Impacts of Climate Change on Urban Infrastructure & the Built Environment

A Toolbox

Tool 2.5.1: General information on water supply and demand approaches and issues

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1. Introduction

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

Communities can adapt to increasing water variability by increasing storage or supply capacity, reducing water intensity, or by deploying a combination of these options. In a complex and interconnected system, each of these approaches will have wider social and ecological implications. 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*". Climate change adaptation can therefore be seen as a dynamic process occurring between interacting social, economic and physical system components.

1.1 This Tool

Under the Resource Management Act 1991 (RMA), Local Government is required to have particular regard to the effects of climate change. This tool acknowledges the complexity and interconnectedness of human and natural resource systems. It uses systems-thinking tools to explore the complex dynamics of urban water supply and demand approaches, including relevant social factors, with particular regard to communities adapting to the effects of climate change.

This tool is based on findings of the Wellington case study on urban water supply management, which is part of a FRST funded collaborative research project on community vulnerability, resilience and adaptation to climate change led by the New Zealand Climate Change research Institute (CCRI). This case study used scenarios to explore the impacts of key factors such as population growth, water intensity and climate change on water supply and demand in Wellington, and systems-thinking tools to explore the implications of response options. A key finding of the Wellington case study is the importance of demand management, along with community engagement, participation and collaboration for adapting to an increased risk of water shortages. A full case study report will be available on the CCRI website - http://www.victoria.ac.nz/climate-change/. This case study also informs [Tool 2.5.3], SYM approach to present-day and future potable water supply and demand.

1.2 Water Management - A Multi-dimensional System Challenge

Water management requires decisions on long term infrastructure projects which are highly dependant 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[1], in which water management becomes a complex, multi-dimensional system challenge. 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).

In general, past approaches to water management have been characterised as being 'prediction and control' orientated technical responses (Pahl-Wostl et al. 2007). This overview of water supply and demand approaches acknowledges water management as a multi-dimensional system challenge, and uses a resilience/ systems perspective to provide general policy and management insights.

[1] 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).

1.3 Key concepts - Resilience, Vulnerability and Adaptive Capacity

> *The concept of resilience shifts policies from those that aspire to control change in systems assumed to be stable, to managing the capacity of social-ecological systems to cope with, adapt to, and shape change* (Folke et al. 2002, p.4).

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).

> *In a resilient system, change has the potential to create opportunity for development, novelty and innovation. In a vulnerable system even small changes may be devastating* (Folke et al. 2002, p.4).

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. 1.1). 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*."

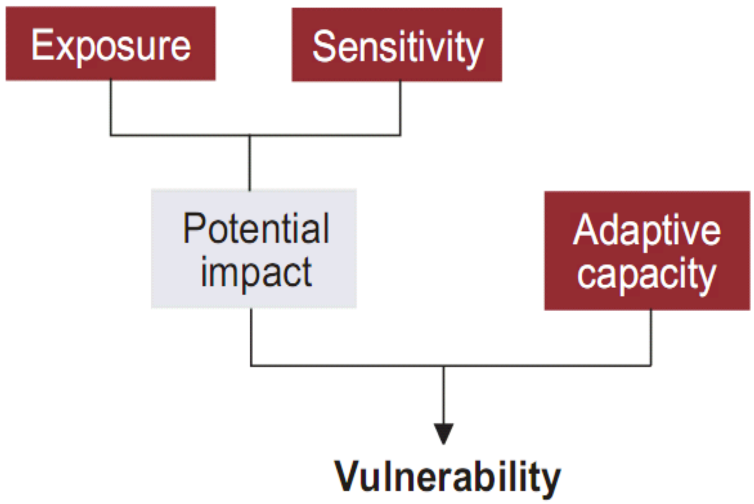

Figure 1.1: Vulnerability and its Components (Allen Consulting Group 2005).

Adaptive capacity describes the ability of a system to adapt to climate change in order to moderate potential damages, make use of opportunities, or cope with adverse impacts (IPCC 2007). **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 tool, 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.

1.4 Systems Thinking

The composition of a complex issue can be understood using the metaphor of an iceberg (Maani and Cavana 2007, see also Figure 1.2). The events we usually observe represent the 'tip of the iceberg' and most of the problem is hidden below the surface as patterns, structures and mental models. The analogy also serves to illustrate 'four levels of thinking', the problem being that in most decision situations very few people delve below the surface layers of events or patterns (Maani and Cavana 2007). Simple solutions that apparently address emergent events and symptoms of the underlying system may only be 'quick fixes' that either shift the problem in space or time, or further increase the emergent symptoms in the long run (Meadows 1999). Figure 1.2 illustrates the underlying features of systems using the iceberg metaphor, and gives examples of methods and indicators that can be used to look at each level within the system.

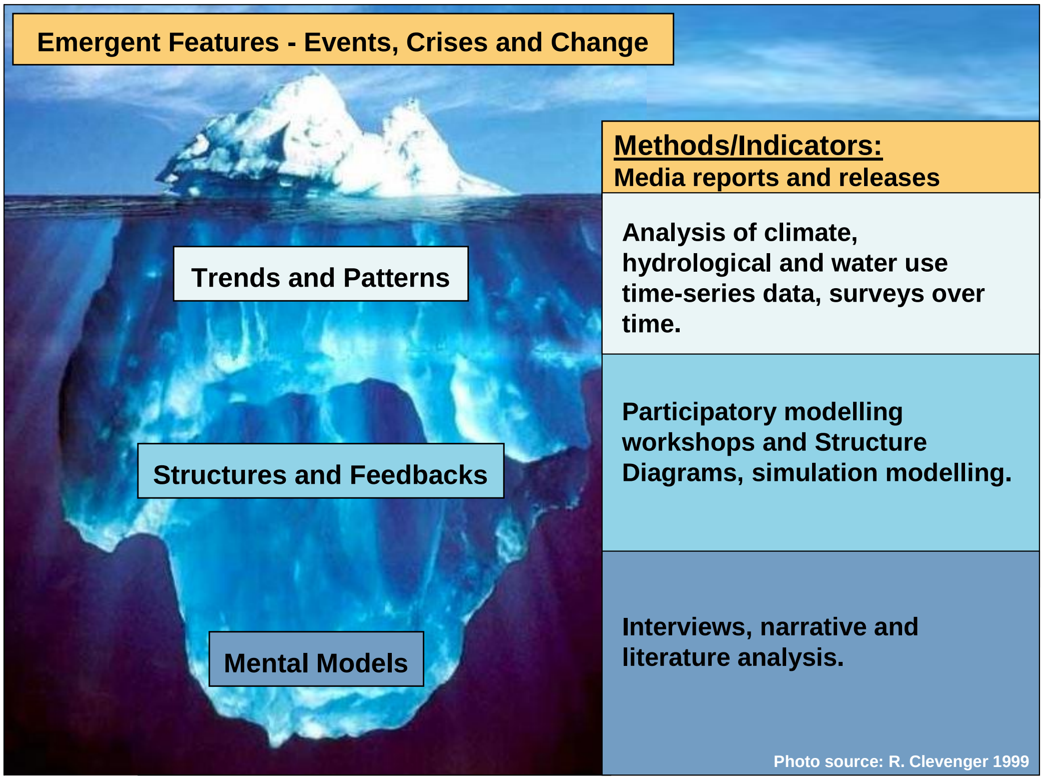

Figure 1.2: The Iceberg Model, and methods and indicators for looking deeply at a system. Systems thinking attempts to identify and address underlying conditions, 'events' are seen as emergent features of complex systems.

This tool uses 'structure diagrams' to illustrate system structures and feedbacks according to the conventions outlined in Appendix 1. Structure diagrams provide a means to explore and interpret the relationships and interactions between many system variables. The structure diagrams were derived from workshops, interviews and literature analysis. 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 tool as a structure diagram. Insights from this participatory modelling workshop with a wide range of stakeholders was combined with insights from interviews and literature to produce the following structure diagrams. A range of literature was accessed, from local news articles, to local government publications and peer-reviewed journal articles.

2. Response Pathways and Adapting to Climate Change

2.1 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**. 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).

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 2.1 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, see Tool 2.5.3). 'Water conservation' refers to reducing water use in general, including through water efficiency.

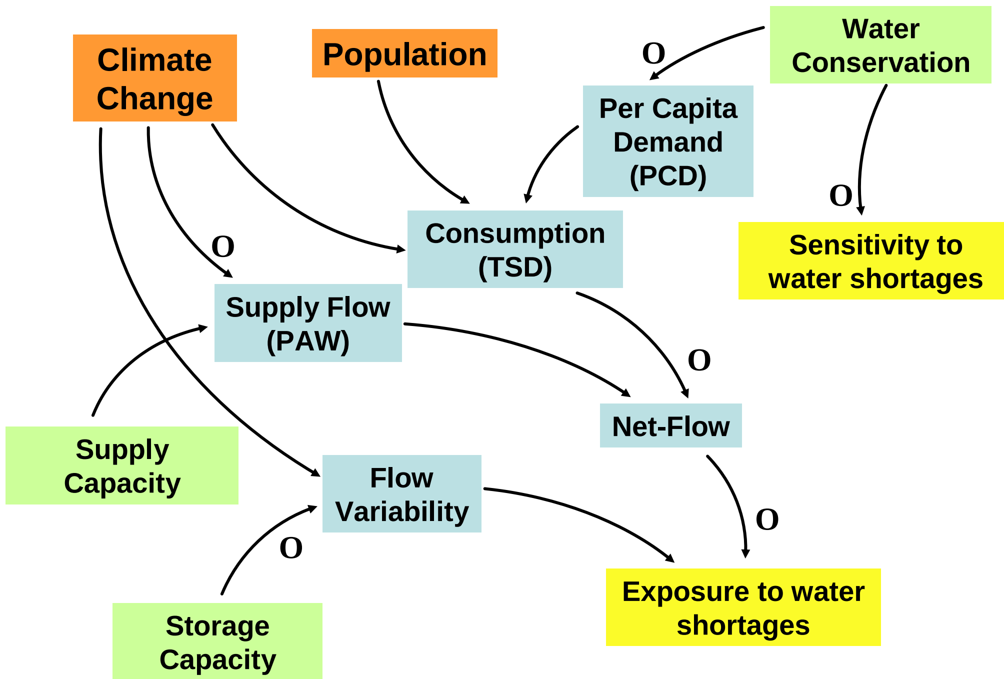

Figure 2.1: Response pathway diagram: showing influence of key responses (green) on system variables (blue) to reduce community exposure and sensitivity (yellow) to water shortages due to increasing climate change and population[2]. As discussed in Appendix 1, an 'O' at the end of an arrow indicates 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 2.2); the increasing exposure leads to an increasing awareness of an impending or actual shortage problem. From here

[2] Guidance for interpreting structure diagrams is in Appendix 1. Feedbacks and system dynamics are illustrated in following figures.

the community has three primary response pathways (or a combination of these three)[3].

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).

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

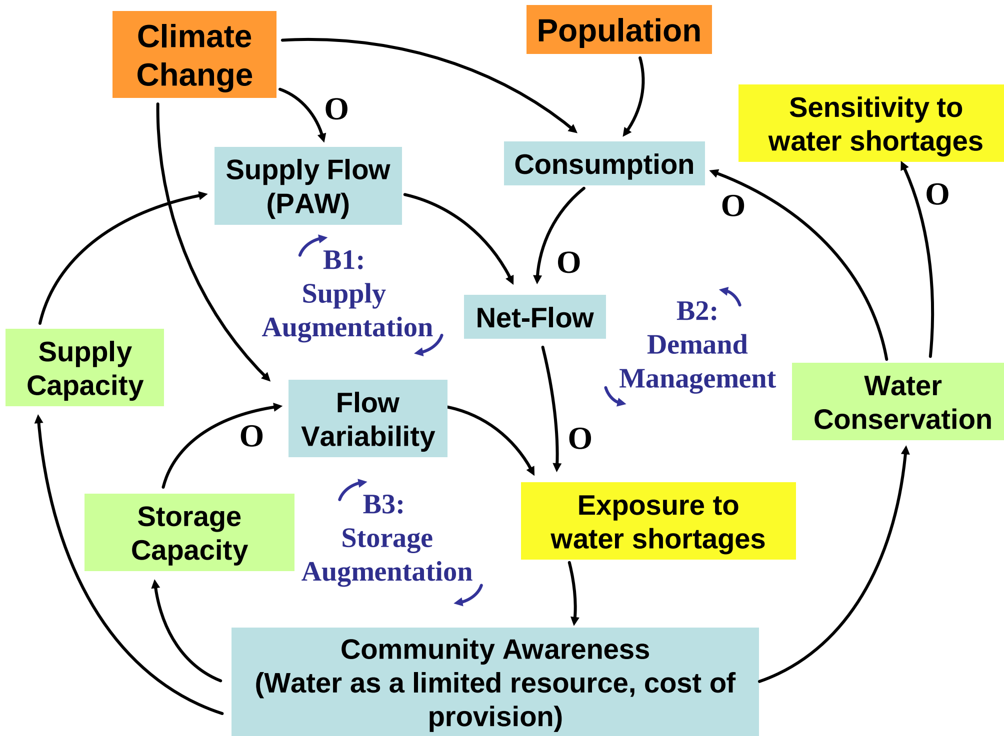

Figure 2.2: Structure diagram demonstrating socio-ecological system feedbacks resulting from response pathways (green) with regard to exposure and sensitivity to water shortages. 'Capacity' is a measure of consumption to supply, e.g. number of days of storage or percentage of supply consumed at peak consumption.

Over time and with decreasing community awareness, plus population growth and climate change[4], the ratio of storage and supply to consumption falls to the point where exposure to shortages again becomes a problem (Figure 2.3). The sudden drop in exposure due to the intervention, as illustrated in Figure 2.3 relates to the 'lumpiness' of supply and storage augmentation, which tend to occur in large increments. However, without demand management as the primary response option, sensitivity continues to increase, since the community continues to grow in a water-intensive manner. As noted in Tool 2.5.3, the occurrence of a drought that exceeds the design capacity of the water supply system cannot be ruled out for a coming

[4] Analysis for the Wellington case study found an average annual decrease in supply of 5%, and an average annual 1% increase in demand by 2040 due to climate change.

summer. Therefore, the higher the community's water dependence, the more sensitive it is to a water shortage caused by an extreme event.

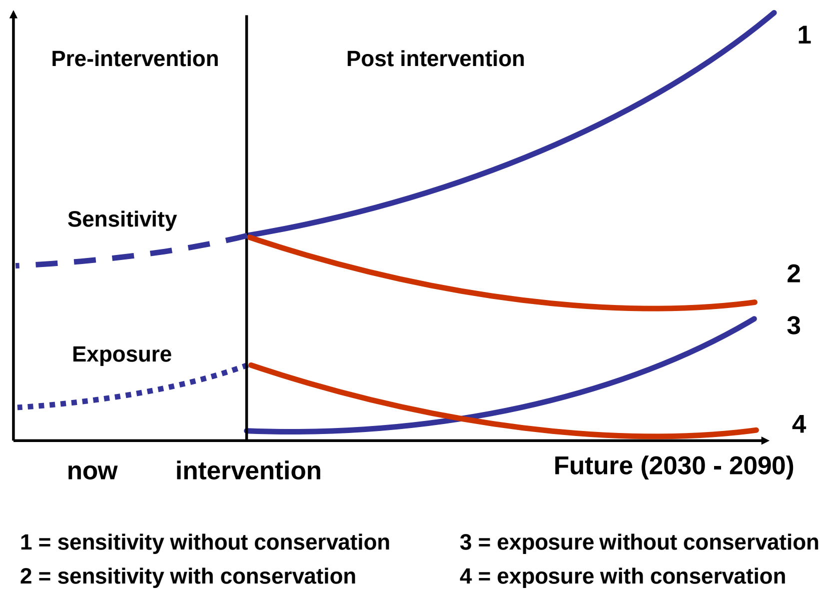

Figure 2.3: 'Behaviour over time' (BOT) graph[5] demonstrating implications for exposure and sensitivity to water shortages with and without water conservation as the primary response pathway.

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

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[5] 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.

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 2.4, the Supply Management loop (B1) forms a tight feedback that can quickly satiate the need to reduce exposure, whereas demand management increases water security less directly, and through longer-term or ‘slow feedbacks’. Broadly, a community’s water-intensity is indicated by its ‘per-capita demand’, and the ‘security of supply standard’ or ‘Annual Shortfall Probability’, indicates the range of variability that the bulk system is designed to manage exposure to.

The variables ‘inclusion, interaction, engagement’, and ‘social learning’ in Figure 2.4 are discussed in relation to adaptive capacity in the following section.

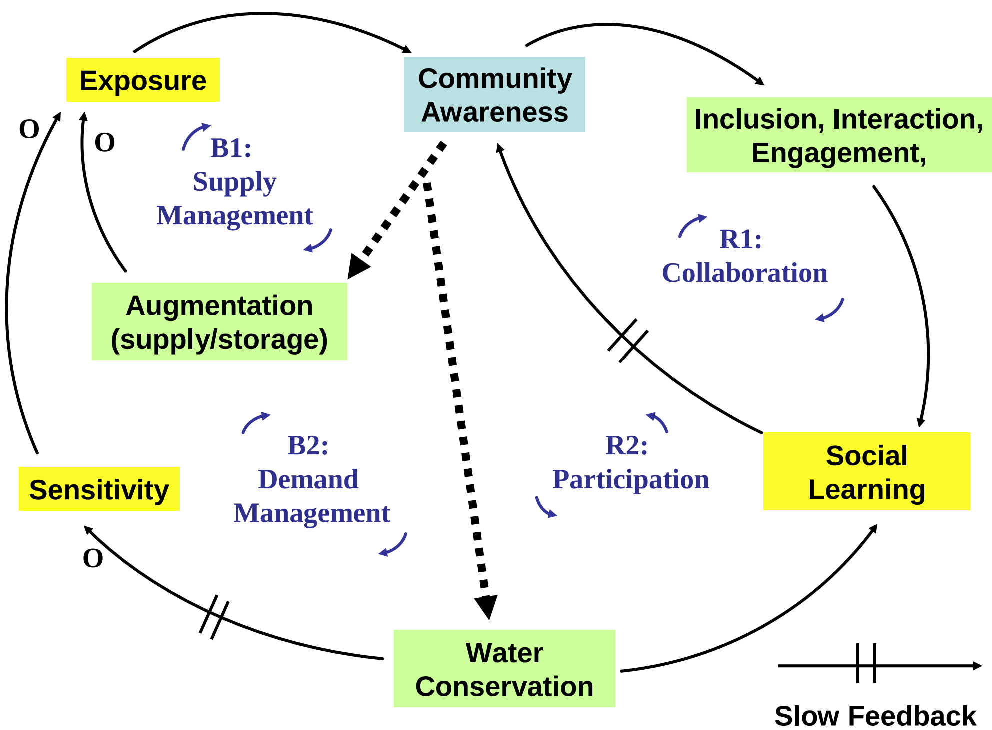

Figure 2.4: Structure diagram demonstrating feedback differences between ‘supply management’ (B1) and ‘demand management’ B2. The water security standard serves as a proxy for exposure, while Per Capita Demand (PCD) could be used as a proxy measure of sensitivity.

2.2 Adaptive Capacity

The previous section identifies the importance of a 'water conservation' pathway for reducing exposure and sensitivity to water shortages. Figure 2.4 then illustrates that increasing community awareness regarding the need and means to save water requires an increase in social learning. The structures 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 2.5).

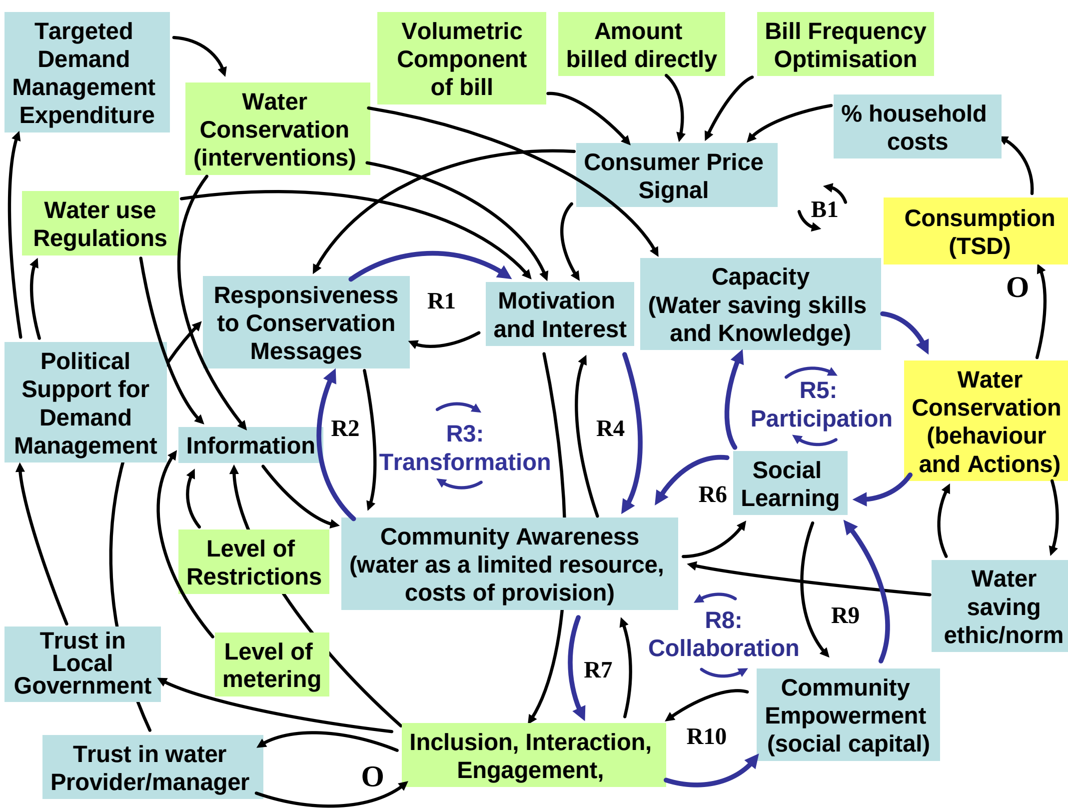

Figure 2.5: Feedback structures and system interactions between demand side intervention options (green) and the target variables 'Water Conservation' and 'Consumption' (yellow). R3, R5 and R8 indicate key structures that influence adaptive capacity.

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[6] 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).

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

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[6] 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.

3. Discussion

3.1 Demand Management – The Prudent Response Pathway

As outlined in section 2.2 above, and illustrated in Figure 2.5, the dynamics of demand-side interventions to reduce sensitivity to water shortages, *and* increase adaptive capacity are complex. These processes are also much less tangible than the technical and engineering challenges that tend to be addressed in the tighter 'supply management' structure illustrated in Figure 2.4.

Under Section 3 (f) of the RMA, the meaning of 'effect' includes *"any potential effect of low probability which has a high potential impact"*. In regions where climate change is expected to increase the frequency and severity of droughts over time, 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), and events exceeding current design standards will become more common. In addition, model projections tend to under-represent climate variability at the local level (see Tool 2.5.3), which along with an increasing risk of extremes, increases the level of uncertainty with probability-based water management calculations.

It is also not possible to exclude the possibility of an extreme event for any coming summer, therefore a strategy is clearly required to manage residual risk. As outlined in section 2.1 of this tool, water conservation through demand management interventions is the primary mechanism to reduce the community's sensitivity to an extreme event. While demand management might be more complex, the considerations above highlight the need to prioritise demand-side management and water conservation. In addition, the RMA also requires 'particular regard' is had to *"the efficient use and development of natural and physical resources"*.

3.2 Engagement and Collaboration to increase Adaptive Capacity

As outlined in section 2.2, 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. 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).

3.3 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[7] (Dietz et al. 2003). Adaptive management is an iterative process which links knowledge to

[7] 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).

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.

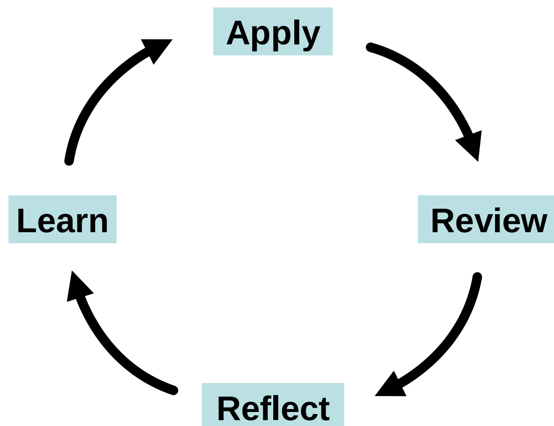

Figure 3.1: The Adaptive Management Cycle.

4. Summary

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, will be of greater benefit to communities adapting to the effects of a changing climate.

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Appendix 1 – Interpreting Structure Diagrams and Behaviour over Time Graphs.

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.

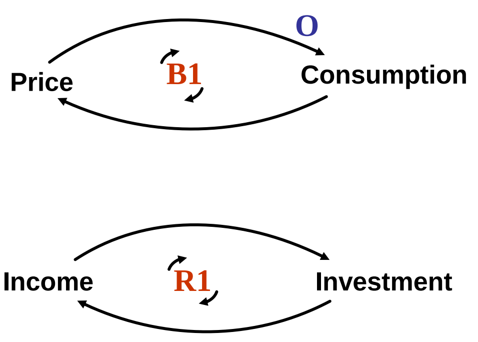

Figure A1: Simple structure diagrams showing balancing and reinforcing feedback structures. In general, an increase in price leads to a decrease in consumption, which leads to a decrease in price, and an increase in consumption (Loop B1). Loop R1 indicates that an increase in income enables an increase 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 (Figure A2). 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).

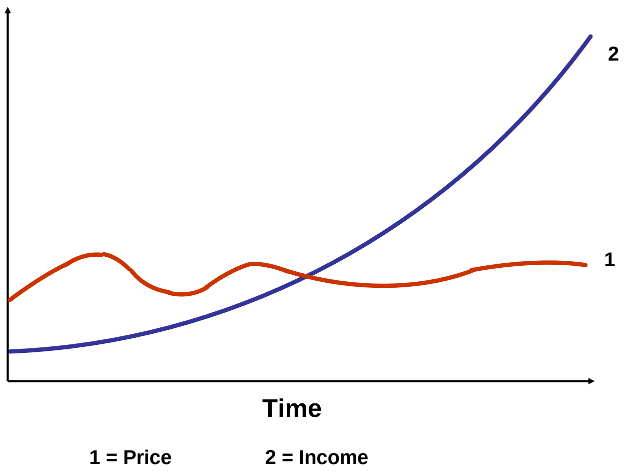

Figure A2: Behaviour over time graph for the variables 'Price' and 'Income' above.