WATER RESILIENCE OR WATER SECURITY? MANAGING RESIDUAL RISK IN URBAN WATER SYSTEMS

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ABSTRACT

A confluence of factors including population growth and climate change poses significant challenges to the sustainability of cities worldwide. A case study into climate change adaptation and urban water management was undertaken in Wellington, New Zealand, using resilience and complex systems science approaches. Climate change and water demand scenarios for 2040 and 2090 were generated using Greater Wellington's 'sustainable yield' model and downscaled climate model data. Semi-structured interviews and a systems modelling workshop were conducted to gain an understanding of the local context for adaptation, resilience and response option selection. Analysis of modelled data indicates that with a 20% reduction in 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. Analysis of workshops, interviews and literature indicates that enhancing community adaptive capacity to increase resilience to water shortages requires social learning, a process that could be facilitated through participative and collaborative approaches to water management. A pilot is proposed to initiate the processes of cross-scale experimentation, learning and adaptation – from end users, to water managers and government decision makers.

KEYWORDS

Climate change adaptation, resilience, residual risk, urban water systems, adaptive management

1 INTRODUCTION

Adapting to a changing climate is now a necessity since past and present carbon dioxide emissions represent a commitment to further warming for the next few decades (Jones 2010, IPCC 2007b). Local-level projections can be used to provide an indication of the likely impacts of climate change and the rate of change that must be adapted to over time. For example, the frequency and severity of drought is projected to increase over time for some regions of New Zealand, particularly northern and eastern areas (Hennessy et al. 2007, IPCC 2007b).

In general an increased frequency and severity of drought will increase the capacity requirements for a water system, since demand for water tends to increase in response to dry conditions, but water supplies become more constrained. However 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). A primary factor many urban water systems must continually adapt to is the increasing water needs of growing populations.

The Intergovernmental Panel on Climate Change (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"*. From a systems perspective, climate change adaptation can therefore 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 pressures and drivers.

In an interconnected system, the decisions communities' make will be influenced by current and previous events, present and projected trends, existing structures and approaches and on previous decisions. The decisions that are made will have wider social, economic, cultural and ecological implications, including for a community's own resilience and sustainability. This paper presents and discusses findings of a case study into urban water management and climate change adaptation in Wellington New Zealand. It then suggests a pilot project to initiate a more flexible and adaptive approach to urban water management. The aim of a pilot would be to initiate cross-scale experimentation, learning and adaptation – from end users, to water managers and government decision makers, to better align urban water management with the demands of a dynamic and interconnected environment and society.

2 RESEARCH BACKGROUND AND FRAMEWORK

A case study into climate change adaptation and urban water management was undertaken in Wellington, New Zealand, using systems-thinking, resilience[1] 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). The case study focused 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 the case study was 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.

3 METHODOLOGY

3.1 HYDROLOGICAL, CLIMATE AND WATER-USE PROJECTIONS

Greater Wellington's (GW) Sustainable Yield Model (SYM) was used to generate daily Potentially Available Water (PAW) and Per Capita Demand (PCD) data, providing both supply and demand projections, without storage for analysis. PAW represents daily abstractable volume in ML from Te Marua, Waterloo and Wainuiomata water treatment plants combined, with existing 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.

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[1] **Resilience** is the ability of a system to absorb disturbances while retaining the same basic structure, ways of functioning and self-organisation (IPCC 2007).

[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).

The National Institute of Water and Atmospheric research (NIWA) provided 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 Intergovernmental Panel on Climate Change (IPCC) emissions scenarios (B1, A1B, A2) for ‘2040’ (averaged over the 2030 to 2049 period[3]) and ‘2090’ (averaged over the 2080 to 2099 period). 12 general circulation models and the 12 model average were used to produce projections for each emissions scenario. Further background to the use of this model set is available in Reisinger et al. 2010).

Data for PAW, Total System Demand (TSD) and PCD were received as SYM outputs from Greater Wellington Water. In addition ‘net-flow’ was calculated by subtracting TSD from PAW. Net-flows and running net-balances (running net-flows) were calculated to explore water intensity and climate change scenarios for 2040 and 2090. For 2040, only the A2 projections are needed since the IPCC emissions scenarios do not differ significantly in 2040 (Reisinger et al. 2010). This paper presents findings from the scenarios and projections analysed for the Wellington urban water management case study. A detailed methodology for obtaining these projections will be published in NIWA’s climate change urban impacts toolbox[4], along with a discussion on the limitations and uncertainties. A case study report will also be available from the NZ Climate Change Research Institute’s website - http://www.victoria.ac.nz/climate-change/.

3.2 UNDERSTANDING THE DETERMINANTS OF ADAPTIVE CAPACITY

This paper uses ‘structure diagrams’ to illustrate system structures and feedbacks according to the conventions outlined in Appendix A. Structure diagrams provide a means to explore and interpret relationships and interactions between many system variables. The structure diagrams were derived from stakeholder workshops, interviews and literature analysis, which were conducted to gain an understanding of the local context for adaptation, resilience and response option selection. The first workshop session used the hexagons method to capture issues identified by the participants during a brainstorming session (Hodgson 1992). 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 of the issues and their relationships could be mapped using a ‘causal loop diagram’ (CLD) (Maani and Cavana 2007), referred to in this paper as a structure diagram, and relates to the structures and feedbacks layer as seen in the iceberg model in Figure 3.1. Insights from the participatory modelling workshop with a wide range of stakeholders was combined with insights from interviews and literature to produce the structure diagrams presented in Section 4.2. A range of literature was accessed, from local news articles, to local government publications and peer-reviewed journal articles.

Figure 3.1: The Iceberg Model, systems thinking attempts to identify and address underlying conditions, ‘events’ are seen as emergent features of complex systems.

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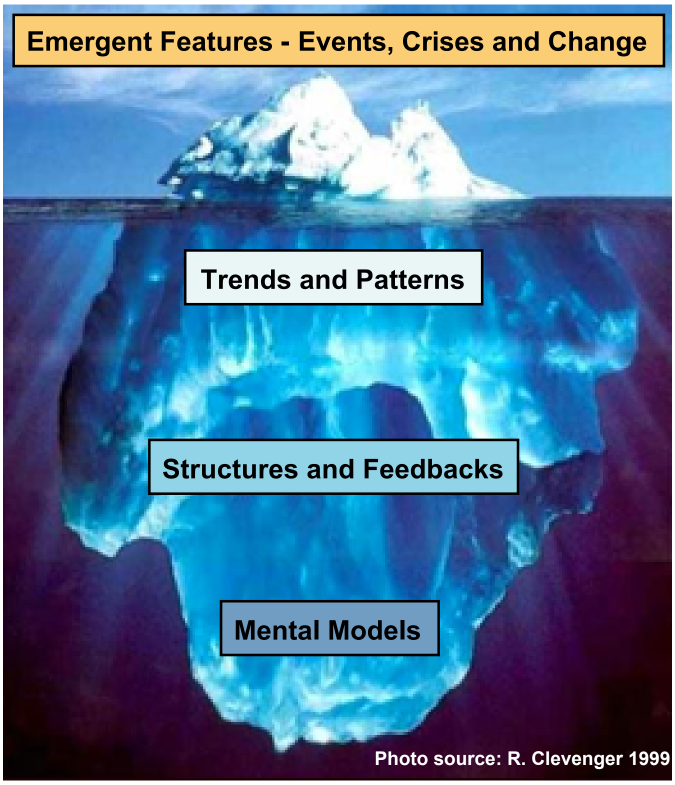
[3] This 20 year averaging removes *“much but not all”* of the natural variability as represented by the models (Resinger et al. 2010).

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

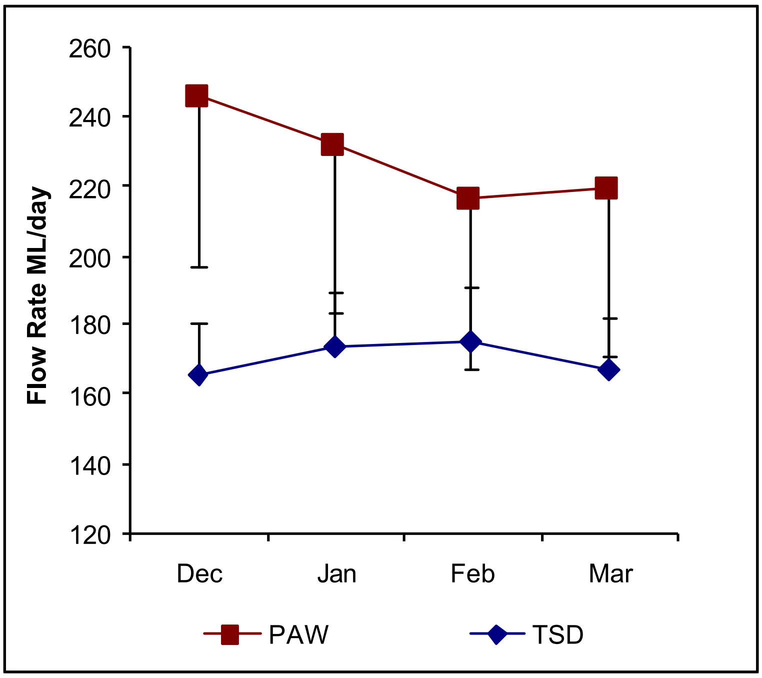


4 RESULTS

4.1 WATER SUPPLY AND DEMAND DYNAMICS

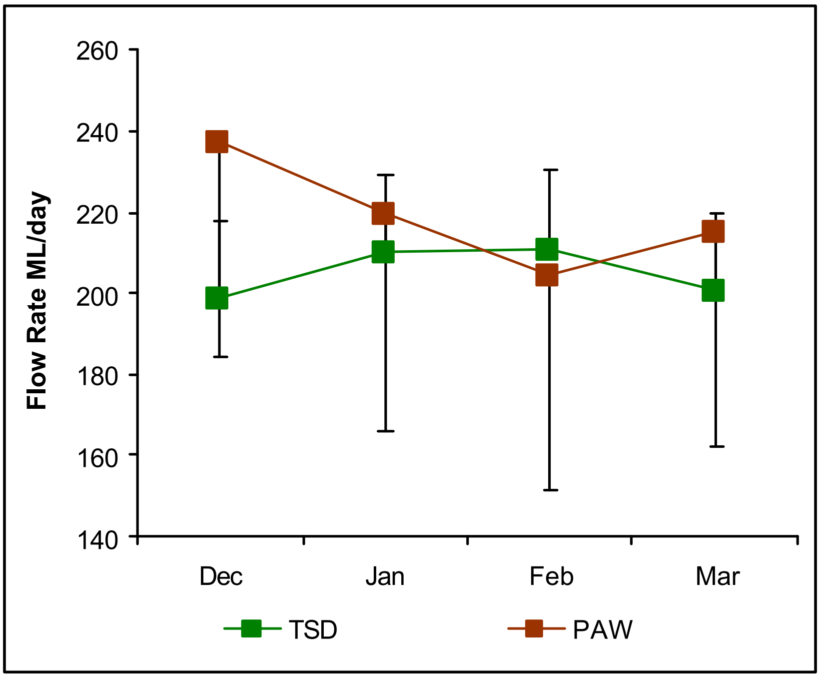
The seasonal variation of supply and demand can clearly be seen in Figures 4.1 and 4.2 below; demand is greatest in summer when supply is most restricted. Whilst there is sufficient water to meet projected demand under average current summer conditions, substantial overlap occurs during January, February and March at just one standard deviation (Fig. 4.1).

Figure 4.1: Average daily supply (PAW) -1 standard deviation, and average daily demand (TSD) + 1 standard deviation in ML/day, from December to March under present climate variability.



As shown in Figure 4.2, 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 4.2: 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).



The potential impacts of climate change on water supply and demand in Wellington were calculated by comparing projections for 2040 and 2090 with current Per Capita Demand (PCD) and Potential Available Water (PAW). By 2040 climate change could decrease PAW by 5% or 12 ML per day on average for January and February (Fig. 4.3). The 12 ML difference in PAW is the gap between ‘current’ and the 2040 scenarios for ‘Jan/Feb’. The projected decrease in PAW between 2040 and 2090 is 5.5%, and the projected increase in PCD from 2010 to 2090 due to climate change is 3%.The combined effect of climate change and population growth on demand would be an average increase of 2.1 ML/day for January and February 2040. With average PCD modelled at 404 L/day[5], and the projected population increase, climate change accounts for 14.1 ML of water for January and February 2040 (i.e. in relation to a reduction in net-flow), or a average daily shortfall of an equivalent volume of water sufficient to supply 35,000 people.

Figure 4.3: Average daily supply (PAW) 2040 and 2090 by month and IPCC A2, B1 and low carbon scenarios (Mod 12).

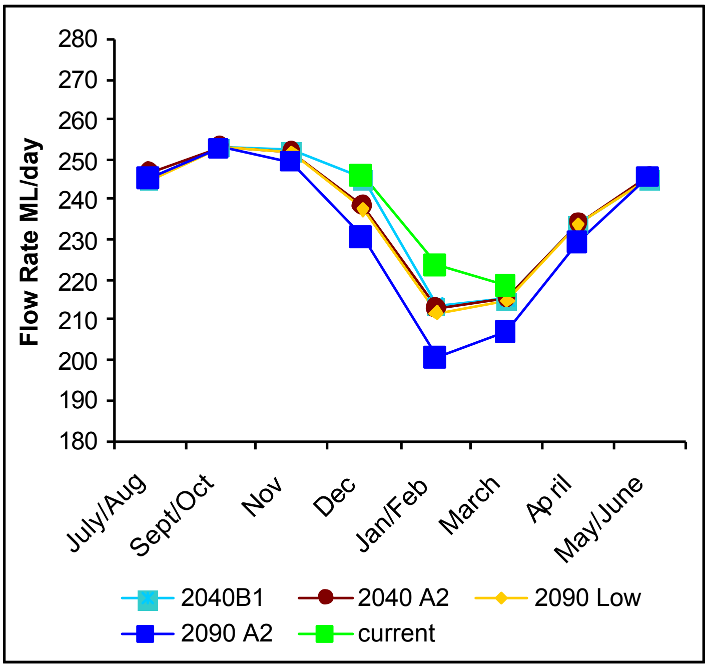
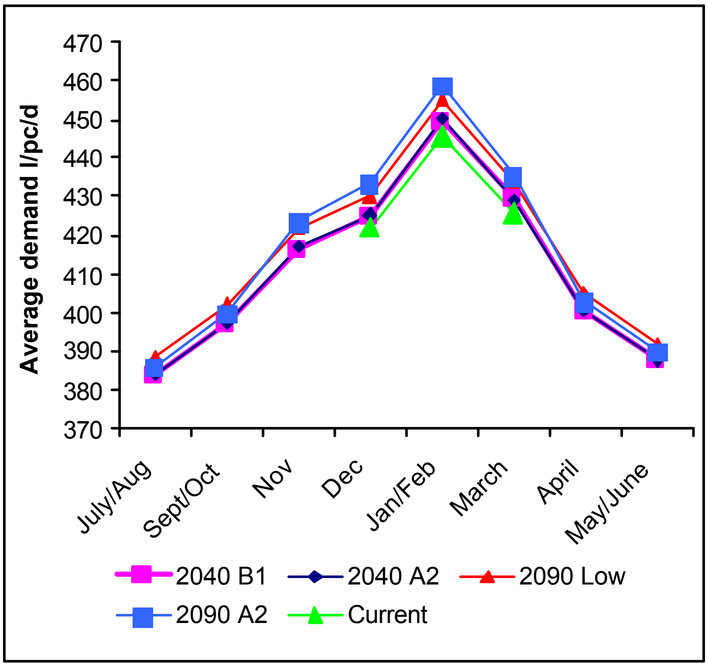


Figure 4.4: Average Per Capita Demand (PCD) 2040 and 2090 by month and IPCC A2, B1 and low carbon scenarios (Mod 12).



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[5] PCD in the SYM model is based on average water consumption of the last 5 years, which is currently 404 ML/day.

4.2 REDUCING DEMAND TO OFFSET CLIMATE CHANGE AND POPULATION GROWTH

While PCD in the SYM model is based on average water consumption of the last 5 years, which is 404 ML/day, daily per capita water consumption for Wellington has been decreasing steadily for both peak and base demand. Wellington's population has been growing at an average of 1% over the last 10 years, yet demand has been falling and in total, PCD fell 25% between 1990 and 2010. The average rate of decline in Wellington's water intensity has been 3.3% per year over the last 4 years, or 1.5% per year averaged over the last 10 years (see Figure 4.5). If the 1.5% average annual reduction in per capita demand continues to 2025, along with a 1% annual population increase, Wellington's aggregate consumption of 375 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 4.1).

Figure 4.5: Declining per Capita Demand in Wellington 2001- 2010 (Capacity 2010).

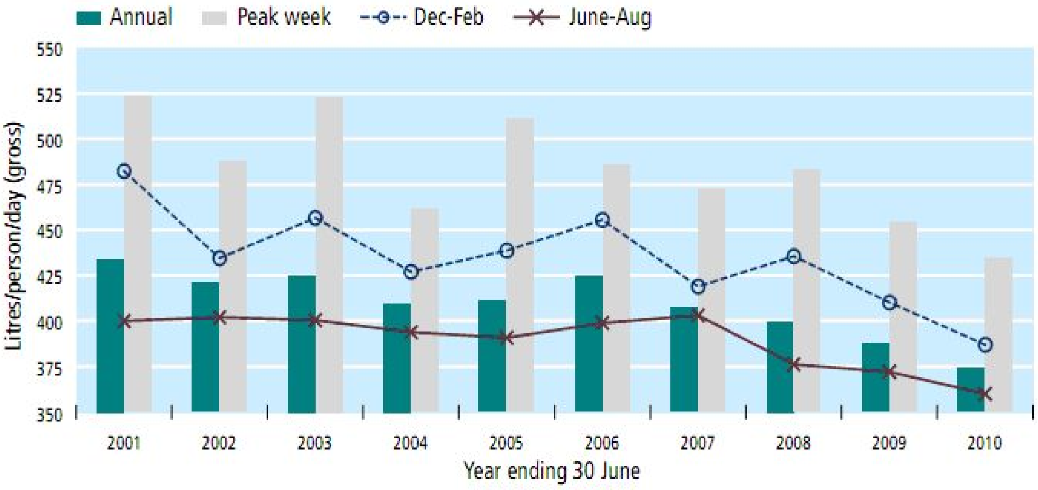

Table 4.1: Water savings and changes in consumption and population to 2025 with 1.5% annual demand reduction and 1% population growth. A projection for the '2040 scenario' column is shown in Figure 4.6.

Year	**2010**	**2015**	**2020**	**2025**	**2040 Scenario**
Aggregate PCD (L/day)	**374**	347	322	***298***	303
Domestic PCD[6] (L/day)	**235**	218	203	***189***	191
Population	**390,000**	410,000	431,000	***453,000***	467,500[7]

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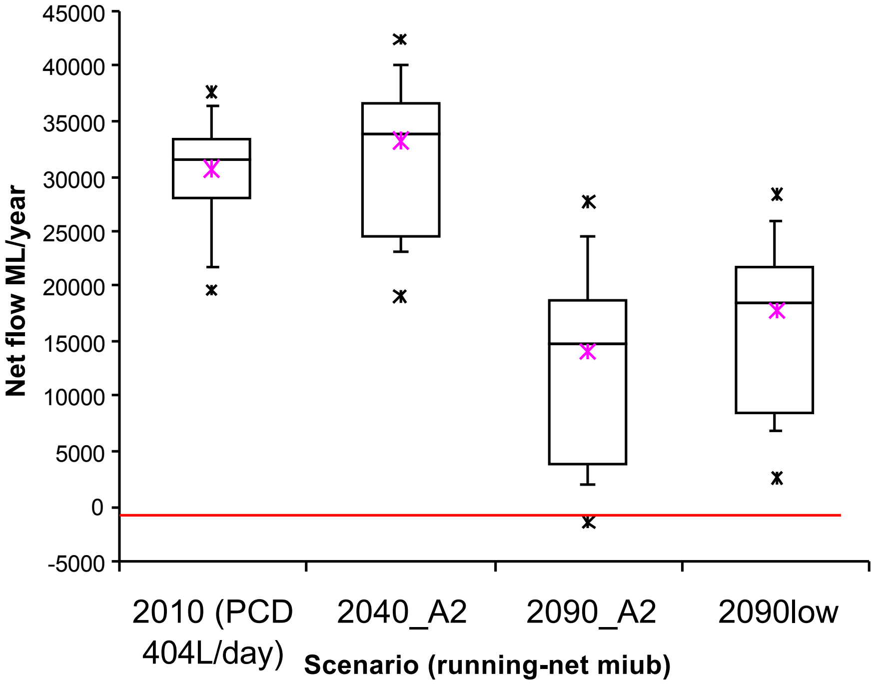
[6] 63% of Aggregate PCD

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

Annual Average Consumption (ML/day)	**146**	142	139	***135***	**142**
Water saving (Per Capita, 2010 baseline)	0%	7%	14%	**20%**	20%[8]

Auckland's current level of water intensity and the calculations in Table 4.1 show that a reduction to 303 L/day is theoretically feasible by 2025. Figure 4.6 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. A contrasting scenario with average per capita demand at 404 L/day is shown in Figure 4.7. Where net flow drops below zero, this indicates that even with adequate storage, there would not be sufficient surplus water to balance supply and demand over a year.

Figure 4.6. 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. 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.



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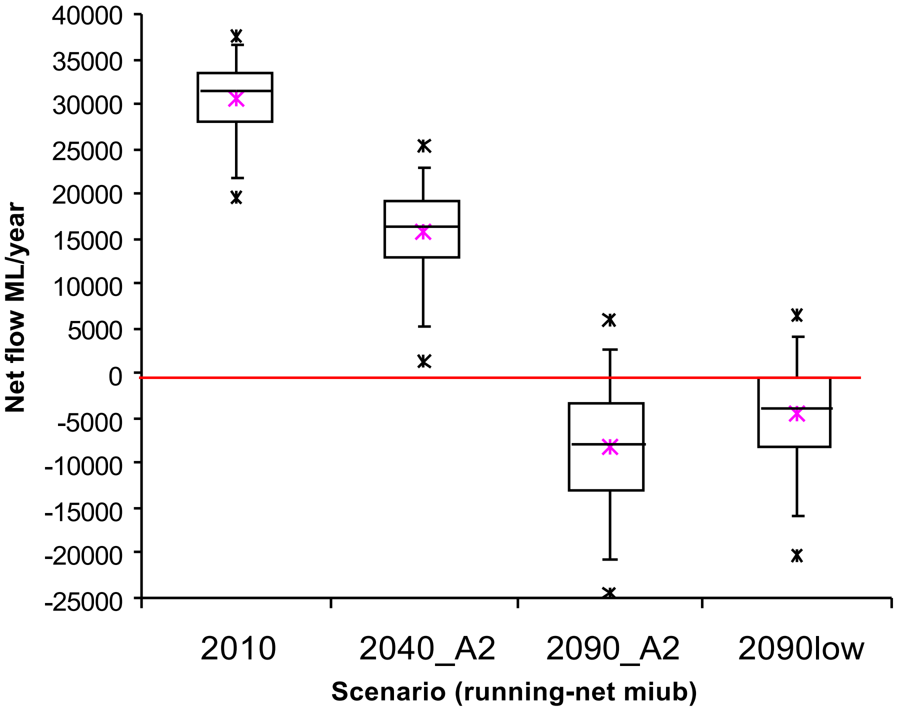
[8] Includes 1% projected increase in PCD due to climate change.

Figure 4.7. Running net-flows for 2040 A2, and 2090 A2 and low-carbon scenarios, for projected population growth with average aggregate per capita demand equivalent to 404 L/day.



4.2.1 EXPLORING EXTREMES

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 may differ 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). For example, a community with a high water intensity, dependent on a 'run of river' supply, and minimal storage, may be more vulnerable to water shortages than a community with a much lower water intensity, and with less dependence on river flows.

Trenberth (2011) suggests that **trend** plus **variability** may be useful for understanding extremes. The 2040 and 2090 projections shown in Figures 4.3 and 4.4 indicate trends for supply and demand with climate change. The means shown in Figures 4.6 and 4.7 indicate the trend for each scenario with climate change, population growth and water intensity. The spread of the box plots shown in Figures 4.6 and 4.7 indicate variability, and these individual events can be seen in the data series. A scenario with average PCD of 303 L/ day was calculated for Wellington for 2040 (A2 mod12)[9]. The net-flow over an 80 day period (80 day running-net, as seen in the event profiled in Figure 3.10 gives the largest deficit for this scenario (a longer or shorter duration fails to capture the full extent of the largest 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, with miub and mpi model projections used to indicate the range of variability at the peak of the deficit.

Two 'extreme' events with deficits of 14,000 to 15,000 ML appear in the data (one per 57.5 years), one of which is shown in Figure 3.8. As seen in Figure 3.8, 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 3.8 also shows a 202 L/day PCD scenario, which indicates a 'minimum bound' for a severe deficit event, such as might occur under

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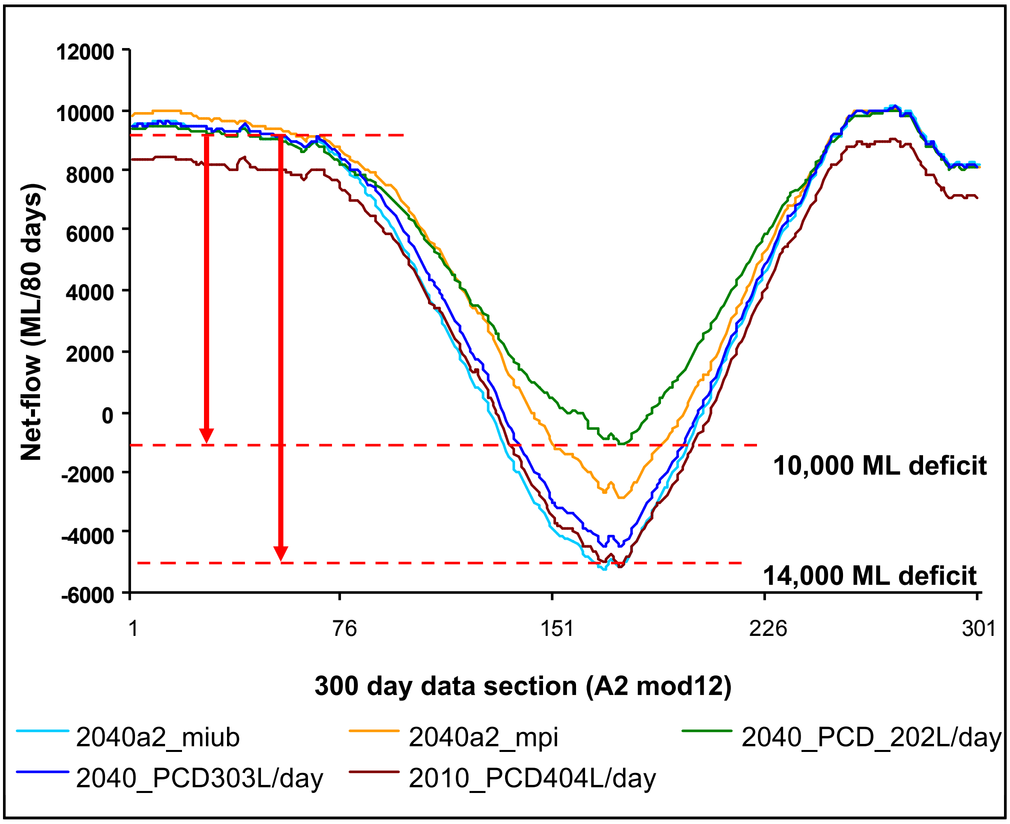
[9] i.e. using the IPCC A2 scenario projected by the 12 model average.

optimal demand management conditions in 2040[10]. The actual average PCD for the section of the 202 L/day scenario shown is 210 L/day, with PCD at 271 L for the maximum day.

Figure 4.8: 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.



4.3 MANAGEMENT PATHWAYS AND REDUCING VULNERABILITY TO WATER SHORTAGES

Vulnerability to the potential impacts of climate change 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. 2.1). In this schematic, policy interventions aiming to reduce vulnerability (in order to increase resilience) can either reduce exposure or sensitivity, or increase adaptive capacity. Vulnerability is defined by the Intergovernmental Panel on Climate Change (IPCC) as:

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

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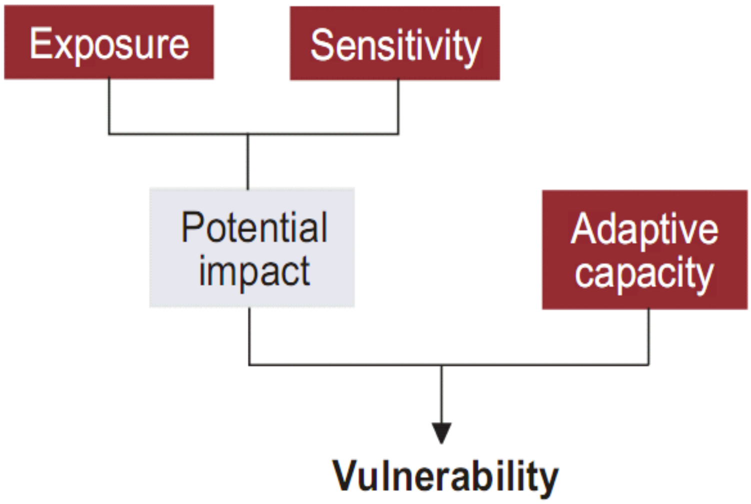
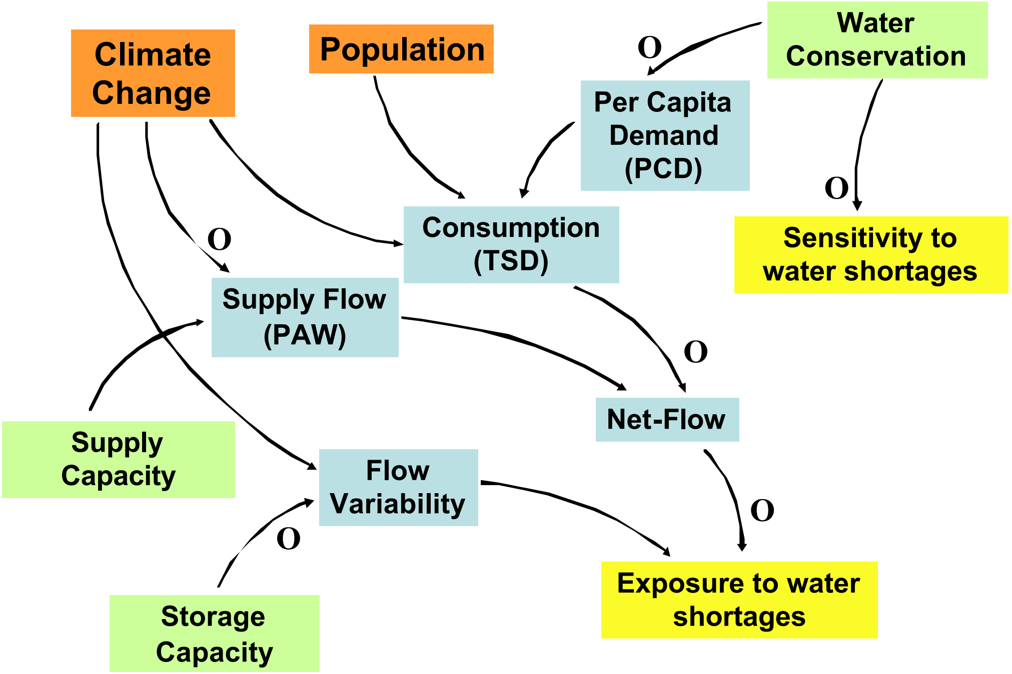
[10] The 202 L/day scenario provides a lower bound as it requires a reduction in PCD of nearly 50% from 2010.

Figure 4.9: Vulnerability and its Components (Allen Consulting Group 2005).



Along with adaptive capacity, exposure and sensitivity are key elements of vulnerability (Adger 2006, also see Figure 4.9). 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 4.10 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. 'Water conservation' refers to reducing water use in general, including through water efficiency.

Figure 4.10: 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[11]*. As discussed in Appendix 1, an 'O' at the end of an arrow indicates that a change (i.e increase or decrease) in the originating variable causes an Opposite change in the destination variable.*



Starting with a community with an increasing exposure to water shortages (highlighted yellow, near the bottom of Figure 4.11); 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)[12].

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 4.11: 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.

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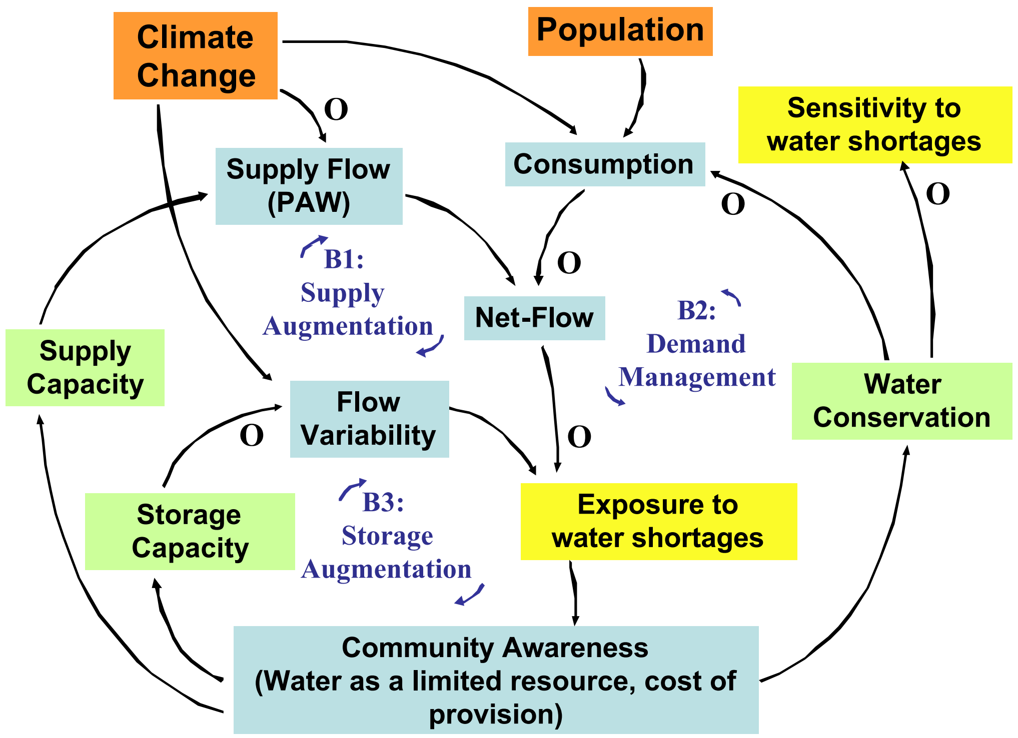
[11] Guidance for interpreting structure diagrams is in Appendix A. Feedbacks and system dynamics are illustrated in following figures.

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



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 (Figure 4.12). The sudden drop in exposure due to the intervention, as illustrated in Figure 4.12, relates to the 'lumpiness' of supply and storage augmentation, which tends to occur in large increments (see also Figure 5.1). However, without demand management as the primary response option, sensitivity continues to increase, since the community continues to grow in a water-intensive manner.

Figure 4.12: 'Behaviour over time' (BOT) graph[13] *demonstrating implications for exposure and sensitivity to water shortages with and without water conservation as the primary response pathway.*

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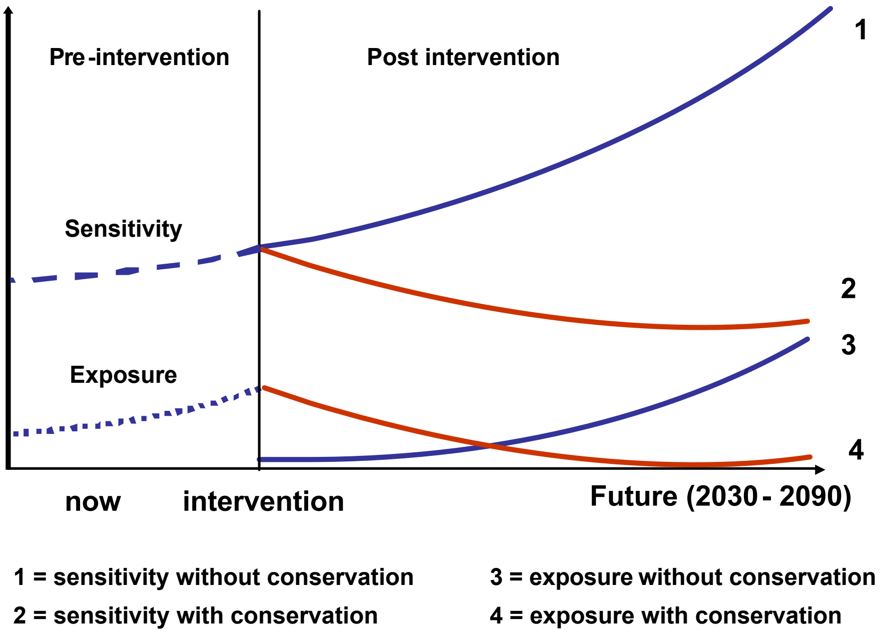
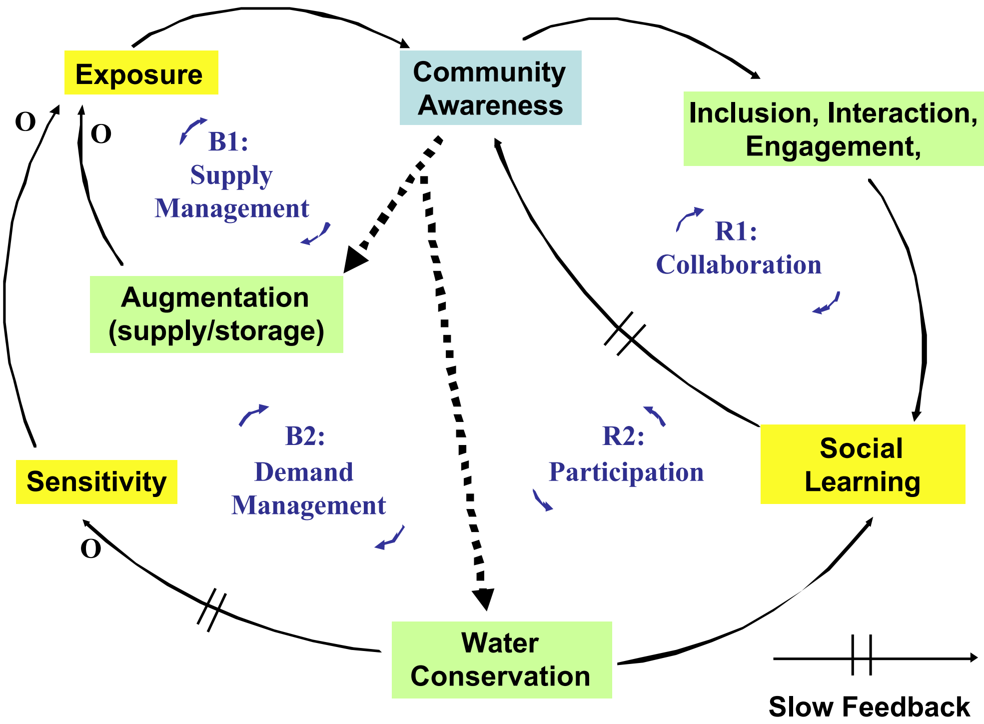
[13] A BOT graph is a systems thinking tool often used in conjunction with structure diagrams, and indicates the trend over time. Further background on interpreting BOT graphs is in Appendix 1.



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, implementation of such a pathway is not likely to be cost-free, either in resource or political terms.

An approach orientated toward supply and storage augmentation decreases exposure only within the ‘engineeringly’ feasible and financially affordable parameters of the system, but exposure to larger magnitude events remains (i.e. residual risk). As illustrated in Figure 4.13, the Supply Management Loop (B1) forms a tight feedback that can quickly satiate the need to reduce exposure, whereas demand management increases water security less directly, and through longer-term or ‘slow feedbacks’. Broadly, a community’s water-intensity is indicated by its ‘per-capita demand’, and the ‘security of supply standard’ or ‘Annual Shortfall Probability’, indicates the range of variability that the bulk system is designed to manage exposure to. The variables ‘inclusion, interaction, engagement’, and ‘social learning’ in Figure 4.13 are discussed in relation to adaptive capacity in the following section.

Figure 4.13: Structure diagram demonstrating feedback differences between ‘supply management’ (B1) and ‘demand management’ B2[14]*. The water security standard serves as a proxy for exposure, while Per Capita Demand (PCD) could be used as a proxy measure of sensitivity.*



4.4 ADAPTIVE CAPACITY

Adaptive capacity describes the ability of a system to adapt to climate change in order to moderate potential damages, make use of opportunities, or cope with adverse impacts (IPCC 2007). **Adaptability in a socio-ecological system is seen as the capacity of actors in that system to manage resilience** (Walker et al. 2004). In the context of this paper, increasing adaptive capacity is the ability of the community to improve institutions, systems, structures, behaviours and practices in order to increase resilience to water shortages. The term community is used in a broad socio-ecological sense, to represent an interdependent population of people, including households and businesses.

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

Adger (2003) highlights that **social capital** is the "necessary glue" of adaptive capacity, 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, a community with strong social capital could implement a maladaptive[15] response pathway if desired. For example Wolf et al. (2010) found that strong social networks could exacerbate vulnerability if they perpetuate maladaptive narratives (e.g. low risk perception).

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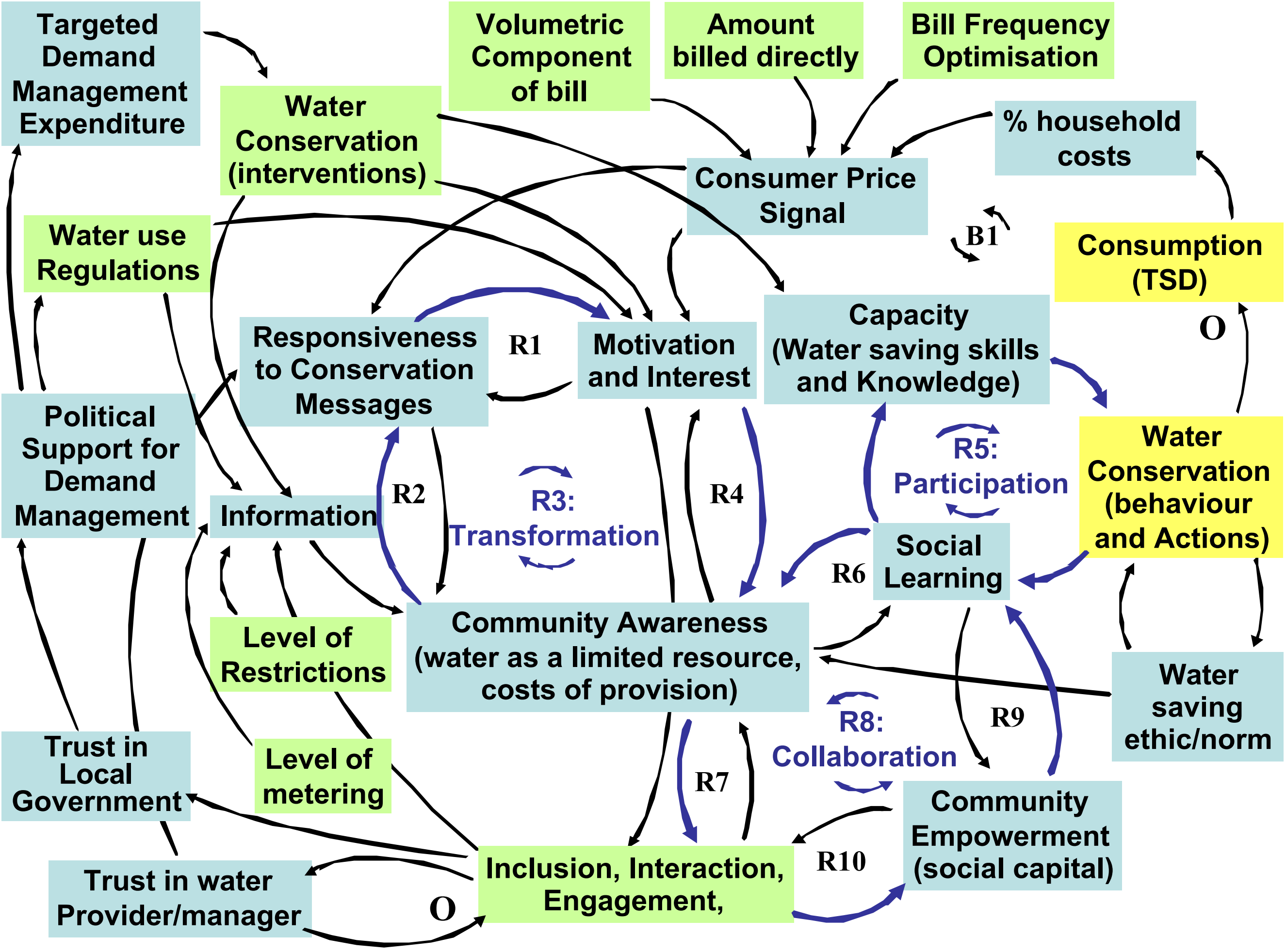
[15] Maladaptation is defined as "*action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups*" (Barnett and O'Neill 2010), 'other groups' could also include future citizens.

If social capital is the 'glue' of adaptive capacity, and collective action is the desired product of social capital, **social networks** are the engine of collective action. Social networks that influence demand management adaptation in a community will include those of the water users, plus the networks of the demand management practitioners, as well as the social networks of any actors opposing demand management (Wolfe 2008).

The previous section identifies the importance of a 'water conservation' pathway for reducing exposure and sensitivity to water shortages. Figure 4.13 then illustrates that increasing community awareness regarding the need and means to save water requires an increase in social learning, through participation in water conservation, and collaborating in managing the resource. The structures in Figure 4.13, R1 – collaboration, and R2 – participation, form virtuous reinforcing cycles to increase social learning, community awareness, and water conservation. A more detailed look at the system dynamics of possible demand side interventions (green) gives some indication of the complexity of the social, cultural and economic interactions that influence water conservation actions and behaviour (Figure 4.14).

Figure 4.14: Feedback structures and system interactions between demand side intervention options (green) and the target variables 'Water Conservation' and 'Consumption' (yellow). R3, R5 and R8 indicate key structures that influence adaptive capacity.



5 DISCUSSION

5.1 CLIMATE VARIABILITY AND LONG-TERM PLANNING

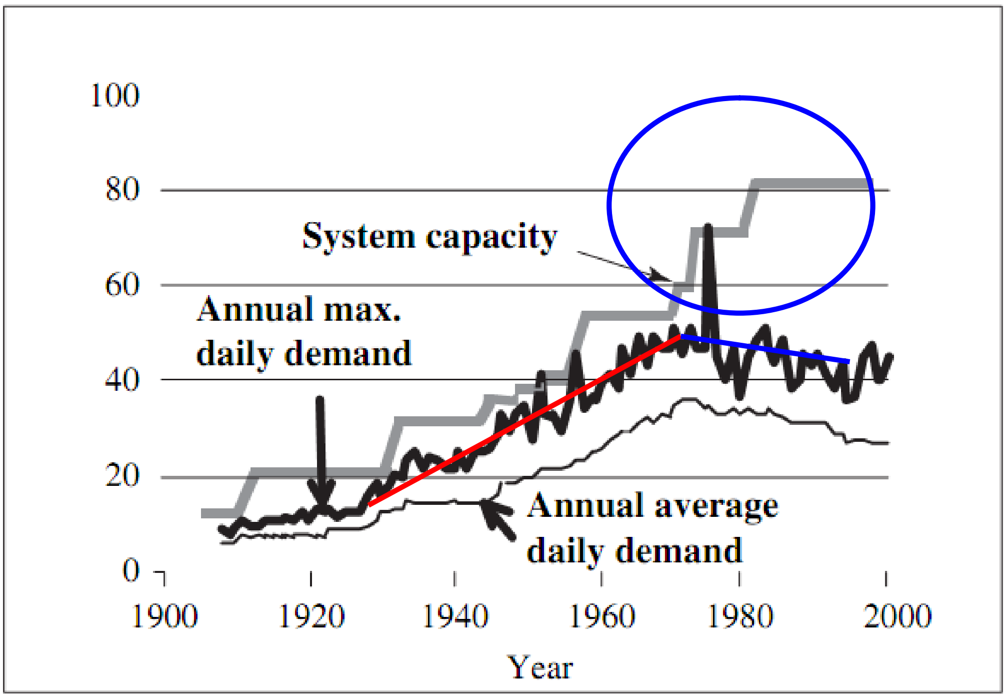
The projected climate parameters for the SYM input files are averaged over a 20 year period, this averaging is necessary in order to capture changes in long-term climate versus more short-term variation. Averaging removes much of the natural variability as represented in the models (Reisinger et al. 2010), yet this variability is a significant consideration at the local scale (Jones 2010). Many of the impacts of climate change are the result of 'surprises' that come with extreme weather (Climate Commission 2011), as this is where most of the damage to communities and assets occurs. However, the most likely failing of local-level analysis is that it **under-represents climate variability** (Jones 2010). Climate models are expected to provide good indications of long-term trends, however, they are not yet reproducing the observed trends in extreme events over the last 50 years (Min et al. 2011). As this observed trend in extreme events may continue, communities will need to prepare for and adapt to extremes.

In some regions of New Zealand, and 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. This increasing risk of extremes, coupled with the under-representation of climate variability in model projections increases the level of uncertainty for probability-based calculations for system capacity requirements (i.e. significantly increases the uncertainty of calculations for long-term infrastructure planning to meet a 1% or 2% water security standard). In addition, 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 (i.e. moderated) summer water use are needed *every* summer.

5.2 SUPPLY MANAGEMENT PATHWAY ISSUES

An adaptation pathway focussed on supply management encounters a number of potential pitfalls. The first is that increasing supply or storage capacity forms a tight feedback that reduces community awareness of water issues: 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 4.11). Increasing system capacity therefore brings the risk of increasing community vulnerability to water shortages. Secondly, 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), but as discussed above in Section 5.1, a more dynamic climate brings increased uncertainty for calculating long-term capacity requirements. Thirdly, the lumpy nature of system capacity increases can lead to 'stranded assets' if capacity is increased in response to an extreme event, but the community's water intensity continues to decline. For example as represented in Figure 5.1, 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 an unnecessary commitment of 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 5.1: Responding to an extreme event and historical trends led to an increasing and expensive gap between capacity and consumption for a big city in Switzerland (adapted from Pahl-Wostl 2005).



5.3 ENGAGEMENT AND COLLABORATION TO INCREASE ADAPTIVE CAPACITY

As outlined in section 4.4, social capital, social networks and social learning are all central to adaptive capacity. Concurrently increasing adaptive capacity whilst reducing sensitivity through demand management therefore requires engaging and collaborating with the community. However water management can be a contentious topic and getting a diverse group of stakeholders to sufficiently consider other legitimate perspectives and mental models is a significant challenge. Examples of successful collaborative water management projects are available in New Zealand, for example the Aorere Catchment Project in the Tasman District (http://www.landcare.org.nz), and significant national level progress was made by participants in the Land and Water Forum. A diverse group of stakeholders have successfully collaborated through this forum to produce a report and recommendations to advise on water management in New Zealand (http://www.landandwater.org.nz).

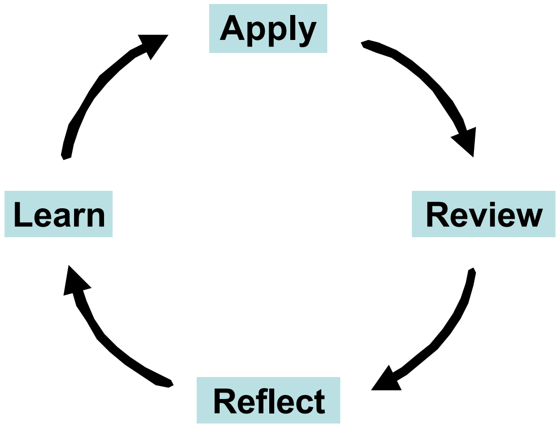
5.3.1 COMMON-POOL RESOURCE MANAGEMENT AND ADAPTIVE MANAGEMENT

Common-pool resource management and adaptive management are management approaches that emphasise engagement, collaboration, and resilience. 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).

Ostrom (2009) has studied CPRs throughout the world, noting that in many cases, users do a better job than governments at managing such resources. Ostrom highlights that increased levels of trust lead to greater co-operation and increased efficacy of social learning. However, trust is often neglected or undermined in order to push through a particular agenda or 'solution' (Ostrom 2009). Ostrom argues that rather than designing institutions to force or 'nudge' people, the goal should be to "*facilitate the development of institutions that bring out the best in humans*" (Ostrom 2009, p.435). With regards to water management, 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, Ostrom and Stern (2003, p.1908) highlight that *"no single broad type of ownership uniformly succeeds or fails to halt major resource deterioration"*, and that governance structures and institutions can help, hinder, authorise or override local control. A key point for devising effective commons governance strategies is to design interventions to facilitate experimentation, learning, and change[16] (Dietz et al. 2003). **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 Figure 3.1). 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 from a top level. 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).

Figure 5.2: The Adaptive Management Cycle.



6 CONCLUSION AND RECOMMENDATIONS

Many communities across New Zealand must adapt to provide for the water needs of their growing populations. For many of these communities, climate change will bring an increasing frequency and severity of drought that must also be adapted to. Many urban water systems are designed to cope with extremes using a probabilistic risk management approach – e.g. annual shortfall probability, drought return period, or security of supply standard (MWH 2011). Meeting the needs of a growing population *and* a changing climate both drive system capacity requirements.

However, climate change brings increased uncertainty for probability based system capacity planning. Also, since water intensity tends to increase during dry weather, and since water systems can only be designed to financial and engineeringly feasible parameters, climate change will very likely increase the level of residual risk that communities are exposed to. Reducing vulnerability to this residual risk requires that water intensity is reduced,

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[16] 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).

particularly during summer, and that adaptive capacity is increased so that communities can better manage their ability to increase their own resilience.

Water intensity can be reduced through demand management/water conservation, while increasing adaptive capacity requires strategies to enhance social learning. Conditions for more effective social learning can be created through management approaches that emphasis engagement and collaboration, such as common-pool resource management and adaptive management. In particular, 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.

Water resilience adaptation and water security adaptation can be achieved concurrently. Increasing adaptive capacity, or the ability of the community to manage resilience, requires broad stakeholder collaboration to facilitate social learning.

6.1 RECOMMENDATIONS

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."*

Based on this advice and insights from this case study, the recommendation of this case study is to establish a pilot project in Wellington. The aim of the pilot would be to facilitate the development of community specific initiatives, policy, structures and institutions for increasing resilience to water shortages and reducing water intensity, through the use of a collaborative approach. The pilot would ideally include a range of household and community types, (e.g. intercity apartments; suburban, commercial), and areas of differing socio-economic status. Representatives from the communities in which the pilot will be conducted will contribute to the design, and to help initiate, embed, and evaluate the pilot for that community. Insights from these pilots could then be incorporated into a regional scale adaptive management strategy.

The design of the pilot would draw on common-pool resource management and adaptive management, as well as insights from successful community collaboration projects involving water management (e.g. catchment management, MfE 2010). The pilot 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.

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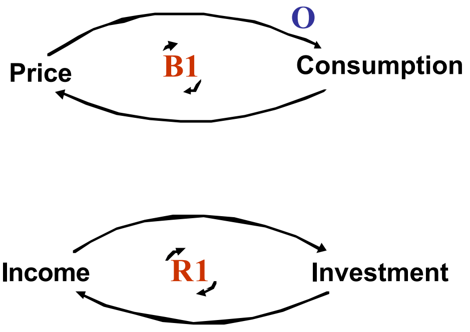
APPENDIX – SYSTEMS THINKING TOOLS

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.

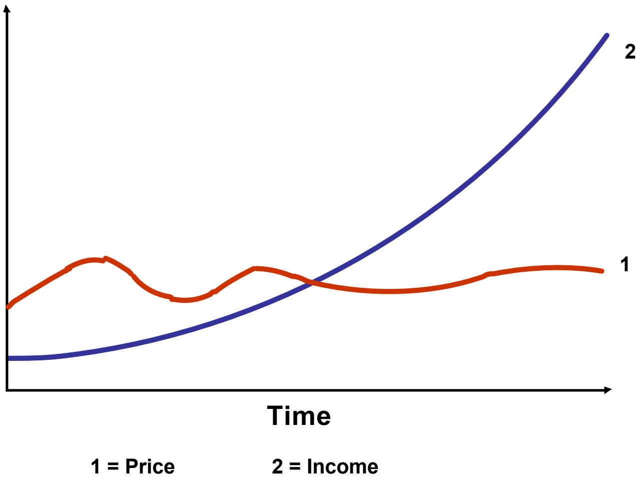
If there is a **balancing or negative feedback effect** in a loop, the loop is labeled with a ‘B’. An ‘R’ indicates that there is a **reinforcing or positive feedback effect**. A reinforcing structure or cycle that produces a desired outcome is referred to as a **virtuous cycle**, while a structure producing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

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



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

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



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.