, which is one of three case studies that form Objective 2 of the collaborative, interdisciplinary research project on Community Vulnerability, Resilience and Adaptation to the impacts of climate change. The project is led by Victoria University and funded by the Foundation for Research, Science and Technology (FRST)[1].

This case study focuses on water supply management for the four cities of Wellington, Porirua, Lower Hutt, and Upper Hutt, which are serviced by the one reticulated network. The aim of this research is to gain a detailed understanding of the factors influencing water use and management in Wellington, and how specific response options could affect future community and institutional adaptive capacity, and increase or decrease resilience to water shortages.

This case study into climate change adaptation and urban water management used systems-thinking, resilience, and complex systems science approaches. Such an approach is indicated when water management is seen as a complex, multi-dimensional system challenge. For example, water management requires decisions on long-term infrastructure projects that are highly dependent on human behaviour and actions (past and future), environmental parameters, and on long-term climate change. These interacting human, physical, and biological factors can be seen as components of a coupled socio-ecological system[2]. Decision makers involved in such issues can expect to encounter a plurality of objectives, politics, and legacies where *'the facts are uncertain, values in dispute, stakes high and decisions urgent'* (Funtowicz and Ravetz 1991).

[1] FRST was merged in February 2011 with the Ministry of Research, Science and Technology (MoRST) to form the Ministry of Science and Innovation (MSI), which is responsible for the policy and investment functions of both those agencies.

[2] A socio-ecological systems view sees human communities and ecological systems as coupled, integrated systems—i.e. human societies are a part of the biosphere and are embedded within ecological systems (Folke et al. 2002).

Research questions

This case study was structured around the following research question.

What factors might lead Wellington as a community to a pathway of greater adaptive capacity and resilience, and what vulnerabilities might lead to insufficient adaptation or even maladaptation[3]?

This question was broken down into the following parts.

1. How might climate change trends interact with water supply-and-demand factors to create water security and management issues for Wellington?
2. What are the implications of primary response pathways and options (including governance and management approaches) for community resilience and adaptive capacity?
3. How might Wellington as a community adapt to water shocks or constraints, and what might impede or facilitate adaptation?

Research findings

Wellington's present water supply capacity is sufficient to meet increased demand due to population growth and climate change in all but the driest years to 2090

Climate change and water-demand scenarios for 2040 and 2090 were generated using Greater Wellington Regional Council's (GWRC) 'sustainable yield' model (SYM) and downscaled climate model data. This data was used to provide a general understanding of trends and dynamics over time, by looking at interacting supply and demand drivers. A general analysis indicates that, with a 20 percent reduction in per capita demand and additional storage, Wellington's present supply capacity is sufficient to meet increased demand due to climate change and population growth, and cope with decreased supply due to climate change in all but the driest years to 2090.

An approach focused primarily on supply management could increase vulnerability to water shortages

Dry conditions concurrently decrease supply and increase demand for water, and climate change is projected to bring increasing frequency and severity of drought to some regions of New Zealand (Hennessy et al. 2007, IPCC 2007b). As dry conditions become more frequent and severe, the risk of water shortages is exacerbated, which also increases the storage and supply capacity requirements for the water system. However, local-level climate projections under-represent climate variability, due to averaging within climate models. This then flows onto probability-based calculations for system capacity requirements which will also underestimate variability and extremes. Moreover, since it is not possible to rule out a water shortage for a coming summer, and since responding to a drought requires demand-management measures be actioned as early as possible, management approaches that encourage sensible (moderated) summer water use are needed *every* summer. Meanwhile, an approach that is primarily focused on supply management could increase vulnerability to water shortages.

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[3] 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.

Wellington's water intensity is declining, in spite of a lack of incentives and signals

Resilience and response option selection, semi-structured interviews, and a systems modelling workshop were conducted to gain an understanding of the local context for adaptation. Despite a lack of incentives and signals, Wellington's water intensity is currently in decline. There is also considerable potential to further reduce Wellington's water intensity, with potentially large inefficiencies in Wellington's metered CBD, and the general absence of residential water metering. Standards, regulation, and financial and environmental concerns drive water conservation efforts at the local government level, while political dynamics and a perceived low priority for water conservation can act as barriers.

A pilot project could facilitate community collaboration and participation in water management

Analysis of workshops, interviews and literature indicates that enhancing community adaptive capacity to increase resilience to water shortages requires social learning, a process that can be facilitated through participative and collaborative involvement in water management. Designing a pilot project to facilitate community collaboration and participation in water management is recommended to initiate cross-scale experimentation, learning, and adaptation—from end users to water managers and government decision makers.

1. Introduction and overview

1.1. Background

Adapting to a changing climate is a necessity since past and present anthropogenic greenhouse gas emissions represent a commitment to further warming for the next few decades (Jones 2010, IPCC 2007b). In some regions of New Zealand, particularly northern and eastern areas, the frequency and severity of droughts is projected to increase over time due to climate change (Hennessy et al. 2007, IPCC 2007b). Dry conditions affect both supply and demand for water. In general, increased frequency and severity of drought will increase the overall variability of water supply and demand that must be 'managed', in particular the risk of water shortages.

The Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007b, p.19) highlight that 'effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints'. In addition, climate change adaptation measures are generally not undertaken in response to climate change alone, but '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). From a systems perspective, climate change adaptation can be seen as part of an interconnected system of social, economic, and physical system components, each changing over time in response to internal and external drivers.

In a complex interconnected system, the decisions communities make will be dependent on current and previous events and decisions, present and projected trends, and on existing structures and approaches. Such decisions will have wider social, economic, cultural, and ecological implications, including for a community's own resilience and sustainability.

1.2. Research purpose

This report sets out the findings of the Wellington case study on urban water supply management, which is one of three case studies that form Objective 2 of the collaborative, interdisciplinary research project on Community Vulnerability, Resilience and Adaptation to the impacts of climate change. The project is led by Victoria University and funded by the Foundation for Research, Science and Technology (FRST)[4].

This case study focuses on water supply management for the four cities of Wellington, Porirua, Lower Hutt, and Upper Hutt, which are serviced by the one reticulated network. The aim of this research is to gain a detailed understanding of the factors influencing water use and management in Wellington, and how specific response options could affect future community and institutional adaptive capacity, and increase or decrease resilience to water shortages.

[4] FRST was merged in February 2011 with the Ministry of Research, Science and Technology (MoRST) to form the Ministry of Science and Innovation (MSI), which is responsible for the policy and investment functions of both those agencies.

1.3. Research questions

This case study was structured around the following research question.

What factors might lead Wellington as a community to a pathway of greater adaptive capacity and resilience, and what vulnerabilities might lead to insufficient adaptation or even maladaptation?

This question was broken down into the following parts.

1. How might climate change trends interact with water supply-and-demand factors to create water security and management issues for Wellington?
2. What are the implications of primary response pathways and options (including governance and management approaches) for community resilience and adaptive capacity?
3. How might Wellington as a community adapt to water shocks or constraints, and what might impede or facilitate adaptation?

1.4. Research framework

A resilience / systems perspective was used as a research framework to provide insights on shifting policy responses away from the present control-orientated approaches that presume a stable system state, to *'managing the capacity of social-ecological systems*[5] *to cope with, adapt to, and shape change'* (Folke et al. 2002, p.4).

1.4.1. Resilience

Resilience is the ability of a system to absorb disturbances while retaining the same basic structure, ways of functioning, and self-organisation (IPCC 2007). Key aspects of resilience are diversity, modularity (division and separation of system components), and redundancy (overlapping functions) (Walker 2009).

1.4.2. Vulnerability

Identifying vulnerability, through the use of resilience principles, provides an efficient framework for assessing resilience, i.e. by asking in which parts of the system is there little or no diversity, modularity, or redundancy (Walker 2009).

Vulnerability can be viewed through a framework consisting of exposure, sensitivity, and adaptive capacity (Adger 2006). The following schematic illustrates how these components can be related (Fig. 1). In this schematic, policy interventions aiming to reduce vulnerability (to increase resilience) can either reduce exposure or sensitivity or increase adaptive capacity. Vulnerability is defined by the IPCC (IPCC, 2007) 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,

[5] A socio-ecological systems view sees human communities and ecological systems as coupled, integrated systems; i.e. human societies are a part of the biosphere, and are embedded within ecological systems (Folke et al. 2002).

magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.'

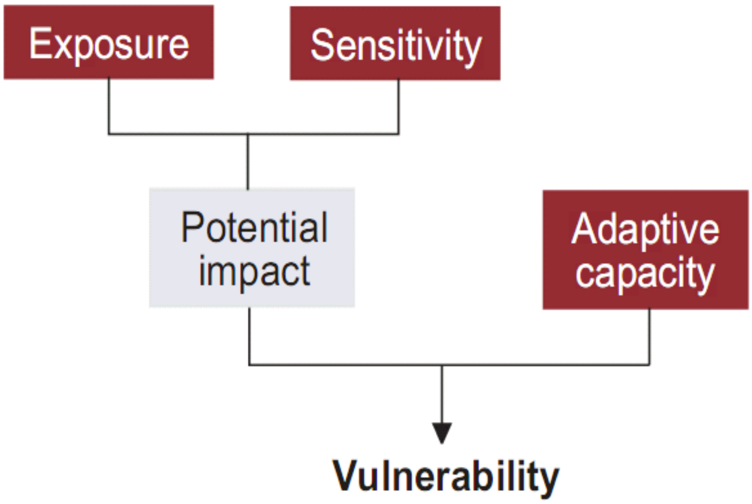

Figure 1. Vulnerability and its components (Allen Consulting Group 2005)

1.4.3. Adaptive capacity

Adaptive capacity describes the ability of a system to adapt to climate change 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). Adaptability in a socio-ecological system is the capacity of actors in that system to manage resilience (Walker et al. 2004).

Holling (1996, 1973) makes a distinction between a traditional view of resilience and a more dynamic approach. Holling characterises the traditional view as engineering resilience, a property measurable by the system's resistance to disturbance and its speed of return to equilibrium (return time). By contrast, Holling's second definition of ecological resilience is a more dynamic concept, *'where the natural state of the system is one of change rather than of equilibrium'* (Nelson et al. 2007, p.398), and where multiple stable states are possible. From this perspective, return time is an insufficient measure of resilience since there are many other ways for a system to fail, other than fail to return to its previous state or to retain previous functions (Walker et al. 2004).

1.4.4. Transformability

For a socio-ecological system, a dynamic view of resilience also acknowledges that a community requires the flexibility to transform itself (Walker et al. 2004), for example, to avoid becoming locked into an undesirable pathway. Transformability is *'the capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable'* (Walker et al. 2004). A narrow view of resilience can be detrimental, for example increasing the resilience of a particular part of a system to specific disturbances can reduce overall resilience (Folke et al. 2010).

2. Water management: A multi-dimensional system challenge

Water management requires decisions on long-term infrastructure projects which are highly dependent on human behaviour and actions (past and future), and on long-term climate change. Moreover, a confluence of interacting factors including population growth, climate change, resource constraints, and legacy effects now present water managers with greater complexity and uncertainty for planning and decision making. These interacting human, physical, and biological factors can be seen as components of a coupled socio-ecological system, in which water management becomes a complex, multi-dimensional system challenge.

2.1. Post-normal science and systems thinking

This case study uses the concepts outlined in Section 1.4, in conjunction with post-normal science and systems-thinking approaches. A post-normal science approach is indicated where both decision stakes and system uncertainties are high (Fig. 2), while the use of systems thinking acknowledges the complexity and interconnectedness of human and natural resource systems.

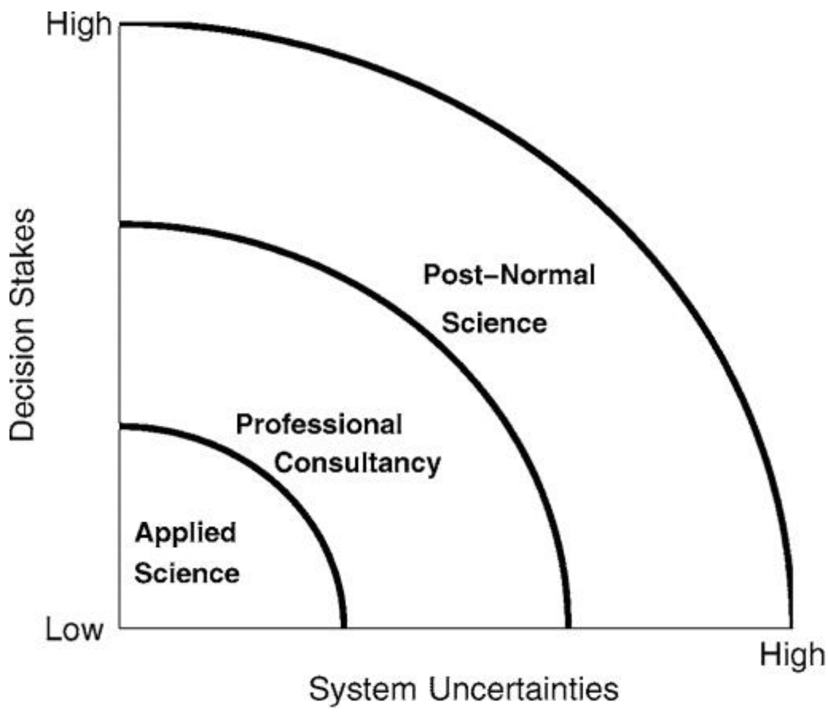

Figure 2. The 'post-normal science diagram' showing three types of problem-solving strategies (Ravetz 2006, Funtowicz and Ravetz, 1993).

System uncertainties in relation to water management and climate change in Wellington include the effects of sea-level rise on the Waiwhetu Aquifer (Ibbitt and Mullan 2007), the interplay of water consumption and population trends (e.g. Fig. 27), the rate and magnitude of climate change, and the resulting impacts at a local level (Jones 2010). Decision stakes become particularly high during and in response to a water shortage, and in complex systems the full implications of such decisions are unknowable (Rittel and Webber 1973). Decision makers involved in such issues can expect to encounter a plurality of objectives, politics, and legacies, where '*the facts are uncertain, values in* *dispute, stakes high and decisions urgent'* (Funtowicz and Ravetz 1991). Such issues are also characterised as 'wicked' problems (Rittel and Webber 1973).

A primary element of a post-normal science inquiry is the full involvement of an 'extended peer community' consisting of stakeholders representing 'multiple legitimate perspectives' (Ravetz 2006, Saloranta 2001). The extended peer community 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).

'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).

Where post-normal science seeks to strengthen decision making by incorporating an extended peer community, getting a diverse group of stakeholders to sufficiently consider other legitimate perspectives and mental models is a significant challenge. Significant progress was made by stakeholders in this regard through the Land and Water Forum. A diverse group of stakeholders participated in the forum, and collaborated to produce a report and recommendations to advise water management in New Zealand (http://www.landandwater.org.nz).

2.2. Wellington's water management context

2.2.1. Water sources

Greater Wellington Water (GWW) treat and distribute 'bulk' water to Upper and Lower Hutt, Porirua, and Wellington cities (Fig. 3). Water is sourced from Waiwhetu Aquifer and the Hutt, Orongorongo, and Wainuiomata Rivers. On average, 40 percent of Wellington's water comes from the aquifer and 60 percent from rivers (MWH 2011). The 3000 ML Stuart Macaskill water storage lakes[6] at Te Marua provide a few weeks of summer storage (MWH 2011) and the Waiwhetu Aquifer[7] 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).

2.2.2. Management

Under the Resource Management Act 1991 (RMA), regional authorities such as GWRC 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 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).

[6] The storage capacity of the Stuart Macaskill Lakes will be 3390 ML once current upgrades are complete (Shaw and McCarthy 2009).

[7] Abstraction occurs at Waterloo and Gear Island, ranging from 20–120 ML / day, and averaging 60 ML / day (GW 2008c).

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 GWRC deliver to Wellington, Hutt, and Upper Hutt city councils. Porirua City Council manages its own water retailing and infrastructure. 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).

'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).

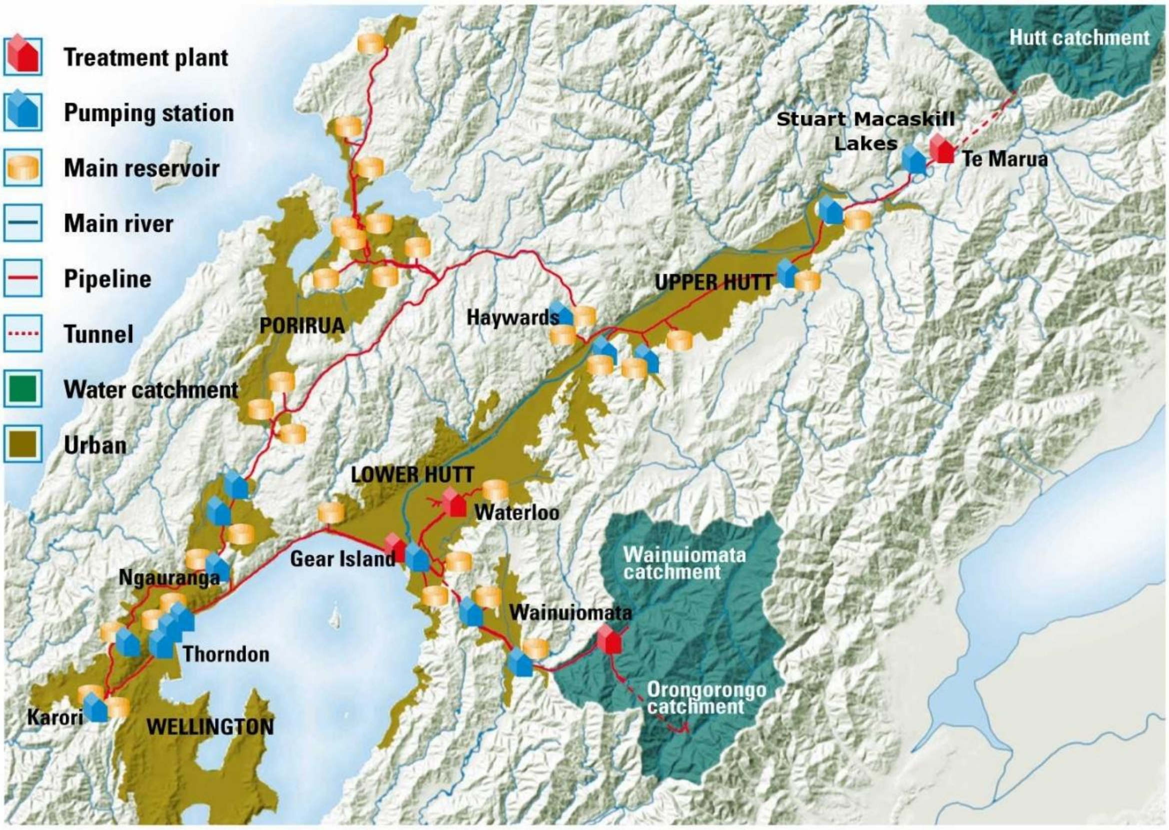

Figure 3. Greater Wellington Regional Council water supply network (GW 2010).

GWW aims to meet a 2 percent '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)[8].

As seen in Figure 4, overall the demand for water has been less than population growth since the early 1990s. This has been due to factors such as the decline in manufacturing in Wellington since

[8] Calculations in 2009 put the standard at 3.9 percent (i.e. a shortage every 26 years on average) (GW 2010). However, further refinements to the SYM model allowing a greater resolution of analysis indicate that GWW currently meets its 2 percent standard (WCC 2011).

the 1980s, urban intensification, infrastructure renewal, and increased public awareness of the need for water conservation (Williams and McCarthy 2010, pers comm.).

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 percent) of the water, Lower Hutt (25.3 percent), Porirua (11.7 percent) and Upper Hutt (9.2 percent) (GW 2010). Most commercial and industrial consumers are metered, though only 1 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.

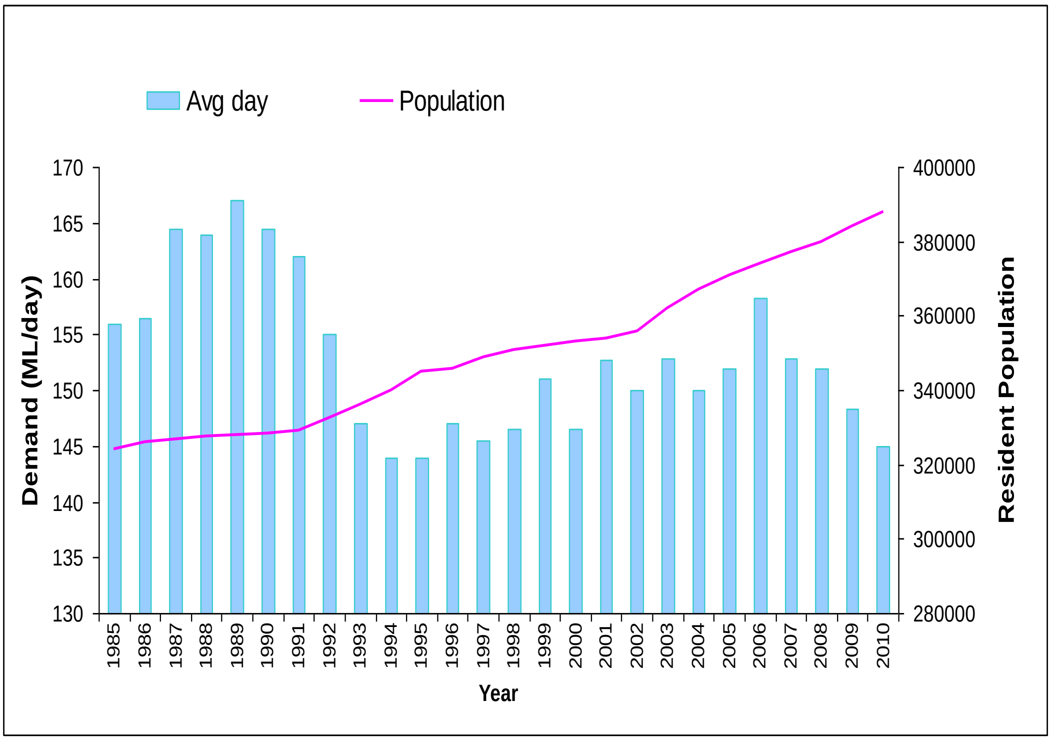

Figure 4. **Average daily demand (Avg day) and resident population (serviced by water reticulation network) for Wellington 1985 to 2010 (Graph updated from GW 2008).**

3. Climate change and water supply and demand drivers

Under the RMA, agencies such as GWRC are required to have particular regard to the effects of climate change. When considering long-term infrastructure projects this has particular salience. For example, rainfall to Melbourne's water supply catchments decreased by about 19 percent in 1997–2008 compared to 1950–1997, reducing dam inflows by about 40 percent (Jones 2010, p.16). Regional-scale analysis may indicate the potential for such shifts in operating conditions, which can then be taken into account when comparing adaptation options and pathways.

This section addresses the first part of the research question by using:

- scenarios and projections based on water use in Wellington
- climate and hydrological modelling.

3.1. Methodology

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. 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 historic climate and water demand data for the four city councils supplied by GWW. NIWA input files were produced for each of three IPCC emissions scenarios (B1, A1B, A2) for '2040' (averaged over the 2030 to 2049 period[9]) and '2090' (averaged over the 2080 to 2099 period).

The NIWA input files for the 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. A 'low-carbon', 2°C stabilisation scenario was also used to produce input files for the SYM. This scenario was used for 2090 only as the scenarios do not differ significantly in 2040 (Fig. 5). Further background on using this model and scenario set for New Zealand is available in Reisinger et al. (2010).

For this analysis, 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. Data for PAW, total system demand (TSD) and PCD were received as SYM outputs from GWW. In addition 'net-flow' was calculated by subtracting TSD from PAW. PAW represents daily abstractable volume in ML from Te Marua, Waterloo, and Wainuiomata water treatment plants combined with existing

[9] This 20-year averaging removes *'much but not all'* of the natural variability as represented by the models (Resinger et al. 2010).

consent limits and treatment plant capacities. 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. The relationship between PCD, PAW, net-flow, and TSD is shown in Figure 6.

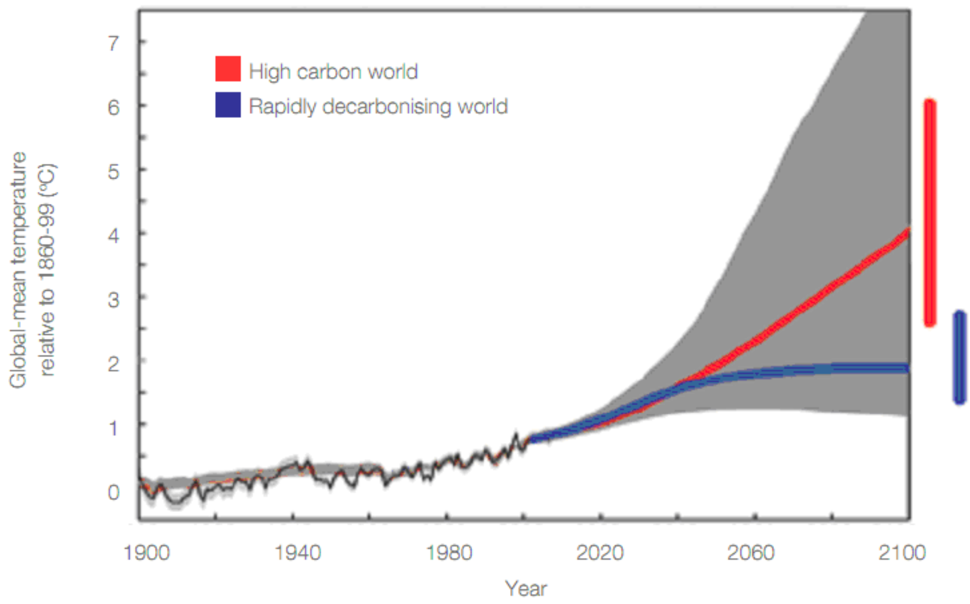

Figure 5. Global average temperature increase relative to pre-industrial times for the A2 'high-carbon world' and the low-carbon 'Rapidly decarbonising world' scenarios (relative to 1860–1899). The vertical bars to the right indicate the likely range (66% probability) for each scenario during 2090–2099 (Reisinger et al. 2010). The grey area shows the range of temperatures simulated for the twentieth and twenty-first centuries, indicating that due to uncertainties in the climate system, the 'high-carbon' scenario is not an 'upper end'.

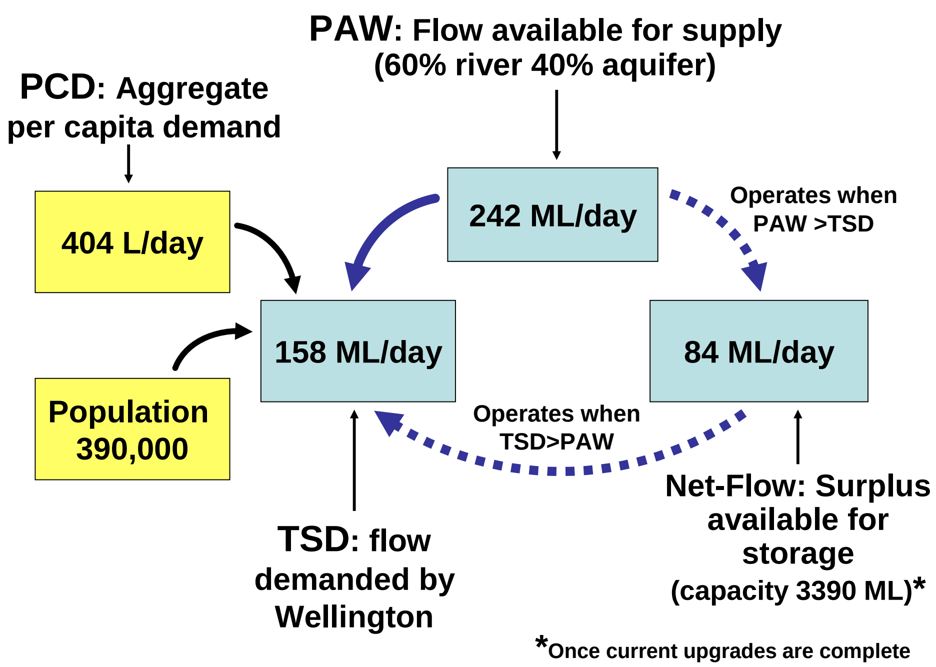

Figure 6. Relationships between PCD, PAW, TSD, and net-flow with their respective daily average current values (data from 2009 / 2010, PCD based on 5-year average).

3.1.1. Scenario and model selection

The projected climate parameters for the SYM input files are averaged over a 20-year period. This averaging is necessary 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 this variability is a significant consideration at the local scale (Jones 2010). Not surprisingly, the most likely failing of local-level analysis is that it under-represents climate variability (Jones 2010). However, many of the impacts of climate change are the result of the 'surprises' that come with extreme weather (Climate Commission 2011) as this is where most of the damage to communities and assets occurs.

Current trends show IPCC projections to be conservative

Current trends show IPCC projections to be conservative since many variables are tracking at or above the level of the 'high' IPCC projections (Jones 2010). Moreover, past and present emissions represent a commitment to further warming for the next few decades, yet sufficient mitigation policy commitments are still lacking, and if / when they arrive will take further time to implement and have an effect (Jones 2010). Therefore, in selecting specific models and scenarios for analysis for this case study, a key principle was that prudent adaptation planning needs to take high projections into account.

Specific details on the approach taken to the selection of projections from the model set, combined with the supply and demand scenarios used in this case study, is available in NIWA's urban impacts toolbox[10], along with a detailed discussion on the limitations and uncertainties.

3.2. Results

3.2.1. Potential impacts: Scenario analysis

The seasonal variation of supply and demand can clearly be seen in Figures 7, 8, and 9; demand is greatest in summer when supply is most restricted. Whilst there is sufficient water to meet projected demand under average summer conditions, substantial overlap occurs during January, February, and March at just one standard deviation (Fig. 7).

By 2040, climate change could decrease PAW by 5 percent or 12 ML per day on average for January and February (Fig. 8). The 12 ML difference is the gap between 'current' and the 2040 scenarios for 'Jan / Feb'.

The projected decrease in PAW between 2040 and 2090 is 5.5 percent, and the projected increase in PCD from 2010 to 2090 due to climate change is 3 percent (Fig. 9), with a corresponding population of 467,500 based on current trends. 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-

[10] See Tool 2.5.3 SYM approach to present-day and future potable water supply and demand.

flow), or an average daily shortfall of an equivalent volume of water sufficient to supply 35,000 people.

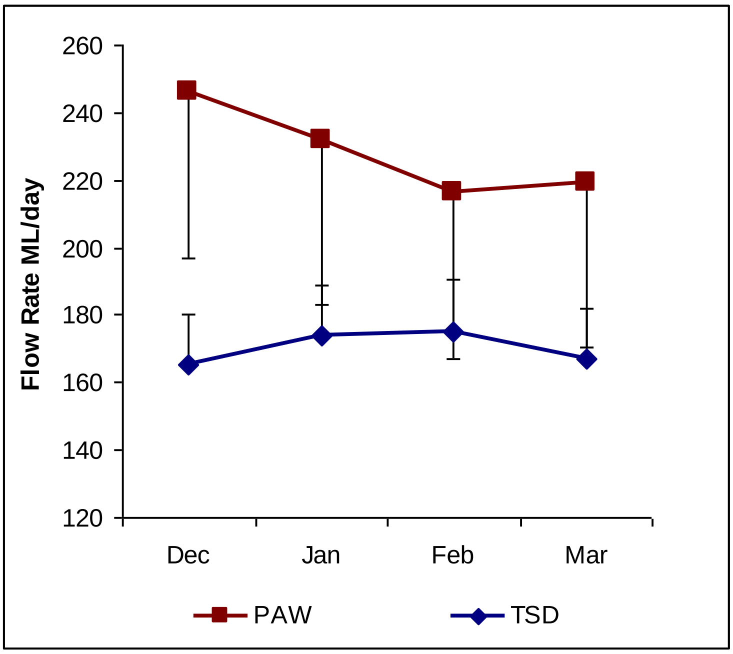

Figure 7. **Average daily supply (PAW) -1 standard deviation, and average daily demand (TSD) + 1 standard deviation in ML / day, from December to March under present climate variability.**

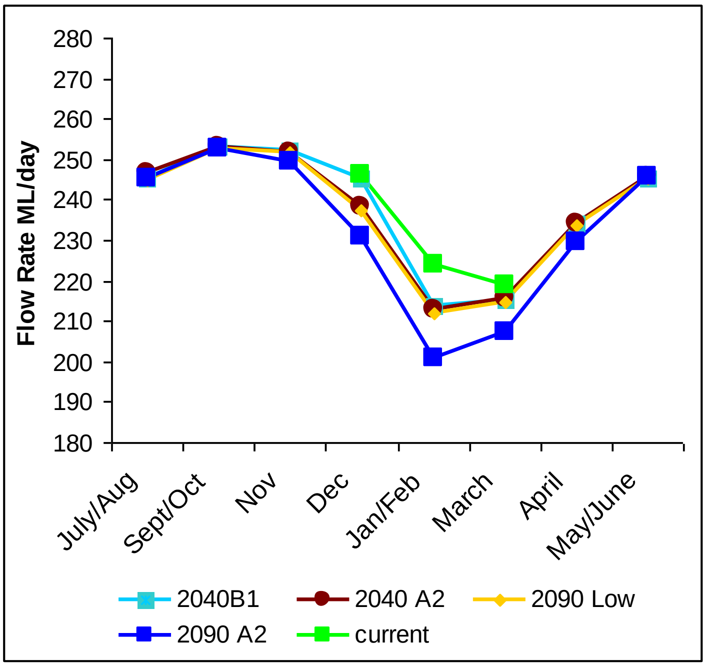

Figure 8. **Average daily supply (PAW) 2040 and 2090 by month and IPCC A2, B1 and low-carbon scenarios (Mod 12).**

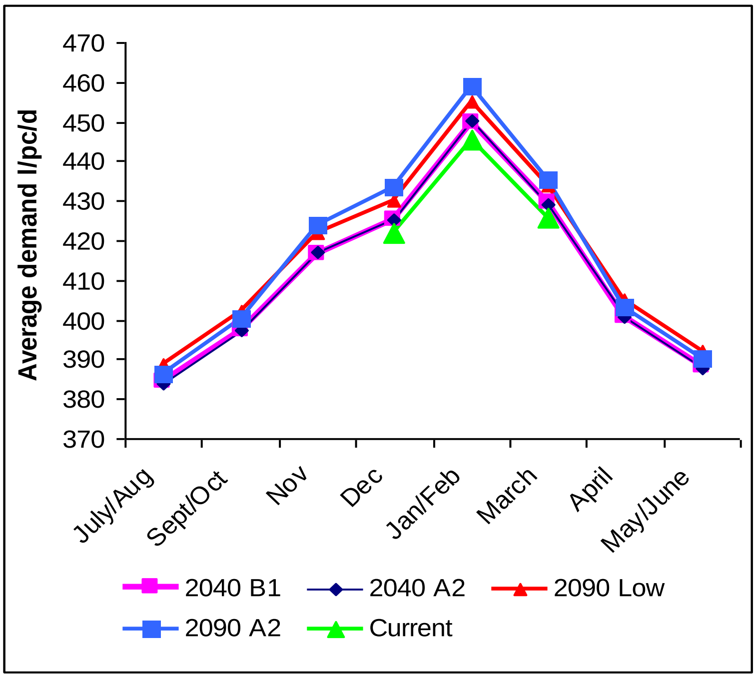

Figure 9. Average PCD 2040 and 2090 by month and IPCC A2, B1, and low-carbon scenarios (Mod 12).

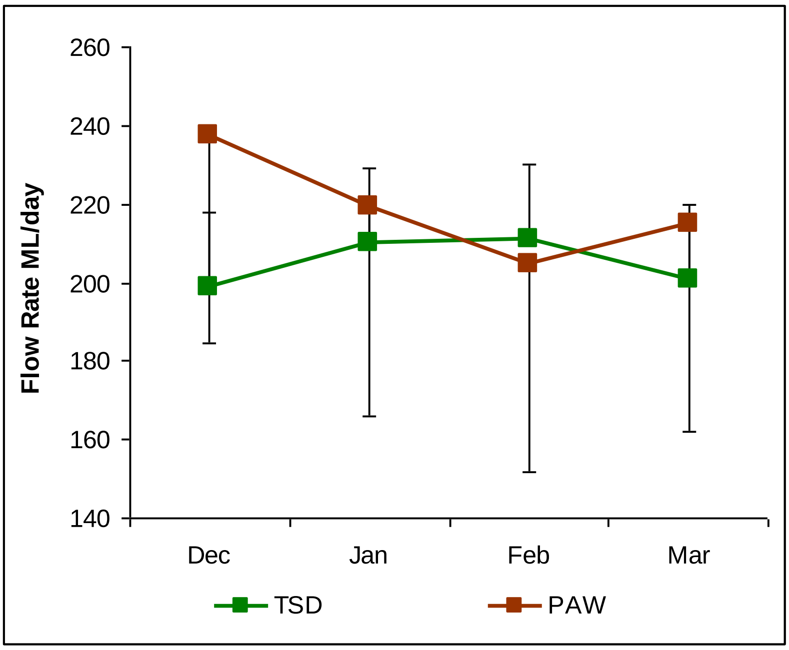

Figure 10. Average daily supply (PAW) -1 standard deviation, and average daily flow demanded (TSD) + 1 standard deviation in ML / day, from December to March under climate variability for 2040 A2 with population growth (Mod 12).

As shown in Figure 10, 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.

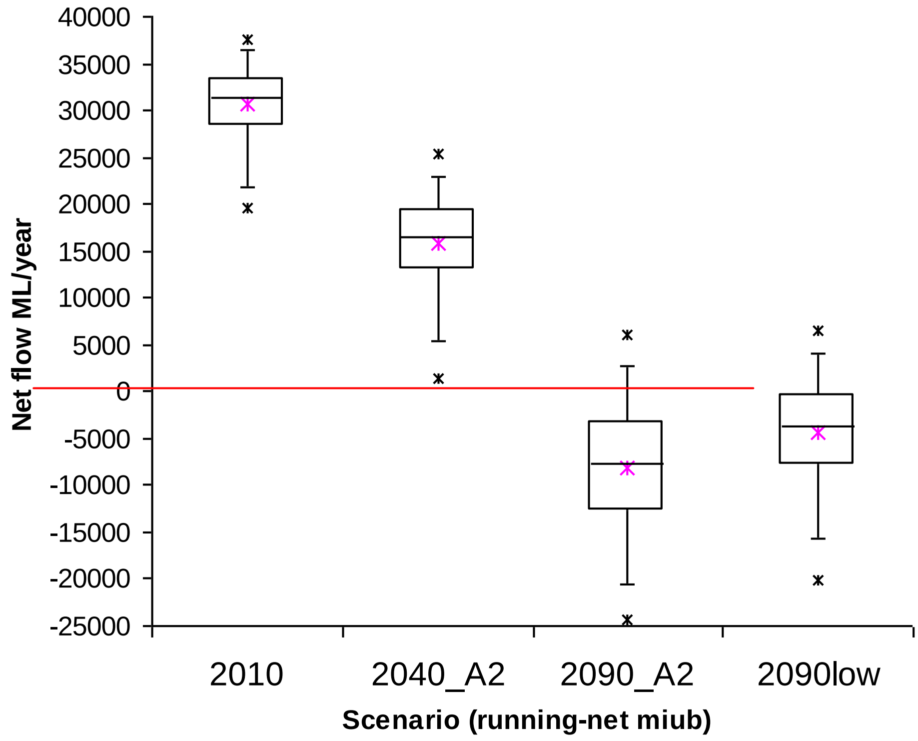

Figure 11. Running net-flows for 2040 A2, 2090 A2, and low-carbon scenarios for projected population growth with average aggregate per capita demand equivalent to 404 L / day. The boxes show the first and third quartiles and median. Whiskers go to the 2nd and 98th percentiles, and the largest and smallest data points are marked as 'outliers' with black crosses. The means are shown with pink crosses.

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 11 shows the potential degree of annual variability for net-flow. As shown in Figure 11, 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.

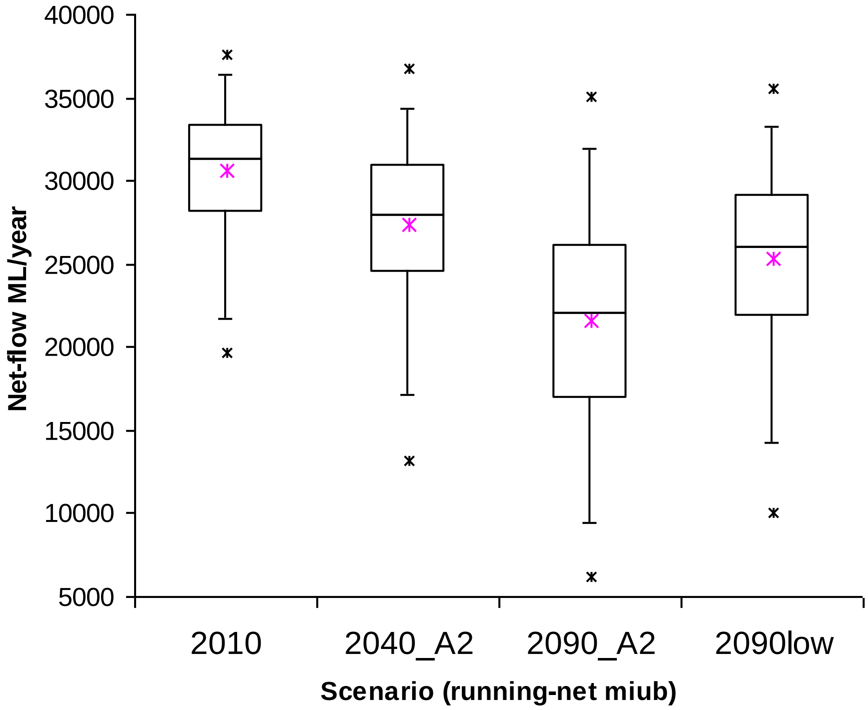

Figure 12. Figure 3.1: Running net-flows with no population increase for 2040 A2, and 2090 A2 and low-carbon scenarios.

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. 11). In Figure 12 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. 12). In percentage terms climate change alone decreases mean annual net-flow by 10 percent from 2010 to 2040, and by 21 percent from 2040 to 2090.

3.2.2. Potential impacts: Wider considerations

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 percent per year over the last 4 years, or 1.5 percent per year averaged over the last 10 years (see Figure 13). While Wellington's population has been growing at an average of 1 percent over the last 10 years, demand has been falling. In total, PCD fell 25 percent between 1990 and 2010[11].

[11] Calculated from data for Fig. 4.

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

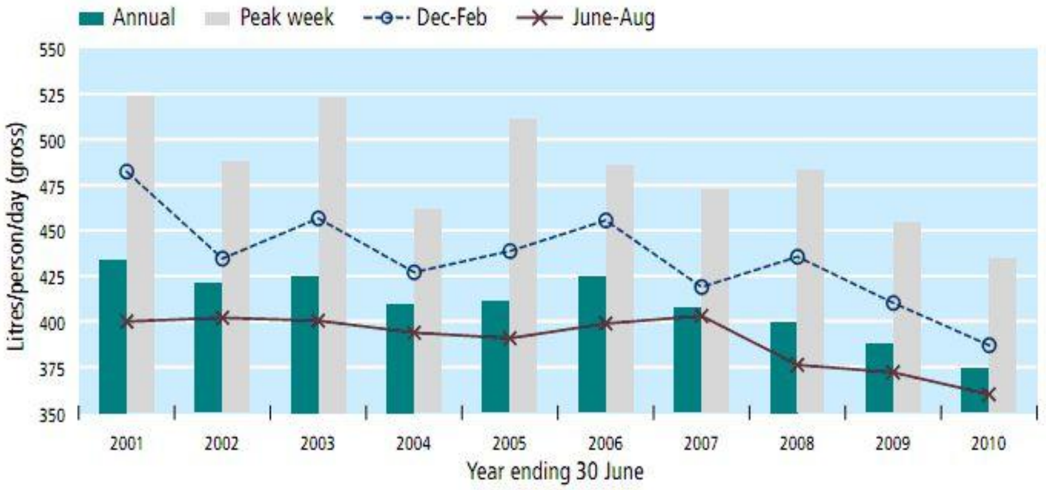

Figure 13. Figure 3.2: Declining PCD in Wellington 2001–2010 (Capacity 2010).

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]

Table 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 14 and 15.

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[12] Sixty-three percent of aggregate PCD

[13] Projected population used for the Wellington case study scenarios, equates to an average annual population increase of 0.6 percent from 2010.

[14] Includes 1 percent projected increase in PCD due to climate change

Auckland's current level of water intensity and the calculations in Table 1 show that a reduction to 303 L / day is theoretically feasible by 2025. Figure 14 presents a scenario where average PCD is reduced to 303 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 303 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. 14).

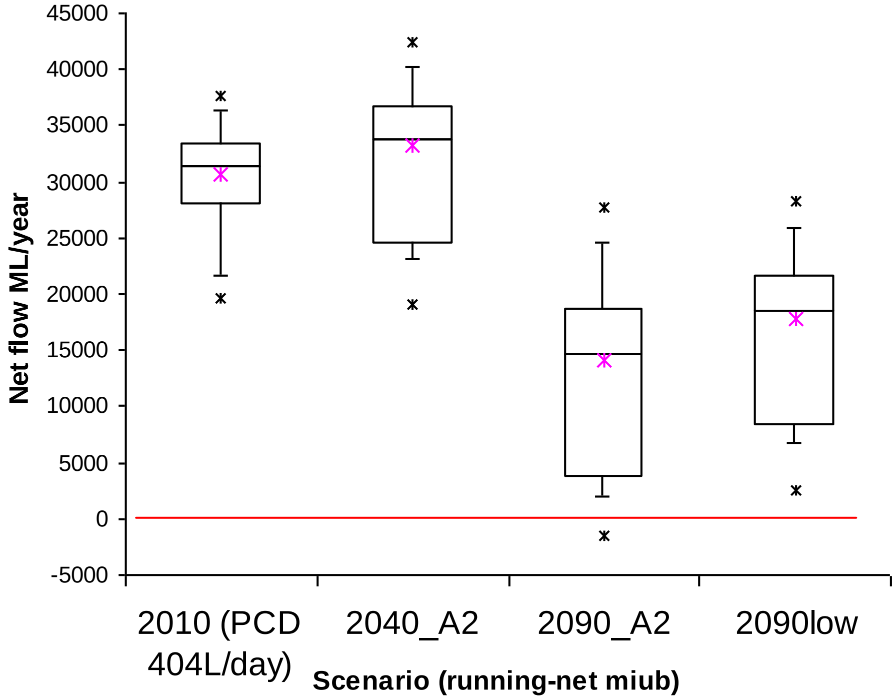

Figure 14. Running net-flows for scenarios 2040 and 2090 using both the A2 and low-carbon scenarios, for projected population growth with average aggregate per capita demand equivalent to 303 L / day.

In Figure 15, population has been held constant at 390,000 and average PCD is 33 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 percent, and between 2040 and 2090 it is 13.5 percent.

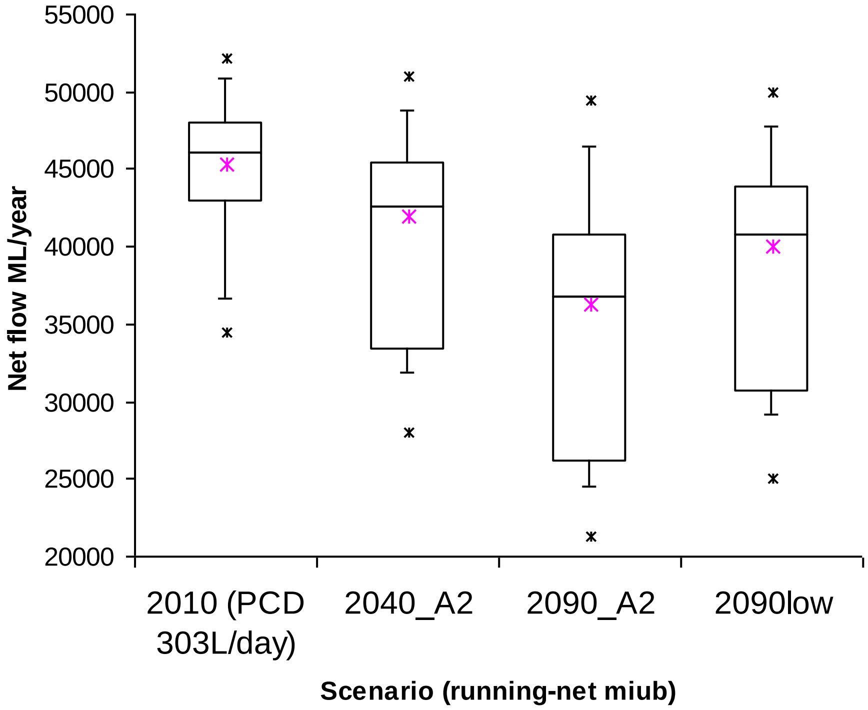

Figure 15. Running net-flows for 2040 A2, 2090 A2, and low-carbon scenarios with average aggregate PCD equivalent to 300 L / day and no population growth.

3.2.3. Water shortage dynamics

A water shortage event is the net effect of both supply and demand factors, which includes a range of variables such as population, intensity of water use, storage capacity, and water supply dynamics (e.g. aquifer and / or river extraction). Therefore the occurrence frequency of 'water shortage' events in the context of an urban water-supply system differs considerably from drought frequency, which is primarily climate related (i.e. a water shortage may be more or less frequent depending on water intensity and supply and storage capacity).

Trenberth (2011) suggests that trend plus variability may be useful for understanding extremes. The 2040 and 2090 projections produced as outputs by the SYM indicate the extent of the trend increase for that point in the future, while a running-net balance can be used to indicate variability. A scenario with average PCD of 303 L / day was calculated for 2040 (A2 mod12)[15]. The net-flow over an 80-day period (80 day running-net, Fig. 16) 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 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 16. In addition, there were five events with deficits of 12,000 to 14, 000 ML (one per 23 years), and 10 events with deficits of 10,000 to 12,000 ML (one per 11.5 years). In total

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

there were 17 events (1 per 6.8 years) that with projected demand, and average PCD of 303 L / day, could produce deficits of greater than 10,000 ML. Figure 17 shows that results for the 2040 scenario with 303 L / day PCD are similar to the 2010 scenario with PCD 404 L / day. This demonstrates the ability of reducing PCD to 303 L / day to 'offset' the effects of population growth and climate change on the water system. Figure 17 also shows a 202 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 202 L / day scenario shown is 210 L / day, with PCD at 271 L for the maximum day.

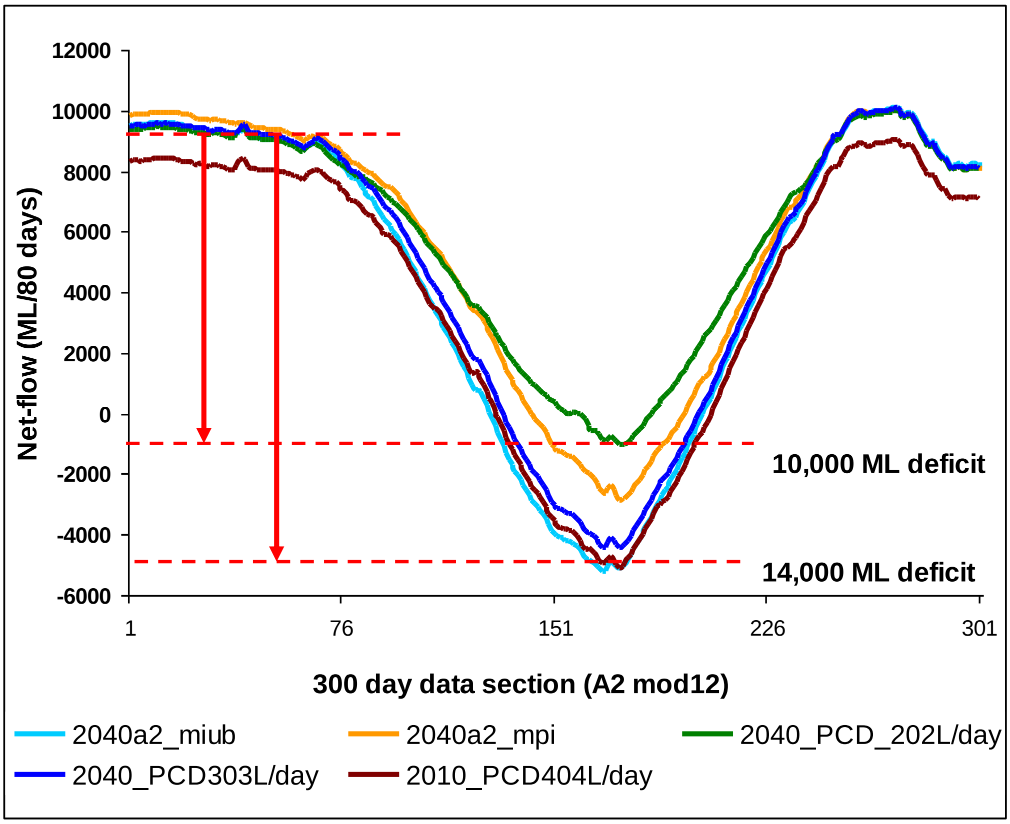

Figure 16. **300-day sequence of the largest deficit event generated for 2010 with PCD of 404 L / day, and 2040 with PCD of 303 L / day scenarios. The green line indicates a 'minimum deficit' with substantial and early demand management (A2 mod12, 80 day running-net). The miub (aqua) and mpi (orange) projections show the model range at the peak of the deficit.**

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 404 L / day and 2040 with 303 L / day), which suggests that 12000 ML of storage is required in order to meet Wellington's 2 percent 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. 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.).

[16] The 200 L / day scenario provides a lower bound as it requires a reduction in PCD of nearly 50 percent from 2010.

3.3. Discussion

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

3.3.1. Implications of general trends

Reducing PCD to 303 L / day is sufficient to 'offset' both projected population growth and climate change sufficiently to defer the need to augment supply until beyond 2090

The general effect of climate change by 2040 is an additional 5 percent decrease in potentially available water (PAW) with a 1 percent increase in per capita demand (PCD) (PCD of 404 L / day). For the 2090 A2 scenario, a 5.5 percent decrease in PAW and 3 percent increase PCD is projected. 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 to manage seasonally water availability is no longer an option, and new water supply sources are required. However, reducing PCD to 303 L / day is sufficient to 'offset' both projected population growth and climate change sufficiently to defer the need to augment supply until beyond 2090.

3.3.2. Implications for managing extreme events

Extreme weather events are considered 'extreme' relative to the historic variability of the specific place affected. As illustrated in Figure 17, a change in climate increases the risk of extremes.

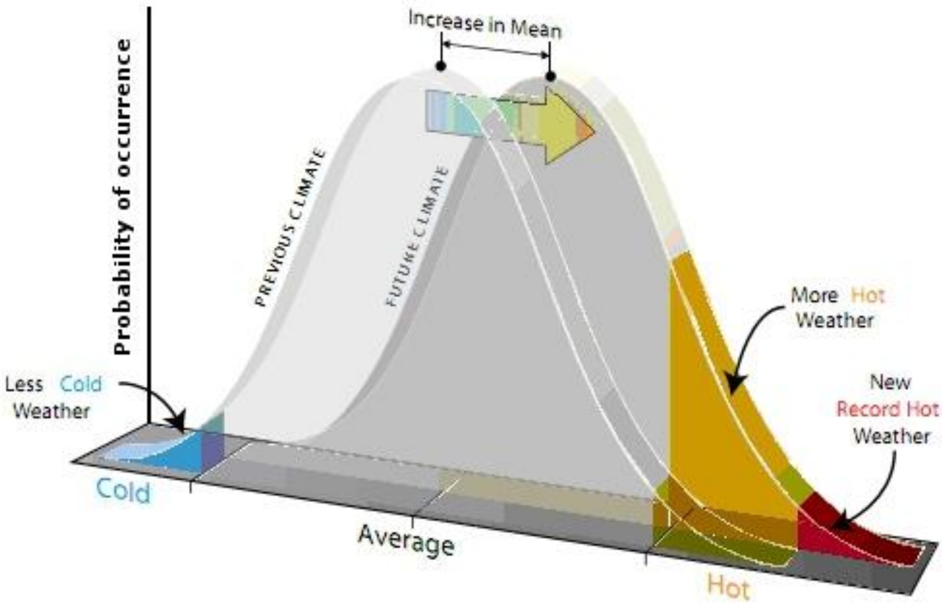

Figure 17. Climate change and increased risk of extremes. With regard to temperature, an increase in mean temperature within reference climate conditions results in a significant increase in the occurrence of hot weather, including record hot weather (Reisinger et al. 2010).

A water shortage event is the net effect of both supply and demand factors. In practice, water management generally focuses on supply management and on meeting demand to an 'acceptable' level of risk based on engineering and financial parameters, whilst avoiding restrictions:

'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).

The expectation that summer water use will not be moderated is unrealistic

However, this approach can give the community the unrealistic expectation that flow variability between PAW and TSD can usually be managed to enable 'unrestricted' summer water use. But 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. The expectation that summer water use will not be moderated is unrealistic since managing for extreme events requires a strategy to implement pre-emptive seasonal demand management.

In some regions of New Zealand, particularly northern and eastern areas, climate change is expected to increase the frequency and severity of droughts over time (Hennessy et al. 2007). Where this is the case, the size of extremes that must be 'managed' will also increase over time (e.g. 1-in-50 year events become 1-in-20 year events), while events exceeding current design standards will become more common. In addition, model projections tend to under-represent climate variability at the local level, which along with an increasing risk of extremes, increases the level of uncertainty with probability-based water management calculations (i.e. significantly increases the uncertainty of calculations for long-term infrastructure planning to meet a 1 percent or 2 percent water-security standard).

A resilient approach is to expect and plan for surprises

From a resilience perspective, an informed community, which is aware that a drought is possible in any given summer, and that knows 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, compared to one that is generally active in reducing its water intensity and understands the need to use water wisely in the summer. Therefore, a resilient approach is to 'expect surprises' and prepare for them.

3.4. Summary

Population growth, PCD, and TSD are key variables within the water supply system that Wellington's water managers must contend with. Increased climate variability makes this job significantly more challenging.

The need to augment supply can be delayed by increasing storage capacity and reducing the relative contribution of projected population growth by reducing average PCD to 303 ML / day

The reduction in net-flow due to climate change and population growth represents a reduction in the amount of water available that can be stored to enable the water system to cope with seasonal flow variability. On the basis of balancing water availability over the year with storage, current supply (PAW) is sufficient to meet a PCD of 404 L / day to 2040, under the A2 scenario and with projected population growth. Towards 2090, the average net-flow from current supply sources is below zero. However, the need to augment supply can be delayed by increasing storage capacity and reducing the relative contribution of projected population growth by reducing average PCD to 303 ML / day.

Per capita demand is high but falling in Wellington

PCD is relatively high in Wellington, but it is falling. With sufficient demand-management efforts, average aggregate PCD could be reduced to 303 L / day by 2025 and maintained at that level to 2040. In this case, and with sufficient storage, reducing PCD to 303 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 303 L / day preserves the ability to use storage reservoirs to smooth out flow variability through to 2090, from present supply sources.

10,000 ML of storage capacity may be required to manage flow variability in Wellington to 2040

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 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 constructing approximately 7000 ML of storage to complement the existing Stuart Macaskill Lakes. 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.

4. Adaptive capacity and resilience to water shortages

> *'…adaptation is a continuous stream of activities, actions, decisions and attitudes that inform decisions about all aspects of life, and that reflect existing social norms and processes' (Adger, Arnell and Tompkins 2005, p.78).*

Adapting to climate change has become a necessity given the warming that we are committed to as a result of past and present greenhouse gas 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 IPCC (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.'*

Wellington's response to climate change will therefore depend on how climate change adaptation can be integrated into adaptation that is currently being undertaken in response to other drivers, as well as on Wellington's social, political, cultural, and economic context. This section synthesises results from interviews, workshops, and literature; discusses these results from a resilience perspective, and within the local context for adaptation; and then uses the resulting insights to answer parts two and three of the research question.

4.1. Methodology

A 6 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?

4.1.1. Instruments

The initial workshop used the hexagons method to capture issues identified by the participants during a brainstorming session (Hodgson 1992) that addressed the workshop question. The 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 between the issues could be mapped using a 'causal loop diagram' (CLD) (Maani and Cavana 2007), referred to in this report as a 'structure diagram'. Structure diagrams provide a means of exploring and interpreting the relationships and interactions between many system variables.

The structure diagrams in this section are used to show underlying feedbacks and structures according to the 'mental model' of the researcher, drawing on the empirical data from hydrological and climate modelling, combined with local contextual knowledge from the workshop participants and interviewees as 'extended peers', and situated in the broader context of relevant theory and literature. Another systems-thinking tool used in this section is the behaviour over time (BOT) graph. The BOT graph is 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.

4.1.2. Participants

Workshop participants and interviewees were identified through their previous involvement in Wellington's water management issues, as well as through personal connections and networks of the researcher. Relevant literature, local media coverage, and press releases produced by organisations such as businesses, NGOs, and local government also informed the analysis. In total 22 people participated over the two workshop sessions and 13 people were interviewed. Key themes for the interviews were developed based on analysis of local media coverage of the issues and relevant academic literature. Stakeholder mapping (Fig. 18) was used to assist in targeting a good spread of participants. Interviewees included five local government water policy and management personnel, an elected city councillor, one non-government organisation (NGO) representative, and five 'citizens' as domestic water users.

4.1.3. Procedure

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. Collaborative input from a range of perspectives helped the researcher to gain a multi-dimensional view of water management.

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

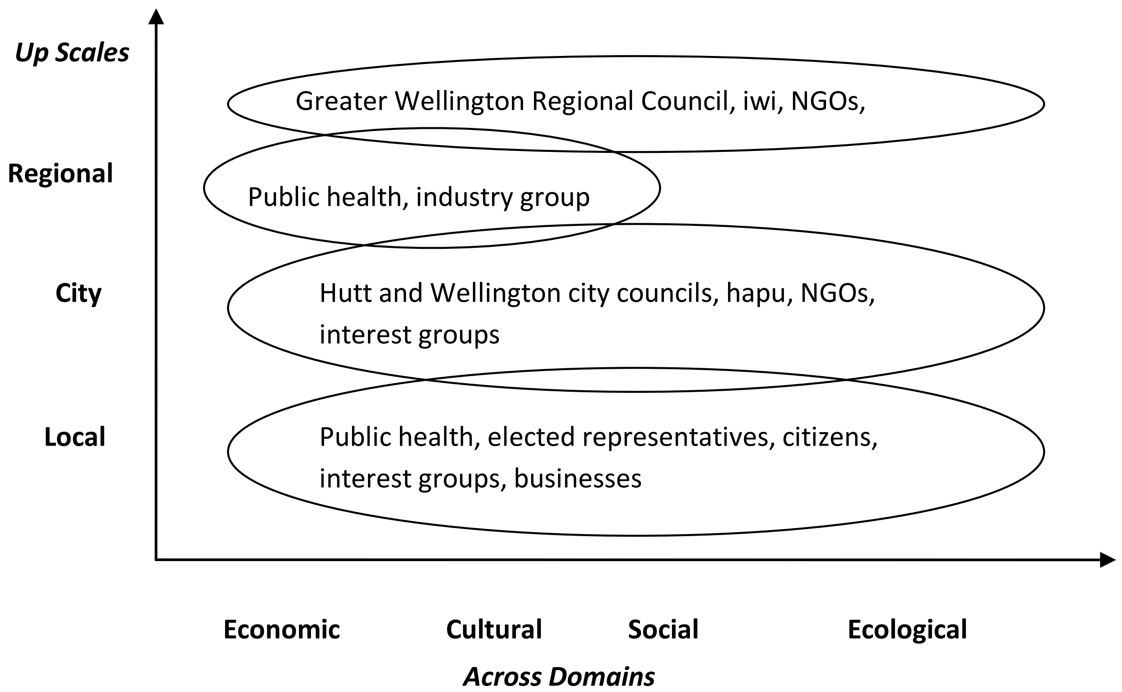

Figure 18. Stakeholder scales and domains. Adaptation of schematic presented by Mortimer (2010).

4.2. Exposure, sensitivity, and response pathways

This section provides a broad overview of the implications of primary response pathways for reducing exposure and sensitivity to water shortages. Along with adaptive capacity, exposure and sensitivity are key elements of vulnerability (Adger 2006). Exposure relates to biophysical factors such as climatic variables, including the variability and frequency of extremes. Sensitivity is 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.

Figure 19 shows how the primary response pathways of supply or storage augmentation and demand management act on system variables in order to reduce the community's 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).

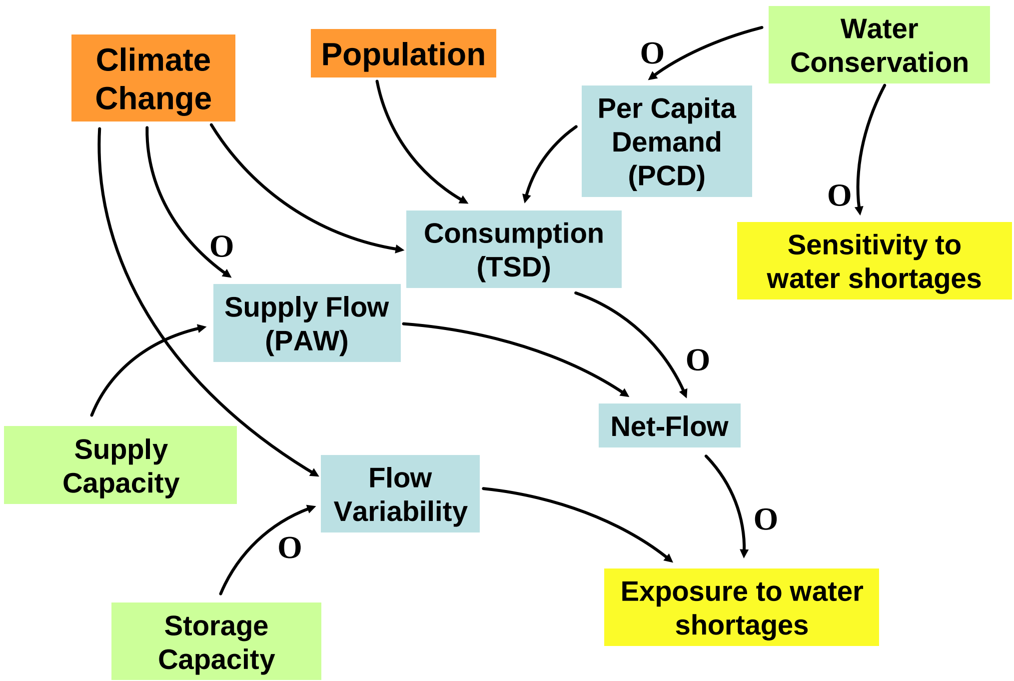

Figure 19. Response pathway diagram showing influence of key responses (green) on system variables (blue) to reduce community exposure and sensitivity (yellow) to water shortages due to increasing climate change and population.

Starting with a community with an increasing exposure to water shortages (highlighted yellow, near the bottom of Fig 19); 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)[17].

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 / concern.
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).

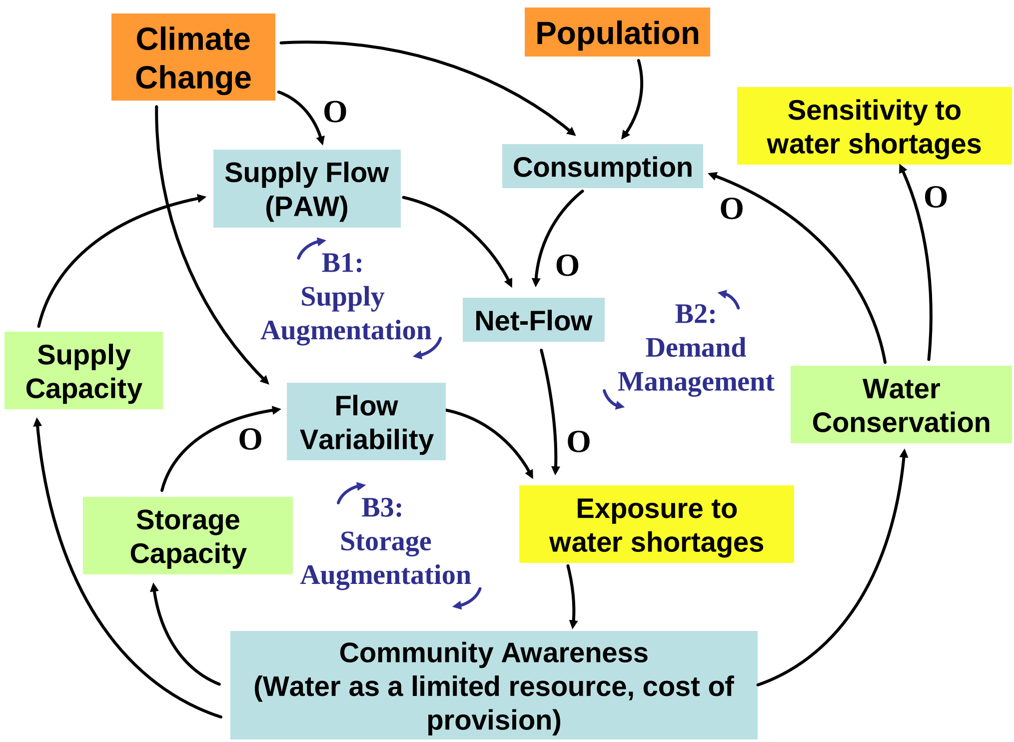

Figure 20. Structure diagram demonstrating socio-ecological system feedbacks resulting from response pathways (green) with regard to exposure and sensitivity to water shortages. 'Capacity' is a measure of consumption to supply, e.g. number of days of storage or percentage of supply consumed at peak consumption.

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. 21). The sudden drop in exposure due to the intervention, as illustrated in Figure 21 relates to the 'lumpiness' of supply and storage augmentation, which tend to occur in large increments (e.g. Figure 27). However, without demand management as the primary response option, sensitivity continues to increase since the community continues to grow in a water-intensive

[17] In reality, a combination of options would be used. For the purposes of this section, the structure diagrams are used to demonstrate system dynamics of each option or pathway.

manner. The occurrence of a drought that exceeds the design capacity of the water supply system cannot be ruled out for a coming summer. Therefore, the higher the community's water dependence, the more sensitive it is to a water shortage caused by an 'extreme' event.

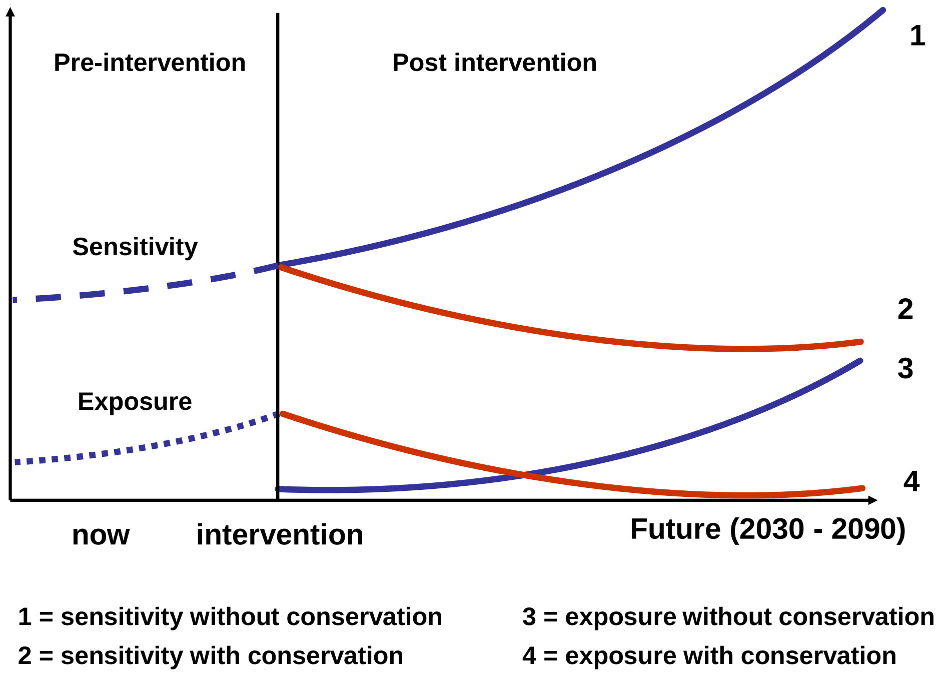

Figure 21. 'Behaviour over time' graph demonstrating implications for exposure and sensitivity to water shortages with and without water conservation as the primary response pathway.

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. Thirdly, the costs of this pathway are, at least initially, likely to be lower than the costs of the supply or storage augmentation (e.g. $142 million for the Whakatikei dam (GW 2008b). However, implementing such a pathway is not likely to be cost free, either in resource or political terms.

An approach orientated toward supply and storage augmentation decreases exposure only within the 'engineeringly' feasible and financially affordable parameters of the system, but exposure to larger magnitude events remains. As illustrated in Figure 22, 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 PCD, and the 'security of supply standard' or ASP, indicating the range of variability that the bulk system is designed to manage exposure to.

The variables 'inclusion, interaction, engagement', and 'social learning' in Figure 22 are discussed in relation to adaptive capacity in the following section.

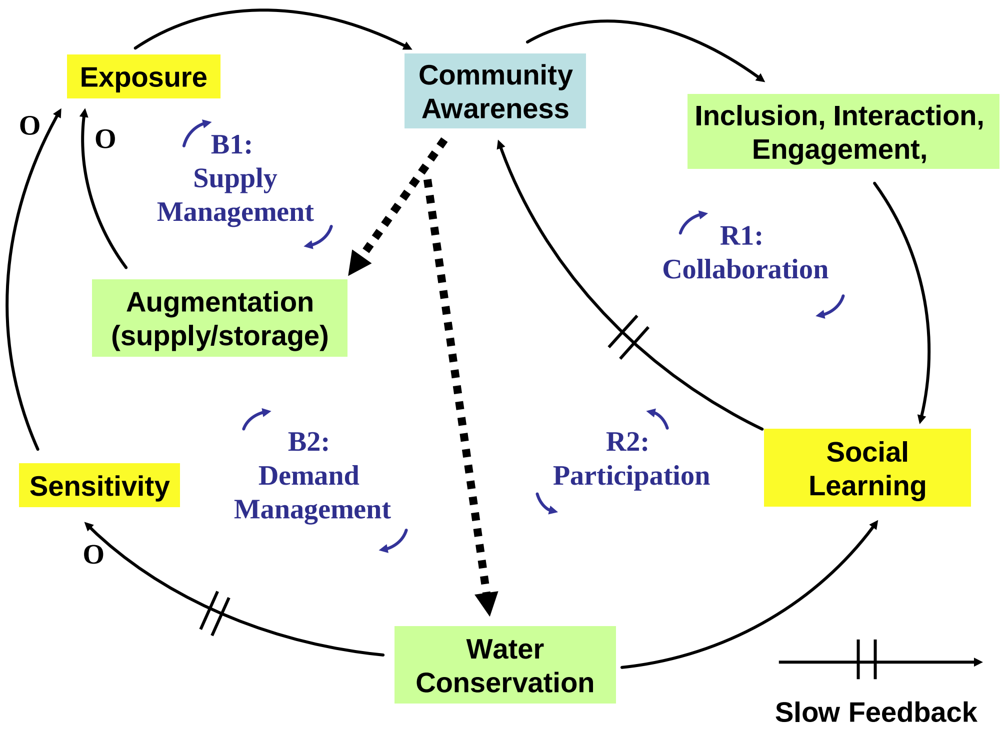

Figure 22. Structure diagram demonstrating feedback differences between 'supply management' (B1) and 'demand management' B2. The water security standard serves as a proxy for exposure, while Per Capita Demand (PCD) could be used as a proxy measure of sensitivity.

4.3. Adaptive capacity and transformation

The previous section identifies the importance of a water conservation pathway for reducing exposure and sensitivity to water shortages. This section briefly situates the choice of response pathways within the social context for adaptive capacity. Adaptive capacity is the community's ability to adapt or respond to change and, in the present study, to improve institutions, systems, structures, behaviours, and practices to increase resilience to water shortages.

4.3.1. Adaptive capacity, social capital, and social networks

Social capital is a prerequisite of adaptive capacity

Social capital is a prerequisite, or 'necessary glue' 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). A community with strong social capital has considerable ability to determine its own future. However, strong social capital and self-determination can also perpetuate vulnerability (Wolf et al. 2010). For example, Wolf et al. (2010) found that strong social networks could exacerbate vulnerability if they perpetuate maladaptive narratives (e.g. low risk perception). This highlights that a community with strong social capital could implement a maladaptive response pathway.

Social networks are the engines of collective action

If social capital is a prerequisite of adaptive capacity, and collective action is the desired product of social capital, social networks are the engines 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 (Wolfe 2008).

For social networks to spark collective action, the network must be 'primed' or prepared for change (Folke et al. 2005). 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. 23). For example the community's awareness of the issues surrounding present water use must give it sufficient 'sense' that collective action to conserve water 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.

'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).

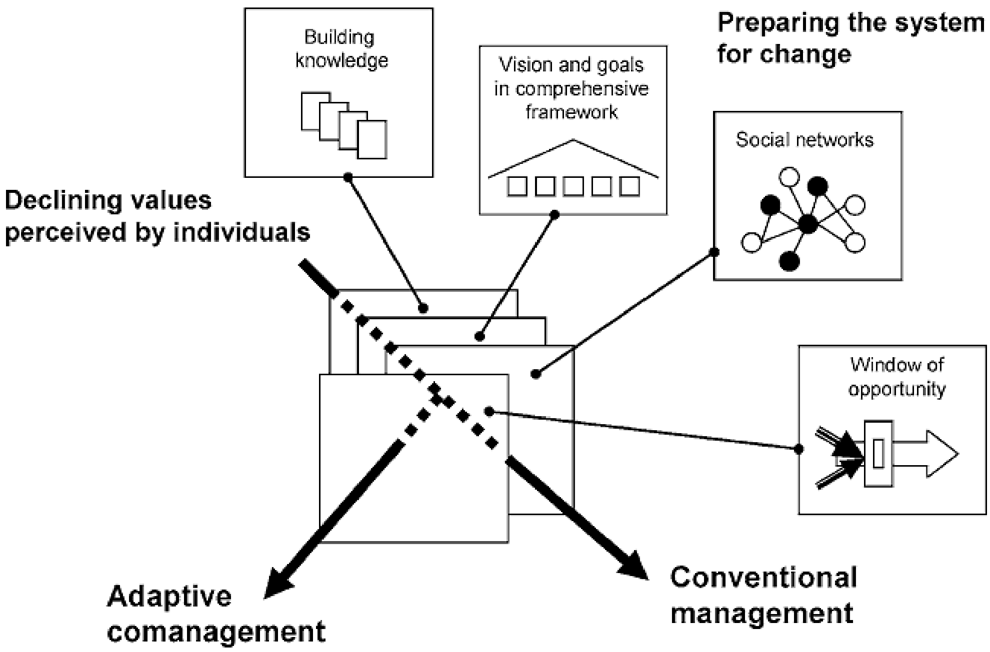

Figure 23. Schematic of a successful example of transformation towards adaptive co-management (Folke et al. 2005).

As seen in Figure 23, once the community is primed for change, the window of opportunity could result in either an 'adaptive co-management' or a 'conventional management' pathway. Which pathway is taken depends on the extent to which the goals, vision, values, and principles underpinning the alternative pathway are integrated within the community's stock of knowledge regarding the issue in question (Folke et al. 2005). 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 24. In turn, these structures are driven by wider system interactions, including the organisational structure, culture of, and external influences on decision makers.

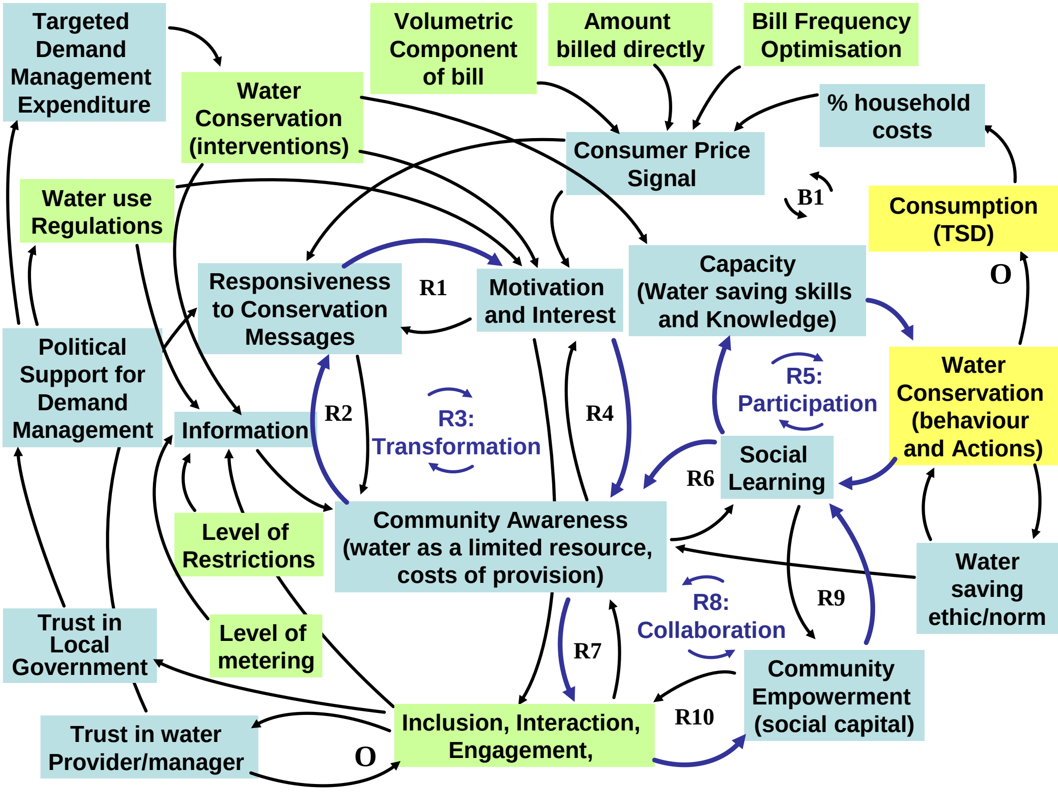

Figure 24. Feedback structures and system interactions between demand-side intervention options (green) and the target variables 'water conservation' and 'consumption' (yellow). R3, R5, and R8 indicate key structures that influence adaptive capacity.

4.4. Local contextual factors

This section presents local water management factors, including drivers and barriers of water conservation, and local factors affecting adaptive capacity, as identified through the analysis of interviews, literature, and in Section 2.

Wellington's current supply capacity is sufficient to meet projected population growth to 2090

By reducing per capita water consumption to a similar level as Auckland (300 L / day), and with additional storage, Wellington's current supply capacity is sufficient to meet projected population growth (e.g. Table 1, Figure 15) to 2090. However, if current levels of demand (404 L / day) continue or increase, the augmentation of storage alone will be insufficient to manage flow variability, since average net-flow drops below zero between 2040 and 2090. As seen in Figures 4 and 14, the general trend for Wellington has been for a decline in water intensity. Significant potential to further reduce demand is also evident. For example, 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, Issacs and Vale 2010). Analysis of metered data by Bint et al. (2010) suggested *'that the office building water demand is driven not by the presence or absence of occupants, but rather by the water using features of the building itself.'* The potential for significant water savings has been identified and Wellington City Council (WCC) has adopting 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).

A range of water conservation activities is undertaken in Wellington

Current water conservation activities undertaken in Wellington include leak reduction and pressure management work by Capacity (Capacity 2010), and information and education activities by GWW and the city councils (Samuel, interview, 07.10.10). Porirua City Council (PCC) employs a 'green plumber' to visit householders to find and fix any external leaks. The plumber also offers advice, distributes free tap-washers, and presents short instructional videos on how to fix leaking taps and toilet cisterns. The videos are on PCC's website (PCC 2011). GWW have run campaigns targeting gardening during summer in conjunction with local gardening retailers, through information and product discounts since 1997 (GW 2004). 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 to decrease consumption (Williams 2010b, Samuel, interview, 07.10.10). Water restrictions were introduced for the first time in 20 years during a dry summer in 2008 (WCC 2009).

4.4.1. Water conservation drivers

Standards and regulations

All four city councils have bylaws that apply to garden irrigation. These are 'odds and evens' or 'alternate day restrictions' permitting garden watering by even numbered houses on even numbered days, and odd numbered houses on odd numbered days of the month. Porirua's restrictions apply only during daylight savings, while restrictions for Wellington City, Upper Hutt, and Lower Hutt apply throughout the year[18].

Alastair McCarthy the Water Supply Development team leader for GWW reported 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). Legislating for minimum efficiency performance standards is one of the lowest per unit cost water conservation mechanisms available (Turner et al. 2009). 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).

[18] http://www.gw.govt.nz/watering-restrictions/

strategic policy analyst, Paul Glennie reported that a key driver of Capacity's current demand management work was calculations by GWW that the security of supply standard slipped (Glennie, interview, 12/10/10). Resource consent conditions are also a driver of water conservation[19]. 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 GWW (McCarthy, interview 07/10/10).

Financial

Bryan Smith, Principal Policy Adviser for WCC, reported 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). Metering has been investigated for Wellington, and the estimated costs are $70 million, while the proposed Whakatikei dam will cost approximately $142 million to build (GW 2008b)[20]. In addition, water meters lose accuracy over time due to wear and need to be replaced after about 10 years (Girard and Stewart 2007, Gribble 2010, quoted in Bint et al. 2010 (pers comm.).

There are direct financial benefits to the council from deferring either a dam or metering. For example, PCC's investment of $84,000 in demand management for the 2010–2011 year produced immediate annual water savings worth $100,000 (PCC 2011). However, a plan capable of balancing out population growth and meeting an acceptable security of supply standard will need to be in place to defer these more onerous options (Smith, interview, 12/10/10). Enforcing restrictions also has a cost and people have a limit for tolerating restrictions (Smith, interview, 12/10/10).

Environmental

A key concern for Hutt Valley residents is the health of the Hutt River—the primary water source for the four cities. Councillor Margaret Cousins of Hutt City Council (HCC) 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 (Cousins, interview, 15/12/10). GWW's recent application for resource consent to reduce the minimum flow of the Hutt River caused tension between GWW and Hutt City councillors (Shierlaw 2011, pers comm., Cousins, interview, 15/12/10). According to GWW, reducing the minimum flow 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 the toxic algal blooms that are affecting recreational use and enjoyment of the Hutt River (Shierlaw 2011, pers comm., Kopp 2010, Cousins, interview, 15/12/10). It should be noted that the lower flows are temporary while the upgrade of the Lakes is taking place.

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[19] Under the RMA, resource consent is required for water abstraction. To minimise adverse affects of water abstraction, such an activity must comply with specific consent conditions, which are rule-based parameters.

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

4.4.2. Barriers to water conservation

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. Behavioural changes tend to be temporary and made in the short term in response to current conditions, while structural changes provide ongoing water savings. Structural strategies include pricing, regulation, and bulk purchasing and finance initiatives. This section presents some local contextual barriers to water conservation that may need to be addressed with structural strategies.

Water conservation is not generally perceived to be a priority

In general, many New Zealanders have strong anti-waste attitudes and value water as a vital necessity of life (MfE 2009). However, water is generally not a 'top-of-mind' issue and it tends to be taken for granted (MfE 2009). New Zealand has no water-efficiency standards other than a shared water-efficiency product-labelling standard with Australia. In Wellington, restrictions and information / education are used to manage summer demand, although WCC and HCC have no enforcement policies in place to promote compliance with bylaws. PCC targets high use areas with 'letter box drops' to remind people of bylaws, responds to calls from the public, and council officers keep watch during regular activities or conduct patrols if required (Scrimgeour 2011, pers com.). Upper Hutt contracts a private security firm to do patrols (Glennie 2011, pers comm.).

Andrew Samuel, senior marketing advisor for GWRC reported that in the 1990s GWW felt it had a system that could supply to the 2 percent standard till about 2020, which 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 people's experience (Samuel, interview 07/10/10). However, GWRC were caught out by revisions to population projections for Wellington, made by Statistics New Zealand, which occurred between 2002 and 2005 and brought forward the need to have augmented supply in 15 to 20 years, based on GWW's revised security of supply calculations (WCC 2009, Shaw 2008).

There are political difficulties relating to water management

Metering is a political 'hot-potato' in Wellington and during the 2010 local body elections, mayoral candidates distanced themselves from metering, and the incumbent HCC Mayor even accused his rival of supporting metering (Edwards and Boyack 2010). 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 authorities and their communities (PCE 2001). 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'. 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 that can only provide indirect savings. However, Maria's biggest concern is that that charging for water has inequitable results for demand reduction, since the price signal will be highly dependent on the water bill as a proportion of household income (McMillan, interview, 22/11/10).

Andrew Samuel is a senior marketing adviser at GWRC. From his perspective, the absence of universal metering limits the availability of information, as well as the effectiveness and range of options available for responding to a dry summer (Samuel, interview, 07/10/10). For example, metering provides high-resolution information that can be used to design targeted demand-reduction strategies and obtain feedback to evaluate and refine such strategies (Samuel, interview, 07/10/10). Information from meters and additional pricing tools would also assist in providing water efficiency signals and information to households (Samuel, interview, 07/10/10).

Water-efficient showerheads became a hot issue during the 2008 general election, after being labelled 'nanny state' by then opposition energy spokesperson Gerry Brownlee. 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). The promotion of the benefits of water-efficient showerheads is planned after collaborative work between GWW and the Energy Efficiency and Conservation Authority and a product test by *Consumer* magazine (GW 2010). However, GWW 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). The politicising of water-efficient showerheads, along with framing as 'low-flow showerheads' (e.g. WCC 2011) will have contributed to this unfavourable publicity.

4.4.3. Adaptive capacity and resilience

Several factors contribute to the adaptive capacity and resilience of communities and the responses made on their behalf by local government. The following reviews some of the factors that emerged from this case study.

Trust is central to coping with social dilemmas

> *'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).

Value conflicts and trust issues are present within Wellington's water management context as can be expected for any complex socio-ecological issue. For example, WCC was accused of inflating the water shortage situation to justify metering (Cook, Chipp 2009), and HCC councillors felt they were being pressured to comply with GWW's bid to reduce the minimum flow of the Hutt River (Shierlaw 2011, pers comm., Cousins, interview, 15/12/10).

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. However, trust is often neglected or undermined to push through a particular agenda or 'solution' (Ostrom 2009), with current privatisation and amalgamation agendas being topical examples. In November 2010, Auckland's water services were amalgamated into a single provider; previously Auckland had six retailers and a bulk supplier. This amalgamation of Auckland's water services was part of the merging of Auckland's governance entities into a unitary authority, and similar discussions on the future of Wellington's governance are presently underway (PWC 2010). Fears of a privatisation agenda have been stoked by Government plans to partially privatise state-owned power companies (Kay 2011), and recent changes to the Local Government Act:

'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[21] was appropriate' (McMillan, interview, 22/11/10).

Polycentric governance is useful for complex economic systems

Nobel Prize winning economist Elinor Ostrom highlights the role of 'polycentric' governance for 'complex economic systems' (Ostrom 2009). Polycentricity (many centres) or 'nestedness' 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). Wellington's separate bulk supply and retail services, along with a degree of horizontal separation within retailing services currently provide some polycentricity.

Dealing with the conflicting values of water is challenging and any structure is likely to have its drawbacks. Councillor 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

[21] 'Urgency' refers to a Parliamentary process where legislation is rushed through, leaving little time for public input or scrutiny.

(Cousins, interview, 15/12/10). City councils and councillors can act as 'aggregators' for constituents, and when the city council itself is the customer this aggregator role is much more structural.

Modularity increases resilience

Centralised mains water systems provide the community with low-cost water due to economies of scale. The Wellington Fault bisects the region (Fig. 40) and a key consideration is the risk of disruption to the water supply system, and how long it would take to get it back up and running after being damaged by a major earthquake (Smith, interview, 12/10/10). It is estimated that in the event of a large earthquake it would take at least 30 days to restore the mains supply to Wellington City (GW 2008b, p.18)[22], and it may take months to re-establish water services to some areas, rendering them uninhabitable (Cousins et al. 2010). Rainwater systems can provide an alternative source of water under such conditions, or should a toxic algal bloom or water-borne pathogens compromise the mains supply (NRC 2010, Chapman et al. 2003). Climate change adds to the confluence of factors which can promote the growth of harmful algae (Paerl et al. 2011).

[22] GWRC'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.).

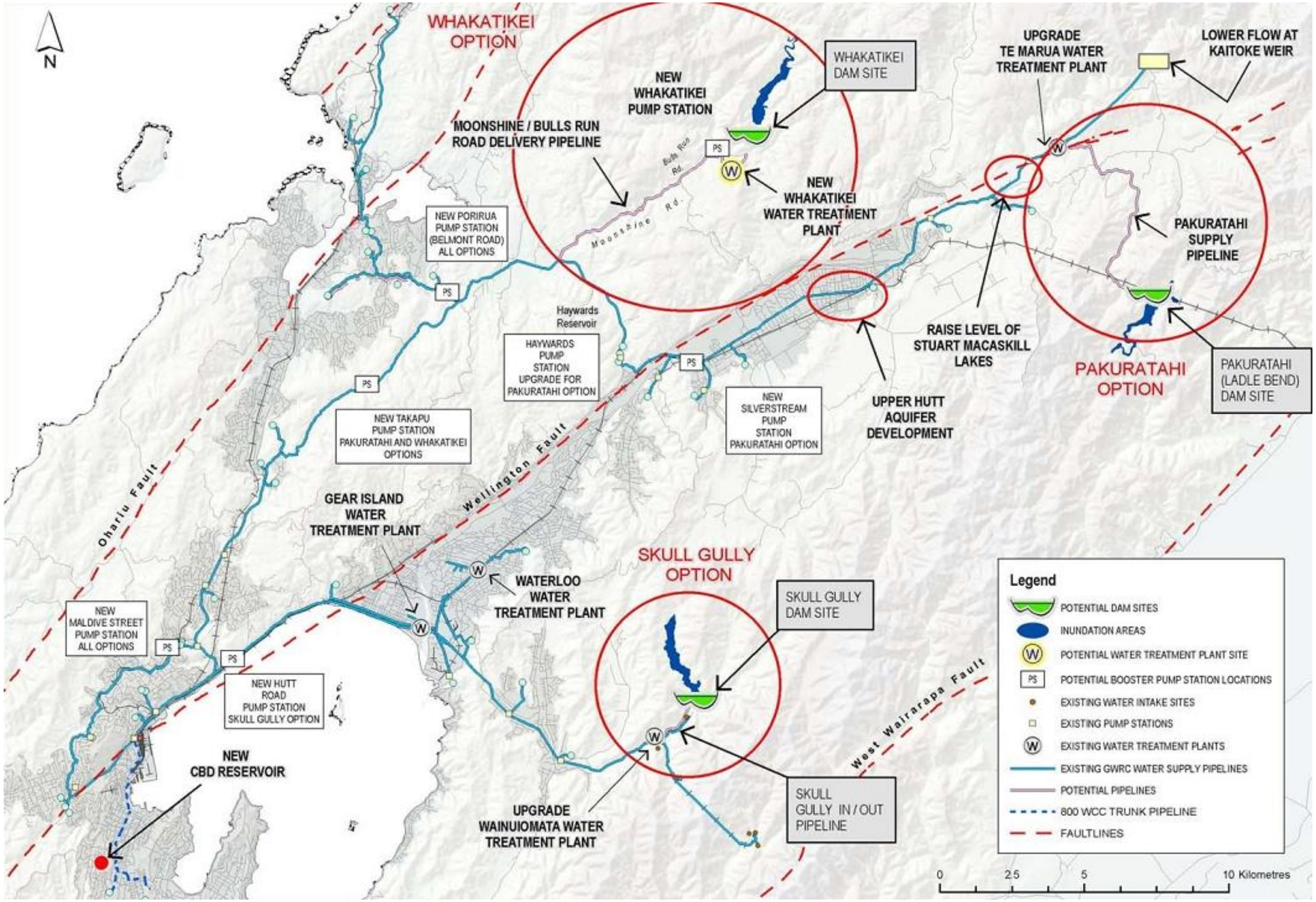

Figure 25. Augmentation and upgrade options, plus Wellington Fault location (GW 2008b).

Rainwater systems increase system resilience through 'modularity': *'in resilient systems everything is not necessarily connected to everything else'* (Walker and Salt 2006, p.146). However, as seen in Figure 26, household rainwater systems ('tanks') are an expensive option from a demand management perspective (see also Roebuck et al. 2010, and Mithraratne and Vale 2007).

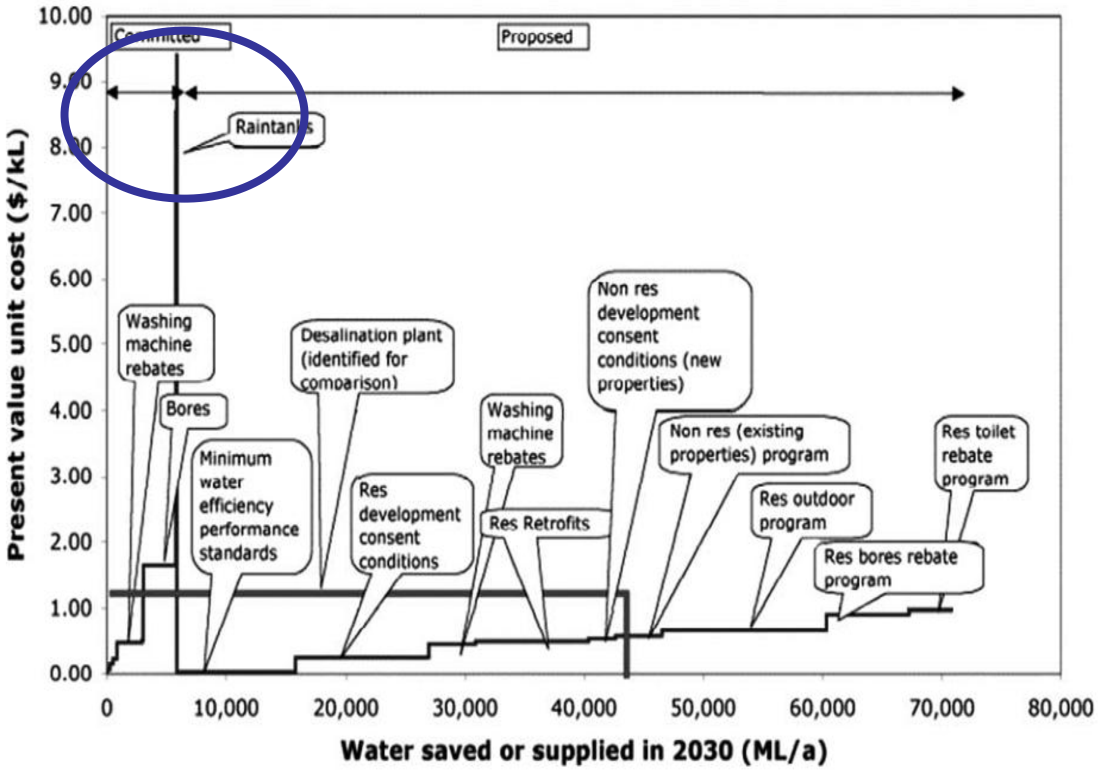

Figure 26. Comparison of unit costs for various demand management options including rainwater (blue circle) in an Australian context (Turner et al. 2009)[23].

In addition to modularity, rainwater tanks provide a number of benefits within integrated water management portfolios including:

- reducing demand on mains water, deferring the need for supply and storage augmentation (Coombes and Kuczera 2003)
- increasing water resilience during dry periods (urban roof water collection is not affected by catchment recharge) (Coombes and Barry, 2007)
- reducing capacity requirements and associated infrastructure expenses (rainwater tanks with mains water 'trickle top-up' and mitigate daily mains supply demand peaks) (Lucas et al. 2010)
- reducing urban runoff and stormwater peaks (modelling shows that rainwater tanks with trickle-top-up provide stormwater retention capacity)(Coombes and Kuczera 2003).

[23] The abbreviation 'Res' in Fig. 26 is short for residential.

4.5. Discussion

What are the implications of primary response pathways and options (including governance and management approaches) for community resilience and adaptive capacity?

4.5.1. Augmentation

Short-term possibilities include building dams and storage reservoirs

GWW identified a range of short-term possibilities to achieve its 2 percent security of supply standard at current levels of consumption (PCD at 404 L / day), and with population growth projections till 2030 (GW 2008b). Building a dam on the Whakatikei River has been identified as an option that may need to be initiated soon (Shaw 2011). Two other potential dam sites (Skull Gully and Pakuratahi, Figure 25), and more recently, a storage reservoir site (at Kaitoke) have also been identified. A particular attraction of the Whakatikei dam is that it would be on the western side of the Wellington fault, and reduce the exposure of Porirua and Wellington to disruption of supply as a result of a large earthquake on the Wellington Fault, as all other supply sources are on the eastern side (GW 2008b).

Increasing supply or storage capacity can lead to maladaptation

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 but can lead to maladaptation (Barnett and O'Neill 2010) and 'stranded assets', due to the 'lumpy' nature of system capacity increases (e.g. Fig 27). Maladaptation can result if increased security of supply leads to increasingly casual attitudes to the use or wastage of the resource (e.g. decreasing awareness leads to a decrease in water conservation—Figure 20). 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 need to address inefficient water use into the future, further entrenching inefficiencies. Also, if augmentation occurs in response to a particularly dry summer and PCD continues to fall (as seen in the present decline in PCD) then a stranded-assets scenario emerges. For example, as represented in Figure 27, system capacity is increased in response to the historic trend (ca. 1940 to 1975—red line), then further increased in response to an event exceeding system capacity (ca. 1978). However, post-1978 the trend in both maximum and annual average daily demand is downward (blue line), the excess system capacity (e.g. within the blue circle) represents unnecessary capital and infrastructure, i.e. stranded assets. The stranded-assets scenario presents an opportunity cost both in terms of capital and also for the resource, the risk of this scenario emerging should therefore be carefully assessed.

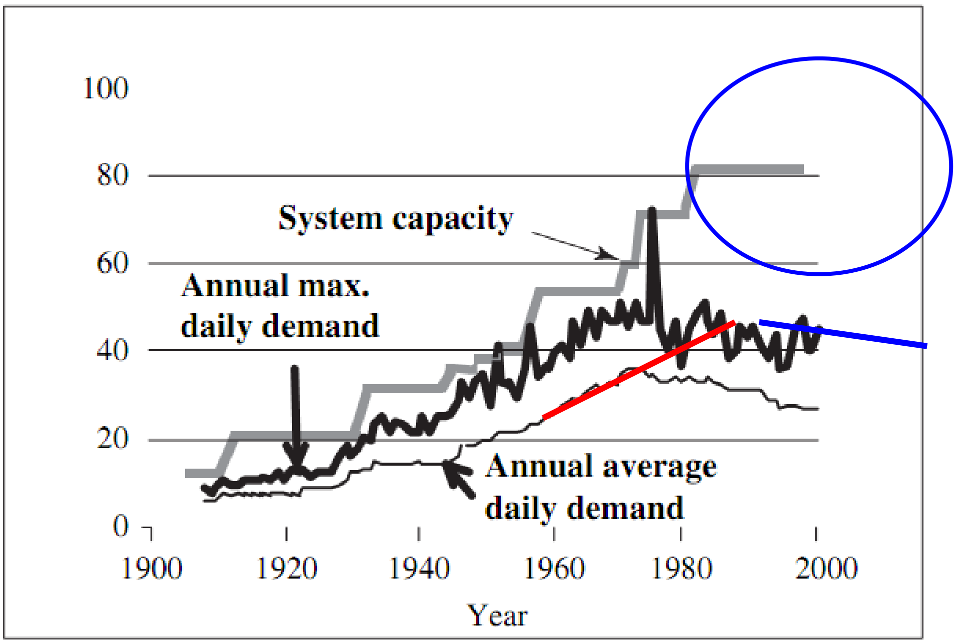

Figure 27. Responding to an extreme event based on historical trends led to an increasing and expensive gap between capacity and consumption for a big city in Switzerland (adapted from Pahl-Wostl 2005).

4.5.2. Management and governance

> *'Water management regimes are still shaped by the tradition of a command and control approach focusing on technical solutions'* (Pahl-Wostl 2007b).

Command-and-control approaches see humanity and nature as separate entities

Adaptation response options include retaining present approaches and assumptions, or changing the mental models and structures on which chosen pathways will be based, including government and institutional arrangements (e.g. retaining Wellington's present governance or water-management structure). Many authors writing from adaptive management, resilience, and systems perspectives highlight a contrast between their views, and 'traditional', 'hierarchical' and 'command-and-control', or 'market-based' management approaches. For example, the command-and-control approach is seen as an overly simplistic and a 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, Gunderson and Ludwig 2002).

Systems-perspective approaches see humanity and nature as existing within a coupled system

In contrast, an adaptive / systems / 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. Ostrom's work demonstrates that the 'conventional wisdom' of 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 non-private goods, and individuals as rational utility maximisers is 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).

However, pre-conditions for resilience such as diversity, modularity, and overlap are often seen as signs of waste and inefficiency within the present dominant paradigm (Ostrom 2009, Folke 2005). For example, the PricewaterhouseCoopers report on governance options for Wellington (PWC 2010) identifies issues such as 'diffuse leadership', 'duplication' and 'fragmented decision making' as common undesirable themes identified by recent governance studies.

A hierarchical governance structure can increase power imbalances

A further concern is that the uneven balance of power in society advantages more powerful actors who can '*tilt the playing field such that information and knowledge are further skewed in their favour'* (Adger et al. 2006, p.9). A more hierarchical governance structure increases this power imbalance, and affords greater opportunity for those with power to push agendas or solutions (Adger et al. 2006). Moreover, such a 'top-down' structure is often impervious to feedback from resource users and civil society (Adger et al. 2006), undermines trust (Ostrom 2009) and legitimacy (Adger et al. 2006), and is therefore detrimental to the social interactions and processes required for increasing adaptive capacity. Ioris (2008) also identifies that conflicts of interests between government agencies and lobby groups, policy inertia, and an uneven balance of power often distort water-management outcomes.

Water management presents an issue of commons governance

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. Water management therefore presents a commons governance issue. 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. 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). With regard to water management in Wellington, this would mean that a more collaborative, participatory, and incentive-based approach is taken, to facilitate community participation, innovation, and the emergence of community-based institutions.

Dietz et al. (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, which 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. 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,** i.e. facilitate iterative development, community participation, and social learning.[24]

Adaptive management acknowledges uncertainty and facilitates experimentation, learning, and change

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), (e.g. see Fig. 28).

[24] 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).

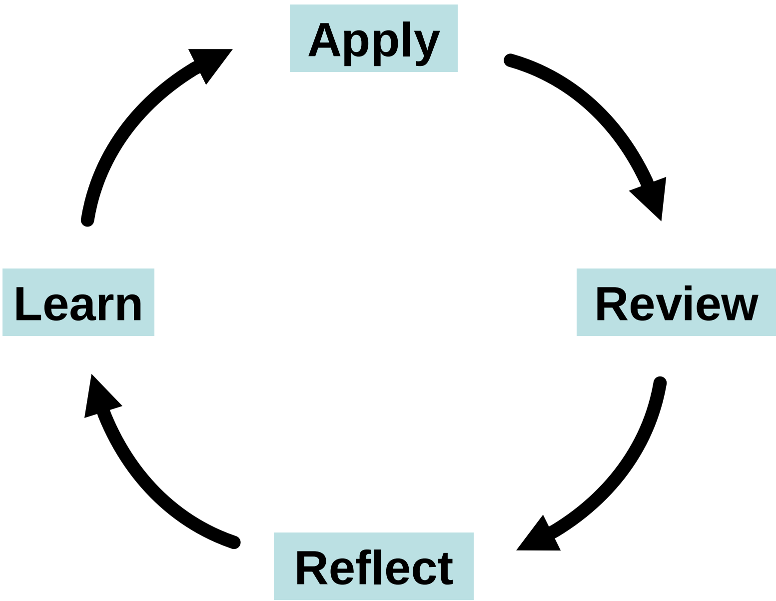

Figure 28. The adaptive management cycle.

The adaptive management concept can be used in a broad sense to inform the design of policy (Pahl-Wostl 2007b). Applied in this way adaptive management is an example of an intervention to facilitate experimentation, learning, and change that can be applied at a high level (ie. consistent with the above points from Dietz et al. 2003). 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). This participatory form is consistent with recommendations from the literature for dealing with wicked problems, highlighting the need to include 'multiple legitimate perspectives,' or at least a broad range of perspectives in decision making (Ravetz 2006).

4.6. Summary

How might Wellington as a community adapt to water shocks or constraints, and what might impede or facilitate adaptation?

The water-management system should be transparent and understandable and can draw on the experiences of other cities

Wellington's water management system contains some 'polycentricity' (Ostrom 2009) and institutional variety (Dietz et al. 2003). For example, responsibility for water supply is delegated to GWRC, a democratic entity with a jurisdiction based on water catchment boundaries. WCC and HCC 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, providing greater potential for learning and adaptation. Any changes to governance arrangements would need to consider that a more hierarchical structure could be detrimental to Wellington's adaptive capacity, and might restrict learning by policy and programme experimentation. On the other hand, the water management system should be transparent and understandable to the public, and the experience of other cities (especially in New Zealand) can reasonably be drawn on to learn lessons about adaptiveness of water management.

From a resilience perspective, Wellington currently has the advantages of:

- vertical and horizontal separation of water services
- declining per-capita consumption (indicating that the community is responding positively to water constraints
- being able to support greater-than-expected population growth by 2025, with current supply capacity
- the centralised water supply being exposed to fault movement, providing an opportunity to highlight general resilience adaptations—e.g. rainwater use.

However, given the following issues, Wellington could easily maladapt, or adaptation could be inadequate.

- **A lack of trust:** perhaps resulting from failure to acknowledge the full complexity of urban water management, and to effectively engage the 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. Augmentation, by reducing exposure could also reduce awareness and reverse the current trend of declining per capita water use.
- **Lack of signals:** commercial water users have a price signal too weak to incentivise structural efficiency, and no legislative signals. Domestic water users have only restrictions and their own moral and cultural motivations.
- **Assumptions:** the tendency to assume hierarchical governance, centralisation and rationalisation, and market economic solutions, coupled with political manoeuvrings that pose significant barriers to retaining or implementing resilience precursors—i.e. diversity, modularity and redundancy.

Shifting greater attention to the demand side, and using collaborative and participatory approaches, is likely to be of great long-term benefit to communities adapting to climate change

An increase in supply or storage capacity that leads to increasingly casual attitudes to the use or wastage of the resource is an evident form of maladaptation. 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. When the community's water intensity is relatively low, augmentation will be necessary.

While the attention of water managers may be naturally drawn by the tightness and tangibility of the supply-side loop, shifting attention to the demand side, *and* using collaborative and participatory approaches, is likely to be of greater longer-term benefit to communities adapting to the effects of a changing climate. Attention to the latter approach could increase adaptive capacity, while a supply management focus could increase vulnerability.

5. Conclusion: Resilience and urban water management

This research used modelled climate data, interviews, and a systems-modelling workshop to address the following question. What factors might lead Wellington as a community to a pathway of greater adaptive capacity and resilience, and what vulnerabilities might lead to insufficient adaptation or even maladaptation?

5.1. Resilience and vulnerability

5.1.1. Enhancing resilience

Key components of resilience are diversity, modularity, and overlap. In general, these components of resilience are enhanced by:

- polycentric governance and management structure
- treating mains water and rainwater as complementary, and fostering the latter.

A further consideration for resilience is transformability, or the ability to fundamentally change the system if required (Walker 2004). Transformability is enhanced by:

- mental models able to navigate complexity
- participatory adaptive management and the inclusion of a broad range of perspectives in decision-making.

5.1.2. Reducing vulnerability

Elements of vulnerability are exposure, sensitivity and adaptive capacity. The following factors and options beneficially influence these elements.

- Structural demand management policies, including water pricing.
- Trust and awareness building (e.g. around conservation options).
- Participation and collaboration, particularly over long-term management options.

5.2. Participatory adaptive management

Instituting a participatory adaptive-management approach and incorporating insights from common-pool resource management can increase adaptive capacity

In particular, instituting a participatory adaptive-management approach and incorporating insights from common-pool resource management are options that increase adaptive capacity. Participatory adaptive management provides a platform for ongoing participation and collaboration, which is required for social learning and collective action, and provides the flexibility to change when conditions change.

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. Pahl-Wostl (2007b) suggests that to achieve changes to enable innovative approaches to water management, the initial focus for a way forward should be on initiating processes of change and experimentation, rather than *'on developing and analyzing models for an optimal integrated and adaptive water management regime'.*

5.3. Wellington water management

There must be sufficient understanding of the local context to take local factors and dynamics into account

This case study was centred 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 to take local factors and dynamics into account. Factors of particular significance to Wellington include declining water intensity, strong public aversion to water metering, potential changes to governance and management structures that could reduce resilience, and that future climate dynamics may involve increasing rates of change and greater extremes.

5.3.1. Pilot project

A pilot study could gain further insights, which could then be applied and up-scaled in an iterative manner, consistent with an adaptive-management approach

Within the diversity currently provided by Wellington's disaggregated water management structure, it would be possible to establish a pilot study of demand management with a participatory / collaborative focus (i.e. drawing on insights from management and governance of common-pool resources). Such a study could be used to gain further insights, which could then be applied and up-scaled in an iterative manner, consistent with an adaptive-management approach. Based on the analysis conducted for this case study, the following principles could be used to inform the design of such a study.

1. Prioritise structural demand management.
2. Rainwater and mains water are complementary—water security AND water resilience.
3. Provide all water users with a price signal linked to consumption.
4. Meter only to the required information needs[25].
5. Regulate old and undesirable behaviours and habits.
6. Facilitate change through collaborative / participatory and iterative development strategies.

[25] For example, it may be possible to charge a partial volumetric component (e.g. 50 percent) based on average demand for a given level of resolution, e.g. a large apartment building, or a residential demand zone of up to 1000 households. Metering to an individual household level is expensive and may not be possible in the example of an apartment building, or may not be politically feasible in Wellington.

Based on this advice and insights from this case study, a pilot project could be used to pilot a collaborative / facilitative approach to water conservation. Such a study could include a range of household and community types, (e.g. intercity apartments; suburban, commercial), and areas of differing socio-economic status. Participants contributing to the design would help to embed and evaluate the pilot for their community. Insights could then be incorporated into a regional scale adaptive-management strategy.

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7. Appendix 1: Systems-thinking tools

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 labelled 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.

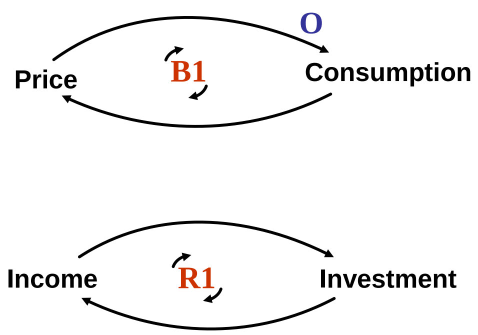

Figure 29. Simple structure diagrams showing balancing and reinforcing feedback structures. In general, an increase in price leads to a decrease in consumption, which leads to a decrease in price, and an increase in consumption (Loop B1). Loop R1 indicates that an increase in income enables an increase 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. 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).

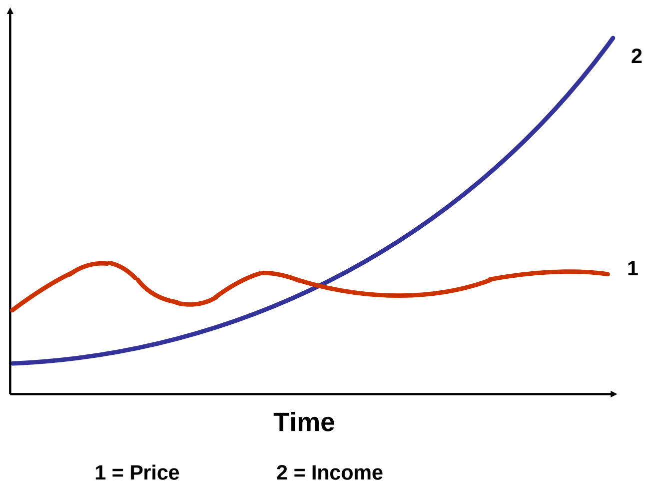

Figure 30. **Behaviour over time graph for the variables 'Price' and 'Income' above.**

7.1. 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 a researcher to minimise the time commitment, and a considerable effort was made to include and accommodate a diversity of perspectives. 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. As a dynamic system is always changing, and our knowledge is never complete, a shared mental model will also never be complete.