CLIMATE CHANGE, WATER SUPPLIES AND HEALTH: INTEGRATING TECHNICAL AND SOCIAL SCIENCES

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ABSTRACT

Climate change has been referred to as one of the most significant challenges we face over the coming century. Its impacts will be broadly felt, and will require responses from the whole community, including water suppliers, council asset managers, public health officers, emergency response teams, politicians, climate science modellers, and farmers. We argue that successful adaptation planning requires integration of a number of factors including data, information and expertise from different community and professional sectors of society. Achieving this degree of integration may require new skill sets and resources, and has important implications for planning processes.

This paper looks at recent work to help address potential impacts of climate change on water supplies and health in which ESR water scientists and social scientists carried out joint interviews in Taranaki in 2009 with District Health Board staff, Regional Council staff, water suppliers, community members and iwi representatives.

Specifically, this paper outlines how the qualitative data collected jointly by biophysical and social scientists has enabled a deeper understanding of adaptation planning within two projects: i) Ministry of Health-funded research to provide guidance for planning for the health impacts of climate change on water supplies[1]; ii) FRST-funded research to develop a data modelling system that can support adaptation planning for the effects of climate change on human health[2]. Both these projects share a key aim: helping people and communities to plan for, manage and cope with the impacts of climate change. Whilst still in progress, the latter project has thus far included a literature review exploring the capacity, assumptions and barriers that exist for coordinated adaptive planning between the health and environment sectors, and detailed consideration of how the vulnerability of drinking-water quality to climate change and variability might be assessed.

Key findings from each project are presented, including:

- concepts from the national and international literature;
- a ‘fit for purpose’ planning tool for use by local drinking water supply operators;
- preliminary working models for the assessment of water supply vulnerability.

The work has shown that combined social and biophysical approaches can be useful in supporting the participative adaptation planning required for Public Health Risk Management Plans (PHRMP), Long Term Council Community Plans, Annual Plans, Asset Management Plans, Health Impact Assessments (HIA), and Assessments of Environmental Effects (AEE).

KEYWORDS

Climate change; health impacts; drinking-water supplies; adaptation; vulnerability; integrating technical and social sciences

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[1] The booklet is available on the following website: http://www.esr.cri.nz/SiteCollectionDocuments/ESR/PDF/MoHReports/climatechangewatersupplieshealth-dec09.pdf.

[2] For more information see ESR website link: http://www.esr.cri.nz/competencies/HumanBiosecurity/Pages/HealthImpactsofEnvironmentalChange.aspx

1 INTRODUCTION

Predictions of climate change are increasingly well documented and disseminated. Yet these predictions involve significant layers of complexity and uncertainty, and are often contentious. For instance, a number of biophysical factors (i.e. topography, precipitation) and population factors (land use and settlement patterns) mean that despite an anticipated global (warming) trend, regional differences in temperature and weather events within countries are expected to be large. Predictions for New Zealand include temperature increases (but only by about two-thirds as much as the global mean); increased average rainfall in the west of the country and decreased average rainfall in many eastern regions; increased intensification and prevalence of prevailing westerly winds; fewer frosts; and sea level rise (Ministry for the Environment, 2001). More detailed predictions are available from New Zealand's Ministry for the Environment (www.mfe.govt.nz) and from the National Institute of Water and Atmospheric Research (NIWA) (www.niwa.cri.nz).

There are several potential climate change related scenarios that are relevant to water supplies;

1) Drier conditions expected in eastern areas – in tandem with expected increases in temperature will likely lead to decreased runoff into rivers and increased evaporation causing drought and increased competition amongst water users.
2) More frequent floods on the western coasts of New Zealand – causing more flooding, landslides, avalanches and mudslides; increased soil erosion; and increased pressure on government and private flood insurance schemes and disaster relief.
3) Retreating snowlines and glaciers – affecting seasonal river flows.
4) Changes in climate extremes – the greatest negative impact of climate change on New Zealand could arise from more frequent and more intense droughts, extreme winds, fire risk and floods.

The biggest direct threat to water supplies will likely come from heavy rainfall (and associated floods), low river flows and drought, and strong winds. These challenges are not new to water suppliers, but they will need to be prepared to cope with less as well as more precipitation. In other words, there will be a heightened need to respond to increased variability and frequency of events. Fundamental challenges for water suppliers, identified in a recent World Bank article, include urbanisation pressure, outdated infrastructure, and competition for water resources (Danilenko, Dickson, & Jacobsen, 2010). Coupled with the effects of climate change, these issues provide real challenges for water suppliers, especially over the longer term.

Planning for the impacts of climate change will require integration of different types of information and different methods for gathering, analysing and using this information. This paper describes two New Zealand projects that aim to provide practical 'tools' to aid adaptation for climate change. The tools are aimed at water suppliers, health practitioners and communities.

1.1 HEALTH IMPACTS OF CLIMATE CHANGE

Climate change in New Zealand and around the world will have significant and wide-ranging impacts on many aspects of people's daily lives. Societies and their climates are inextricably linked, both directly and indirectly. Climate change is expected to have five main impacts on human health: temperature-related illnesses, mortality and morbidity as a result of extreme weather events, air pollution-related illnesses, vector-borne illnesses and waterborne and food-borne illnesses. The following summary of water supply-related health impacts comes from personal communication with water scientists, health practitioners, iwi and community members, as well as from academic papers on the subject (Ebi, Mills, Smith, & Grambsch, 2006; Haines, McMichael, & Epstein, 2000; McMichael, Woodruff, & Hales, 2006; Patz et al., 2000).

1.1.1 WATERBORNE ILLNESSES

Climate change scenarios may increase the risk of contracting gastrointestinal disease caused by ingestion of pathogens (disease-causing microbes) in drinking-water. For example, increased water temperatures and/or decreased precipitation may result in growth of waterborne bacteria, and increased frequency and severity of precipitation can wash pathogens into the water supply source. These pathogens can be fast-acting, usually causing sickness in a few days or weeks, can multiply within their hosts, are contagious, and may cause severe illness. Common symptoms are diarrhoea or vomiting – these are particularly dangerous for babies, the elderly, and people with compromised immune systems.

In New Zealand three main types of waterborne pathogens cause gastroenteritis:

- bacteria (e.g. *Campylobacter, legionella*)
- protozoa (e.g. *Giardia* and *Cryptosporidium*)
- viruses (e.g. rotaviruses and noroviruses).

Climate change scenarios may also result in the presence of pathogens that are not a current health risk (new or re-emerging), causing increased incidences of diseases such as Hepatitis A, Hepatitis E, *Legionella* or Cholera. Scenarios that include smaller volumes of water, increased humidity and warmer water temperatures may increase cyanobacterial levels leading to a rise in health impacts of cyanotoxins (on humans and animals).

1.1.2 IMPACTS ON HEALTH AND WELL-BEING

Climate change scenarios may have wider impacts on the health and well-being of groups and individuals. For example, increased severity and/or frequency of extreme events such as floods, droughts or storms can have major impacts on safety (e.g., risk of drowning or trees falling) and on stress levels (e.g., being separated from friends and family by flooded roads or coping with the impacts, business decisions or competition over scarce resources related to a drought). Colder and damper conditions may lead to an increase in respiratory illness and conversely warmer and drier conditions may result in heat-related illness e.g., heat stroke.

Māori have important spiritual and cultural connections to waterways based on whakapapa. This kinship-based connection establishes a reciprocal relationship, requiring local hapū and iwi to care for and sustain the natural environment as it has for them. The potentially damaging effects of climate change to the environment combined with an only recently improving economic position may make Māori more vulnerable to some aspects of climate change than non-Māori. For example, floods that uncover urupā (burial sites) can cause stress and a sense of loss, as can contamination of kaimoana due to flooding, increased farmland run-off or drought. This can cause illness within the community or for manuhiri (visitors), impacting on the mana of local hapū and compounding whakamā (cultural shame).

It is important to note that for planning to prevent, respond to or manage the health impacts of climate change, the context is very important; different groups will have different health impacts and different methods for coping. The degree of community spirit, for example, may be difficult to assess, but very important for helping a community to manage adverse effects of climate change. The severity of health impacts will depend upon much more than climate change alone. Changing demographics such as an increasingly elderly population will also have a strong impact on the extent of the health impact, and on people's ability to adapt.

1.1.3 VECTOR-BORNE ILLNESSES

Changes in temperature, humidity and precipitation are expected to alter the spread of a wide range of vector-borne[3] diseases such as dengue fever. Whilst not the focus of this article, some vector-borne illnesses such as dengue fever (spread by mosquitoes breeding in water) may be more easily spread due to the need for increased water storage (in storage dams or tanks) for coping with severe drought.

1.2 METHODS AND RATIONALE

Climate change has been referred to as one of the most significant challenges we face over the coming century. Its impacts will be broadly felt, and will require responses from the whole community, including water suppliers, council asset managers, public health officers, emergency response teams, politicians, climate science modellers, and farmers. Successful adaptation planning will require integration of a number of factors including data, information and expertise from different community and professional sectors of society.

In recognition of the range of groups and individuals who have knowledge and expertise in this area and those who may be impacted by climate change, we carried out interviews and focus groups with as many different 'voices' as possible. In our case-study located in Taranaki, social science and biophysical science researchers worked together to gather information, views and perspectives. This partnership approach worked well, with the

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[3] Vector-borne diseases are those transmitted by another organism, most frequently an invertebrate, such as an insect.

researchers asking different yet complementary questions to elicit the views of interviewees. As seen by the quote below, integrating the social and technical sciences does not always happen well, or indeed at all.

> *"The natural and social sciences have never been comfortable bedfellows. Physicists and chemists have long distrusted the apparent lack of 'hard facts' in what they too often dismiss as the 'soft sciences'. Conversely, social scientists can be equally dismissive of excessive claims to objectivity by their colleagues in the natural sciences"* (Dickson, 2010).

We have made a conscious effort to work together to bring different aspects of this important issue to light. The resulting information and data has been useful for the two different projects which share a key aim of helping people and communities to plan for, manage and cope with the impacts of climate change.

Both the projects included a literature review of the latest research, data, and key concepts related to climate change. The literature in these reviews has been drawn on and referenced throughout this paper (Baker, Lange, & Nokes, 2010; Craigie, 2009).

In-depth interview data informed the two concurrent projects. Initial discussions with nine people from the Taranaki District Health Board, the New Plymouth District Council and the Taranaki Regional Council provided valuable background information to the case-study area and important issues for the region, as well as suggestions for organisations and individuals to be interviewed as part of the project. Using this list, as well as others we identified using a snowball approach, we then spoke with some twenty-eight people in the Taranaki region, either in groups or as individuals. These included people from the District Health Board, Federated Farmers, Taranaki Climate Change Network, three District councils, the Regional Council, a privately run water supplier, a Māori health provider and iwi members.

On the basis of our prediction that past experience of extreme weather events would help to provide an understanding of the sorts of impacts that climate change may bring, we started the discussions by asking people to tell us about a flood or a drought that they or people they know had experienced in the past. Using open-ended questions, we then probed further, asking about how they coped with extreme climatic events in the past and what influenced their ability to cope, about health issues, roles and responsibilities, about water supply issues, and about the adaptive capacity of communities.

The Taranaki region, on the west coast of the North Island, was chosen for a combination of reasons. These include projected changes in increased levels of precipitation in the west of the country, the fact that the New Plymouth District Council had already commissioned NIWA climate modelling for the region, the range of different 'types' of community including rural and urban, and the fact that communities in Taranaki have already been exposed to heavy rain events, which may have heightened their awareness of the consequences of heavy rain and the steps they have needed to take to cope with such events. Since 1980, there have been several major floods – Mangamingi 1986, Waitotara 1987, Cyclone Hilda March 1990, the "Big Wet" New Plymouth April 1995, and the "Long Wet" July to October 1998 (Taranaki Regional Council, 2003). In addition, dairying is a major land-use in Taranaki; run-off from pasture into surface waters may increase the microbiological loading of water supply source waters, thereby increasing the severity of the health impacts of heavy rain events.

Section 2 of this paper outlines the key findings from the two separate but complementary projects for which the data was collected. Project A is introduced along with a brief synopsis of the workbook styled resource that was produced to support local government and others in planning for the impact of climate change on drinking water supply. Project B is still in progress and provides a more detailed appraisal of a risk management framework and resources for those considering how the vulnerability of drinking-water quality to climate change and variability might best be assessed.

The discussion that follows links the projects' findings with key international and national literature on climate change and adaptation. This section further unpacks the notion that successful adaptation planning requires integration of a number of factors including data, information and expertise from different community and professional sectors of society. Several key aspects are highlighted, namely information gathering and communication, developing fit for purpose tools, and ensuring uptake and dissemination.

2 KEY FINDINGS FROM TWO NEW ZEALAND CLIMATE CHANGE PROJECTS

2.1 PROJECT A: PLANNING FOR THE IMPACTS OF CLIMATE CHANGE ON WATER SUPPLIES

This Ministry of Health funded project has focused on providing guidance for health professionals, environmental practitioners, planners and water suppliers to plan for the impacts of climate change and consider water-supply related health issues.

Some drinking-water suppliers in New Zealand, large and small, council-owned and private, are already starting to think about or deal with the impacts of climate change on their infrastructure, source water, catchments and communities. Water suppliers, drinking-water scientists, health professionals, emergency response staff, planners, farmers, iwi and community members described how they think about climate change, what the likely effects might be, and about the progress (or lack of) that they and others are making towards preventing, managing, or adapting for some of the impacts of climate change.

In order to present this information to others in a practical way, we created a workbook-styled booklet that aimed to provide a guide for planning for the health impacts of climate change, and for incorporating water supply related health issues in Long Term Council Community Plans, Health Impact Assessments, Assessments of Environmental Effects and other planning processes.

This resource presents the information using familiar principles of risk assessment and management to enable users to clearly see how specific impacts on water-supplies might be related to health, and to show how planning (preventing, responding or adapting to an impact) by different groups and individuals might impact on others. The booklet describes climate change predictions for New Zealand, the structure of and responsibility for New Zealand water supplies, and links between climate change and health. The second half of the booklet contains a number of worksheets for different topics (providing a list of examples as well as space for the user to add their own examples and details relevant to their context). The following table summarises the worksheet topics in the booklet.

Table 1: Worksheet topics from the 'Climate Change, Water Supplies and Health' booklet, ESR 2009

<table>
<tr><td colspan="6">In relation to climate change, what event could happen that would impact on access to safe drinking-water & health?
More intense or frequent heavy rain events:</td></tr>
<tr><td colspan="2">Possible impacts on physical environment
E.g.,
- High river levels & flows impacting on water quality & quantity</td><td colspan="2">Possible impacts on drinking-water supply
E.g.,
- High & persistent run-off from farmland, industrial activities &/or overflowing sewage systems in source water</td><td colspan="2">Possible impacts on health
E.g.,
- waterborne illness</td></tr>
<tr><td colspan="6">In relation to climate change, what event could happen that would impact on access to safe drinking-water & health?
More severe or frequent droughts:</td></tr>
<tr><td colspan="2">Possible impacts on physical environment
E.g.,
- Increased water temperature</td><td colspan="2">Possible impacts on drinking-water supply
E.g.,
- Restrictions imposed on river & bore abstraction rates</td><td colspan="2">Possible impacts on health
E.g.,
- increase in numbers & variety of disease vectors</td></tr>
<tr><td colspan="6">In relation to either of the climate change scenarios:</td></tr>
<tr><td colspan="2">What is the chance the event & associated impact on the environment will happen?
E.g.,
- have you experienced these events before or seen increased frequency of these events in this location?</td><td colspan="2">What is the chance the event & associated impact on the water supply will happen?
E.g.,
- How does knowledge about the geography & geology of your region help you to predict the likely chance of the impact happening?</td><td colspan="2">What is the chance the event & associated impact on health will happen?
E.g.,
- Are there national, regional or local health records that show health impacts of water supply-related incidents</td></tr>
<tr><td colspan="2">How would you know the event & associated impact on the environment was happening (in time to take appropriate action?)
E.g.,
- what data or information will notify you that the event is happening?</td><td colspan="2">How would you know the event & associated impact on the water supply was happening (in time to take appropriate action?)
E.g.,
- how will you access/make sense of data or information?</td><td colspan="2">How would you know the event & associated impact on health was happening (in time to take appropriate action?)
E.g.,
- do you need to share information or data? With whom? How?</td></tr>
<tr><td colspan="3">What can be done about preventing the impact on the water supply?
E.g.,
- does the design of water supply infrastructure help to prevent the impact on the water supply?</td><td colspan="3">What can be done about preventing the impact on health?
E.g.,
- could water suppliers organise adequate pre or post treatment stored water for times when production is limited or nil?</td></tr>
<tr><td colspan="3">What can be done about managing or responding to the impact on the water supply?
E.g.,
- Treatment & process control to remove turbidity or pathogens (coagulation, filtration, disinfection)</td><td colspan="3">What can be done about managing or responding to the impact on health?
E.g.,
- communications strategy with the public e.g. boil water notices, provide health advice about who to contact</td></tr>
<tr><td colspan="3">What can be done about adapting to deal with the impacts on the water supply?
E.g.,
- optimising existing treatment operations & maintenance, including documenting procedures & staff training</td><td colspan="3">What can be done about adapting to deal with the impacts on health?
E.g.,
Sharing & responding to local & cultural measures of water quality, disease & well-being such as school absenteeism as a measure of waterborne illness</td></tr>
<tr><td colspan="6">What affects the ability to prevent, manage or adapt to the water supply or health impacts?
Past experience, geography & geology, type/magnitude of event & size/sophistication of water supply, how well people & organisations work together, institutional capacity, community spirit & capacity, assumptions & perceptions, information availability & accessibility, regional development & land use, political context</td></tr>
</table>

As can be seen in Table 1, a mixture of technical and social and cultural information has been included, aiming to encourage high-level and big picture thinking about the context and connections between groups and individuals, as well as some useful advice on practical measures that water suppliers or health professionals can take. Some of the key issues and concepts raised by interviewees are described in more detail in the discussion section of this paper.

2.2 PROJECT B: DATA MODELLING SYSTEM TO SUPPORT ADAPTATION PLANNING

2.2.1 INTRODUCTION

One of the threats to human health that may result from climate change is an increase in infectious disease. The second area of work discussed in this paper is a FRST-funded project led by ESR[4]. The project's aim is the pilot development of modelling based tools for managing the increased likelihood of vector-, water- and food-borne infectious disease. The project has three objectives:

a) developing predictive models for assessing how changes in climatic factors will affect the occurrence in New Zealand of six infectious diseases;
b) developing a GIS web-based graphical interface for the models produced by the first objective;
c) matching the development of the web-based tool with the needs of the users to improve its uptake, and determining where barriers to co-ordinated adaption planning between the health and environmental sectors may arise.

Contained within Project B is a sub-project to determine the feasibility of assessing the vulnerability[5] of water supplies and the communities they serve. This section describes the framework that has been developed for this purpose.

Three primary objectives have guided the development of the framework:

a) To help system operators/owners understand the vulnerability of their system (where, why, degree);
b) To provide a measure of the system's vulnerability, which when compared with the vulnerability of other systems, could guide local, regional and central government in prioritising resources to reduce vulnerability;
c) To identify for local, regional and central government actions they can take, such as changes to policy and regulation, to address vulnerability concerns.

Although the framework has been developed in the context of water supplies, it is intended to be generic, allowing it to be used more broadly. The following discussion provides a summary of the framework and the basis for its operation, with water supply examples, but without the full detail of how vulnerability ratings are determined.

2.2.2 FRAMEWORK OVERVIEW

Figure 1 illustrates the relationship between several fundamental concepts associated with vulnerability whereby exposure, and the characteristics of a system that make the system sensitive to exposure, act to increase the system's vulnerability. Opposing these factors, by reducing the system's vulnerability, is the ability of the system to adapt (its adaptive capacity).

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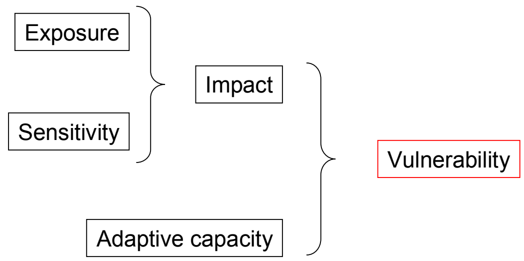
[4] This project, entitled Health Analysis & Information for Action (HAIFA), is a Foundation for Research, Science & Technology (FRST) funded project that aims to develop information analysis systems that will provide end-users with scientifically robust tools for responding to predicted human health effects from climate change.
[5] Vulnerability in this section always refers to vulnerability with respect to climate change and climate variability.

Figure 1 Components contributing to vulnerability (Klein, 2004)



Those having to plan for climate change need an understanding of both their system's vulnerability and its adaptive capacity. The project has used the relationships in Figure 1 to design a process water suppliers can follow to evaluate the vulnerability of their supply and understand their system's adaptive capacity and what may be limiting it.

The framework takes a risk-based approach to vulnerability assessment, and does so for the following reasons:

a) Only broad rather than detailed descriptions of the consequences of climate change/variability are required, not detailed modelling;
b) It draws on experience of past weather-related events – floods, droughts, storms, as the basis for assessing vulnerability, without the need for quantitative information;
c) It makes use of methodology closely related to risk assessment/risk management methodology with which water suppliers are becoming familiar;
d) It is a "no regrets" approach in that it identifies system weaknesses and remedial actions that are important for the functioning of the system irrespective of the extent of climate change;
e) It is a relatively straight-forward approach, which could be further simplified – an important attribute if water suppliers may be required to assist in its development and use;
f) Through the process for assessing a system's vulnerability, it provides direct information about what needs to be done to minimise its vulnerability.

Figure 2 diagrammatically presents the use of the framework through an example. The diagram traces the cause and effect *paths* (shown by arrows) that start with an *Exposure* event (e.g. heavy rain) at the top of the diagram and work down to the *Outcome*. The purpose of the framework is to guide the user in evaluating the likelihood of the Outcome occurring. If the Outcome is considered to be "Members of the community are without potable water", the qualitative likelihood of this happening can provide a measure of the vulnerability of the system.

To assist the user in understanding what may influence the vulnerability of their system, the framework teases out different stages between the Exposure and Outcome: *direct consequences, indirect consequences, impacts* and *results*. These are collectively termed *occurrences*. The likelihood of a particular occurrence depends upon:

a) *sensitivity factors* (red squares in Figure 2), which predispose the system to the occurrence, e.g., in the case of landslide considered in Figure 2, steeply sloping topography is a sensitivity factor, because landslides are more likely on steep slopes;

b) *adaptations* (green spots in Figure 2), which are the steps that can be taken to address sensitivity factors, thereby reducing the likelihood of the occurrence associated with the sensitivity factor, e.g., earthworks to sure up steep slopes are a possible adaptation with respect to landslide;

c) the likelihood of the preceding occurrence on the path, e.g., if the likelihood of a landslide is low, the likelihood of power pylons being damaged by a landslide will also be low (see Figure 2).

Examples of occurrences are given in Figure 2, and examples of the sensitivity factors and adaptations associated with them are given in Figure 3. Neither set of examples is exhaustive.

Direct consequences are the first physical events that happen because of the exposure event (rain, in this example). There are likely to be several direct consequences, but for simplicity's sake, landslide alone is considered in Figure 2. Each direct consequence may have an *impact* on the water supply, such as damage to the treatment plant, but it may also have one or more *indirect consequences*. These are events that do not happen to the supply, but they may have an impact on the supply. An example is the destruction of part of the electricity network. The collapse of the pylons does not damage the water supply, but the consequent cut in power may incapacitate parts of the supply.

Several impacts may affect the water supply. Figure 2 shows that these lead to what are termed *results*. *Impacts* happen to the supply itself, while *results* directly affect the community that is dependent on the supply. More than one impact may contribute to the same result (see Figure 2).

Adaptations that are put in place before the *impacts*, in Figure 2, are measures taken to prevent occurrences. These are mainly biophysical. The set of adaptations that follow the results are primarily socio-economic. Their aim is to mitigate the effects of the results on the community served by the water supply. De Loe et al., (2001) classify such adaptations as "accepting" adaptations.

Figure 2 Framework concepts demonstrated using example of a landslide resulting from increased rainfall

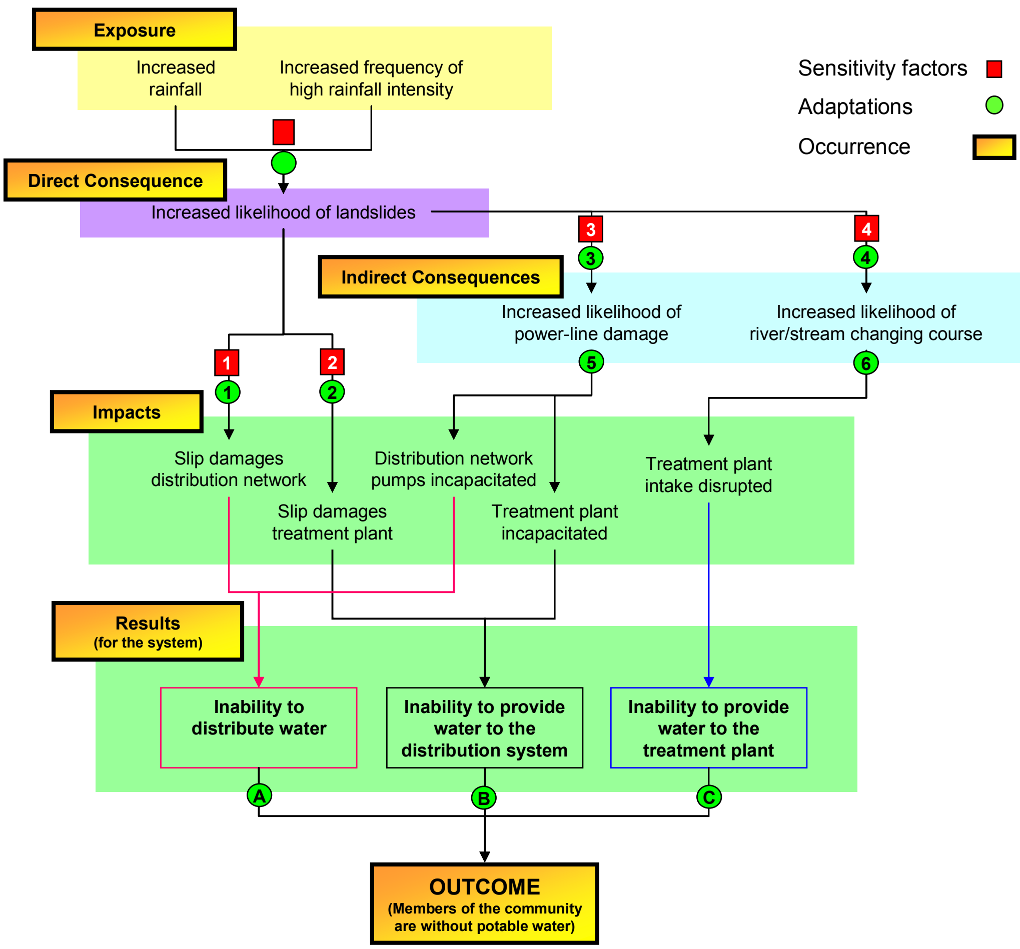
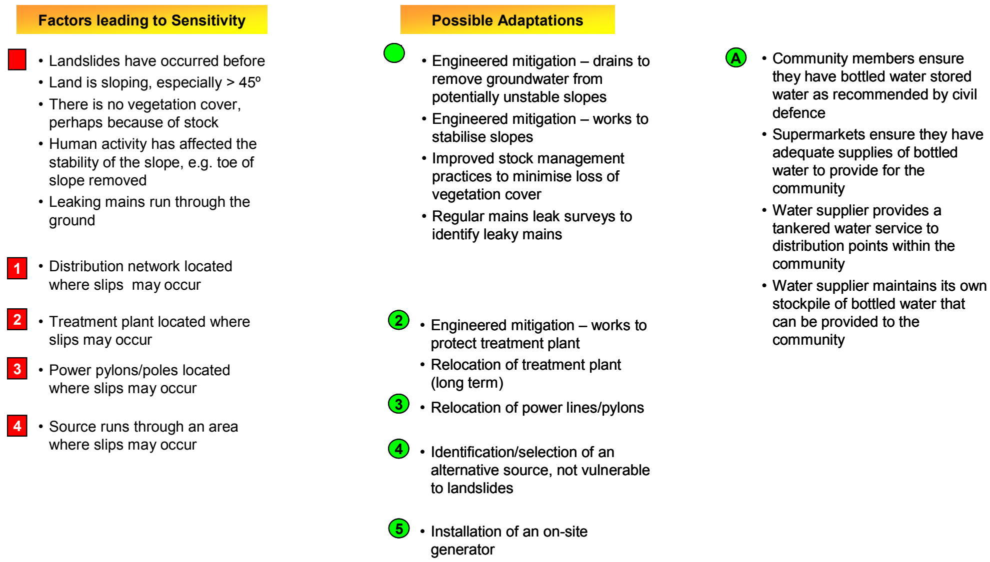


Figure 3 Examples of sensitivity factors and adaptations that might be identified in the example shown in Figure 2.



Estimating the likelihood of the various occurrences is described in the "Vulnerability Assessment" subsection below.

2.2.3 ASSESSING ADAPTIVE CAPACITY

To understand the factors influencing the adaptive capacity of a system, each adaptation that has been identified has to be considered separately. "Assessment" with respect to adaptive capacity refers to understanding why possible adaptations have not been implemented, and what would need to be done to reduce these limitations. As a result of the assessment, reasons for limitations may be identified at various levels: in the community, or associated with the activities or responsibilities of local, regional, or central government. The framework does not attempt to attach a quantitative or qualitative score to adaptive capacity.

The framework approaches the understanding of adaptive capacity by examining each adaptation at three levels.

a) Immediate implementation needs – the immediate physical or non-physical needs for implementation of the adaptation.
b) Determinants of implementation – what influences the system's owner/operator's (the water supplier in this instance) ability to meet the implementation needs identified in a).
c) High level determinants – these determinants sit above the determinants listed in b) and influence the ability to obtain or implement determinants in b). Some may be regulation or policy, but there are also broader determinants (e.g. acceptance that climate change is occurring) that need to be in place.

Table 2 andTable 3 provide examples of the factors that might be identified at the three levels for a biophysical adaptation and societal adaptation, respectively. These are in a very preliminary stage of development and some factors may need revision as the tables are developed, particularly some of the high level determinants.

To identify immediate implementation needs, particularly for societal adaptations, it is helpful to think of three aspects necessary to implement an adaptation:

a) awareness – the community needs to be aware of the actions required if it is to cope with threats;
b) ability – once the community is aware of the actions it needs to take, it must have the ability to act on this knowledge;
c) motivation – despite being aware of the actions that need to be taken and being able to act, the community and the individuals within it must have sufficient motivation to act.

Table 2 Examples of factors influencing the ability to implement a biophysical adaptation

Required Adaptation	Immediate Implementation needs	Determinants of Implementation	High level determinants	
Drains to remove groundwater from potentially unstable slopes	• Earth moving machinery	• Access to machinery (hired or purchased)	• Government policy/regulation that allows importation of machinery OR supports NZ production	**Acceptance that climate change and variability are occurring** **Understanding of the importance of adaptations to cope with climate change and variability**
		• Funds to purchase or hire	• LA gives the work sufficient funding priority to purchase or hire machinery	
			• LA is able to levy adequate rates to meet equipment costs	
	• Machinery operators and drivers	• Availability of trained operators/drivers	• Government policy/regulation supports necessary training	
		• Funds to employ operator/drivers	• LA gives the work sufficient priority to assign operators/drivers to it	
			• LA is able to levy adequate rates to fund staff	
	• Civil engineers and surveyors for design and direction of operations	• Availability of qualified engineers/surveyors	• Government policy/regulation supports necessary training	
		• Funds to employ engineers/surveyors	• LA gives the work sufficient priority to assign engineers/surveyors to it	
			• LA is able to levy adequate rates to employ necessary expertise	
	• Pipes	• Availability of pipes	• Government policy/regulation that allows importation of pipes OR supports NZ production	
		• Funds to purchase	• LA gives the work sufficient funding priority to purchase pipes	
			• LA is able to levy adequate rates to purchase pipes	
	• Suitable locations for discharge of the drainage	• Availability of trained environmental scientists and engineers to identify such locations	• Government policy/regulation supports necessary training	
		• Funds to employ scientists/engineers	• LA gives the work sufficient priority to assign scientists/engineers to it	
			• LA is able to levy adequate rates to employ necessary expertise	
	• Resource consent	• Availability of trained environmental scientists to prepare consent applications	• Government policy/regulation supports necessary training	
		• Funds to employ scientists	• LA gives the work sufficient priority to assign scientists to it	
			• LA is able to levy adequate rates to employ necessary expertise	
		• Consenting authority is prepared to grant the consent application	• Consenting authority has policy that supports the purpose of the drainage	
	• Decision to implement	• All other needs met	(see determinants of other needs)	
		• Support from the LA		

Table 3 Examples of factors influencing the ability to implement a societal adaptation

Required Adaptation	Immediate Implementation needs	Determinants of Implementation	High Level Determinants	
Community makes sure they have bottled water stored	• Awareness of the need to store water, how it should be stored, and how to deal with a water outage	• Advertisements telephone books, websites, radio, TV, newspapers, etc..	• Ministry of Civil Defence and Emergency Management, and local authorities have communication strategies	**Acceptance that climate change and variability are occurring**
			• Appropriate bodies have budgeted adequate funding for the strategies	
		• Community meetings/workshops	• LAs organise and/or support community meetings	
		• Literacy adequate to understand the information being communicated	• Government policy supports and funds education to ensure an adequate level of literacy	
		• Community 'spirit'; sense of community (neighbours helping neighbours to understand what is needed)	• LA has a policy of organising activities that bring communities together – e.g., outdoor family concerts. • Shared experience of threatening situations (e.g., dealing with floods)	
	• Suitable storage bottles	• Grocery retailers stock products in bottles that can be used/recycled for water storage	• Retailer chains have purchasing policies that ensure suitable products are available in their shops.	
		• Adequate incomes to purchase bottles or products contained in bottles	• Government policy ensures an adequate, minimum level of personal income	
	• Bleach for disinfection (and eye-dropper for dosing)	• Grocery retailers stock bleach and eye-droppers	• Retailer chains have purchasing policies that ensure suitable products are available in their shops.	
		• Adequate incomes to purchase bleach and eye-droppers	• Government policy ensures an adequate, minimum level of personal income (?)	
	• Suitable storage location for the water			
	• Motivation to store water and manage this emergency supply	• Experience of past water outages		
		• Awareness of the nature of the hazards involved and their consequences	• LA has a strategy to motivate its community to prepare, and seeks advice on the best approach for doing this	
		• Communication of risk that: ○ Takes account of cultural factors ○ Avoids the perception of risk information as irrelevant ○ Helps in handling denial and anxiety		
		• Households have sufficient income that they can take actions that address issues beyond those of day-to-day survival.	• Government policy ensures an adequate, minimum level of personal income.	

2.2.4 VULNERABILITY ASSESSMENT

To carry out the vulnerability assessment, a *vulnerability assessment diagram* is helpful (see Figure 4).

Figure 4 Part of an example of a vulnerability assessment diagram used for assigning a vulnerability rating to a system

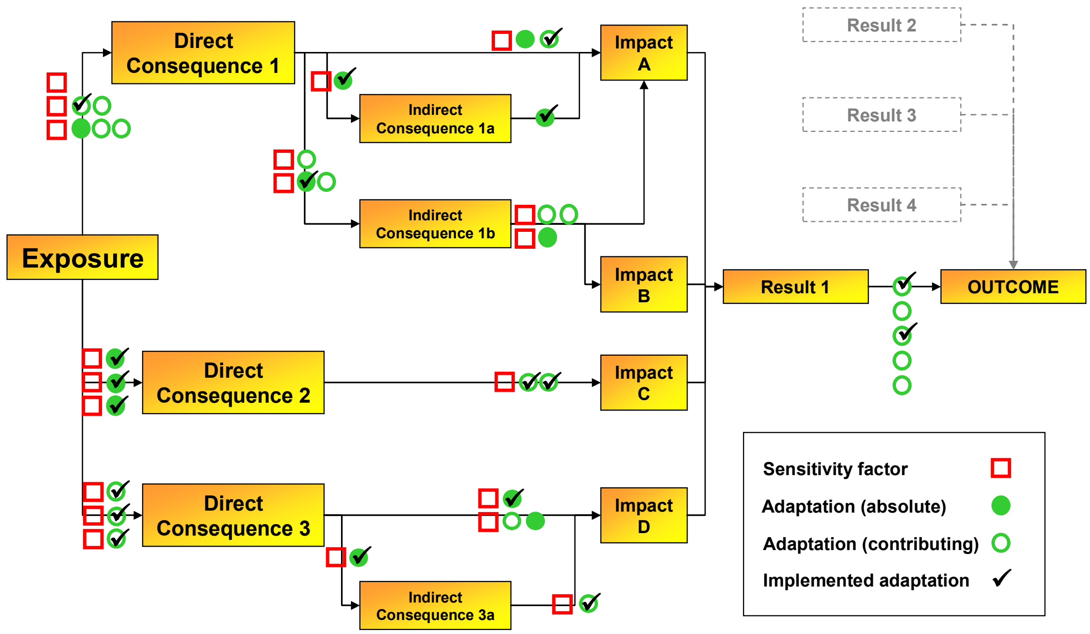


Figure 4 sets out some of the occurrences (boxes containing text) for a fictitious system. The diagram contains the same components as Figure 2, but is displayed horizontally; each sensitivity factor is depicted as an individual red square and each adaptation to manage each sensitivity factor is depicted as a green circle or spot. The green spots denote *absolute adaptations* – adaptations that alone, if implemented, would be sufficient to address the sensitivity factor, e.g., earthworks to sure up a steep, potentially unstable slope. Adaptations denoted by a circle may help to reduce the effect of the sensitivity factor, but are not expected to reduce the effect altogether, e.g., ensuring there is vegetation to help hold a slope together. These are termed *contributing adaptations*. The ticks indicate the implementation of a particular adaptation.

The cluster of sensitivity factors and adaptations prior to an occurrence influences the likelihood of that occurrence, as explained in section 2.2.2. Take for example, the cluster between the Exposure and Direct Consequence 1. There are three sensitivity factors (red squares). For the first of these no adaptation that would help reduce the influence of the factor has been identified (no symbol to the right of the first red square). For the second sensitivity factor, two possible contributing adaptations that could help to address the sensitivity factor have been identified, but only one is implemented. This may result in some reduction in the effect of the second sensitivity factor. For the third sensitivity factor, an absolute adaptation and two contributing adaptations have been identified, but none of them is implemented, therefore the effect of this sensitivity factor is not reduced.

The framework provides a set of simple rules to guide the user in assigning a qualitative likelihood to an occurrence based on the combination of sensitivity factors and adaptations prior to it and the likelihood of the occurrence that causes it. Space does not permit discussion of the rules, but it is sufficient to note that for this example, too few adaptations have been put in place to manage the sensitivity factors, and that the likelihood of Direct Consequence 1, once the Exposure event occurs, would be classed as "high".

By assigning likelihoods to all the occurrences in the vulnerability assessment diagram, the likelihood of the Outcome can be determined and a vulnerability rating given to the system.

2.2.5 FRAMEWORK IMPLEMENTATION

If there is stakeholder interest in the proposed framework, the next step in development would be the preparation of information to assist water suppliers in: identifying the possible occurrences that could result from a particular exposure event, the sensitivity factors that could determine which occurrences would be likely to affect a supply, and what adaptations could be implemented to address each sensitivity factor. Generic information will help the vulnerability assessment, but the water suppliers' knowledge of their specific system will be needed to augment the generic information. Guidance for understanding a system's adaptive capacity could also be developed in due course.

2.2.6 CONCLUSION

The proposed framework aims to provide a structured way of assessing the vulnerability of a system to climate change. In doing so, it offers a consistent approach that could be applied throughout regions, or nationally, to assist in prioritising resources for addressing system vulnerability. The risk assessment basis to the framework has the advantage of requiring the system owner/operator to identify the adaptations necessary for addressing the sensitivity factors that determine how the system will be affected by climate change. While an understanding of the adaptive capacity of the system is not explicitly required for the vulnerability assessment, by identifying the adaptations the framework provides the starting point for understanding a system's adaptive capacity.

We acknowledge that this approach to assessing vulnerability does not provide physically meaningful measures of vulnerability, e.g., the frequency at which a system may flood. However, it provides more useful guidance for a water supplier by helping them in understanding the reasons for their system's vulnerability, what can be done to address the causes, and what may be limiting their ability to put adaptations in place.

The risk-assessment basis to the framework also has the advantage of matching well with existing Public Health Risk Management Plans (PHRMPs). It may assist in making PHRMPs more robust, and *vice versa*. Alignment with PHRMPs assists in "mainstreaming" the steps to protect against the effects of climate change, the importance of which is discussed elsewhere in this paper. The generic basis of the framework will allow it to be adapted for use in sectors other than water supply, or for purposes other than assessing vulnerability to climate change.

There is no intention of making use of the framework mandatory. It is being developed as a tool to assist water suppliers and those at various levels of government in preparing for the challenge of climate change.

3 DISCUSSION: INTEGRATING DATA, INFORMATION AND EXPERTISE TO ENABLE PRACTICAL ADAPTATION TO EMERGING CLIMATIC THREATS

> *"For many water supplies, climate change intensifies existing challenges, risks of demand and supply functions over the medium to long-term for water and wastewater services, and adds additional complexities in day-to-day operations. Effective adaptive responses to potential impacts of climate change often compete with other priorities, poor public understanding of risks and a lack of available financial resources"* (Danilenko, et al., 2010).

An ever-increasing list of publications, documents, reports, advice and examples about how to adapt to climate change is evident in New Zealand and around the world. In carrying out the two projects described in this paper, people told us that it is often overwhelming, they do not know where to start or they are unsure how planning for climate change might be different to the routine planning they already do. In progressing projects A and B, we identified that three practical aims were important in integrating the technical and social sciences, and providing guidance to water suppliers and health professionals in planning for health-related impacts of climate change. We suggest that these three key areas described below will provide a useful starting point for enabling practical adaptation to emerging climatic threats.

3.1 INFORMATION GATHERING AND COMMUNICATION

In beginning the research and project, as technical and social scientists working together, there were some key processes we needed to follow; we needed to organise interviews with very busy people, we needed to be open and honest about our methods and questions, and we needed to encourage our interviewees and project participants to talk openly about their efforts in adapting to climate change. An important consideration was who was in the research team; with expertise in both technical and social issues relating to water supplies, climate change and health, and by building on existing relationships, we had legitimacy to talk with councils, public health organisations, water suppliers, and iwi. The mixture of knowledge, connections, and professional, institutional and personal relationships were key to beginning our research processes. We could not have gained such a good picture of the wide range of impacts and responses to climate change without the technical understanding of some colleagues (e.g., the likely physical impacts of climate change on water quality or quantity), and we also needed the skills for facilitating open discussions with people (e.g., asking people to articulate past experiences in a respectful way), and to ensure we had a good range of people to talk to by undertaking comprehensive stakeholder analysis.

Another important consideration was planning how we would gather information about climate change despite scepticism about its impacts. Building on peoples' experiences of previous flood and drought events helped with 'buy in' to the need for preparation for climate change. Experience provided something that is 'known', despite some of the uncertainties around the wider context. We also based our work on the risk assessment-based framework as something familiar to users. For example, water suppliers who develop a PHRMP, health professionals who develop an HIA, or resource management professionals who develop an AEE. Talking with stakeholders in Taranaki was helpful in shaping ideas about how best to approach the vulnerability assessment; it was important that the resources developed firmly reflected the ideas of the practitioners who deal with some of these issues on a regular basis.

Lessons learned for climate change adaptation

Information gathering and communication is essential for beginning a process of response and adaptation to climate-related impacts on water supplies and health. The levels of uncertainty around different aspects of climate change are frequently referred to in the literature as well as by interviewees from different groups in the Taranaki region. There is uncertainty over:

- appropriate spatial and temporal scales for vulnerability analysis;
- the best methods to downscale global predictions to regional models;
- the biophysical causes and responses (i.e., levels of greenhouse gas emissions and policies that will control emission levels);
- the links between diseases and climate change;
- the amount of mitigation effort that will determine the level of climate change;
- the existing natural immunity of some regions to new diseases;
- the scale at which decision-making should be made (local, regional or national)

(Adger & Vincent, 2005; Ebi, et al., 2006; McMichael, et al., 2006; Patz, et al., 2000; Smit & Wandel, 2006).

Some of the people we spoke to in Taranaki expressed concern that they do not have enough information, saying "*climate change is confusing*" and suggesting the importance of responsibilities for providing information, as evident in the quote "*it is the council's role to provide information*".

Practical information gathering and communication considerations for water suppliers, councils and health professionals could include:

- Gathering information for justifying planning decisions that relate to climate change despite inherent uncertainty (e.g. getting access to a new water source);
- Exploring options for funding;
- Talking to other councils, health professionals, water suppliers etc to find out about potential impacts, what measures they are taking, where their funding came from, what kind of support they need;
- Encouraging colleagues and community members to talk about past experience is a useful way of starting to consider implications for climate change; what useful lessons have been learned from previous heavy rain or drought events, or contaminated water events?
- Gathering information about the adaptive capacity of your community.

The ability for a community to undertake some of these adaptation options depends on adaptive capacity. Adaptive capacity is defined by the Intergovernmental Panel on Climate Change (IPCC)[6] as 'the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (IPCC, 2007, p. 869). Yohe and Tol (2002) provide eight determinants of adaptive capacity, many of which cannot be quantified. These include:

- the range of technological options available;
- the availability of resources and their distribution;
- the structure of critical institutions;
- the stocks of human and social capital;
- access to risk spreading mechanisms;
- the ability of decision-makers to manage risk and information;
- the public's perceived attribution to the source of the stress (ie. is climate change legitimate or not), and;
- the significance of local manifestations (for example what observed local variations mean and what implications arise for whom).

(cited in Adger & Vincent, 2005, p. 402).

These determinants are evident in the New Zealand context as shown in the list below. In most of our Taranaki interviews, adaptation capacity was described in a language of preparedness. Some things that people said affected their ability to adapt were:

- Past experience;
- Geography and geology;
- Magnitude/duration of event and size/sophistication of water supply;
- How well people and organisations work together;
- Institutional capacity (funding and resourcing);
- Community spirit and capacity;
- Assumptions and perceptions (implying a need for behaviour change);
- Information availability and accessibility;
- Political context;
- Regional development and land-use;

Clearly evident in this list is the range of technical and social information that could be gathered to assess adaptive capacity of communities.

3.2 DEVELOPING OR USING FIT-FOR-PURPOSE TOOLS AND PLANS

The development of tools or plans requires a good understanding of the context within which they will be used, and the needs and demands of end-users (Wood, Lange, & Winstanley, 2008). In developing the data modelling system for adaptation planning, much time has gone into producing a framework that is generic (and therefore useable by sectors other than water); provides useful information to water suppliers (to help them reduce their system vulnerability); and provides useful information for various layers of local and central government. It is also designed to be relatively easy to use, compared to approaches to vulnerability that are dependent on the detail of climate forecasts. Developing a useful and useable tool has been dependent on the inclusion of users in the development process, as well as a good understanding of the technical aspects to the issues.

[6] The Intergovernmental Panel on Climate Change is the leading body for the assessment of climate change, established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences.

Lessons learned for climate change adaptation

The development of climate change 'action plans' by water suppliers, health practitioners or communities to identify quantify and prioritise the range of adaption options will similarly require integration of different types of information. One way that is promoted in the literature, and appears to be used by some in New Zealand, is the concept of 'mainstreaming' – aiming to address climate change adaptation alongside other existing programmes of work within institutions. Practical climate change adaptation initiatives are invariably integrated or 'incorporated into existing policies, programmes, or decision-making processes related to resource management, community development, livelihood enhancements, coastal zone management, sustainable development and risk management' (Smit & Wandel, 2006). Disaster and emergency preparedness approaches straddle public health and local government and may be useful places to start mainstreaming. But different languages, paradigms and priorities exist in different settings which may explain why integrated environmental and public health responses to climate change are key, but difficult to achieve in practice.

Closely related to 'mainstreaming' is the recommendation in climate change literature to use policies that are "no regrets" policies. These are steps that address climate change, but in doing so yield other direct or indirect health or other benefits. This approach can help to manage dilemmas, uncertainties, and lack of precision in forecasting. Some individuals and organisations in Taranaki are following no-regrets policies, as indicated by the quote "*this district is very prone to heavy rain events and severe droughts, and as such we feel this would be a very valuable booklet… we'll include these findings in our Asset Management Plans*" (District Council).

3.3 ENSURING UPTAKE AND DISSEMINATION OF TOOLS AND PLANS

There are numerous issues that influence the uptake of tools. A review of some of the barriers to uptake of resource management tools includes perceptions of the technology, choice of methods, trust and confidence in the tools, compatibility with organisational or societal norms, and a user-developer gap (Wood, et al., 2008). Often a combination of these factors may result in lack of tool use. As described above, stakeholder or end-user input into developing the data modelling system for adaptation planning was key. In addition, once a reasonable draft has been prepared, stakeholder input into how it might be made more useful is planned.

The climate change, water supplies and health booklet was designed to be useful for a variety of different groups and purposes. One positive comment from someone who has seen the booklet was:

> "*I could see this as a very useful resource in particular for council operated supplies where volume and quality of source waters are an issue. Clearly the tables are set up as a risk matrix which marry very nicely with Public Health Risk Management Plans (PHRMPs) that more drinking water suppliers are applying for approval by DWAs. I suspect that in rural councils the issue of climate change is seen as a distant thing (if they consider it at all) and drinking water planning seems to be the exclusive domain of the engineers. A word in the ear and a resource like this can assist their thinking about the future of their supplies (or at the very least get them thinking)*" (District Health Board).

Lessons learned for climate change adaptation

It will be interesting to observe how well councils, water suppliers, health professionals and communities are able to implement 'no regrets' policies and other ways of considering potential impacts of climate change into their plans and policies. Some of those we talked to in Taranaki said it is very difficult to know how to do this, and that there is very limited guidance available for incorporating these issues into their plans. It is hoped that presentations at conferences such as this Water New Zealand one, and at other meetings and training sessions around the country will go to some way to helping to integrate data, information and expertise to enable practical adaptation to emerging climatic threats.

4 CONCLUSIONS

Uncertainty around the extent and impacts of climate change remains, but nevertheless, there are increasing numbers of resources, guidelines, reports, models and predictions available. There are several potential climate change related scenarios that are relevant to New Zealand drinking-water supplies, including drier conditions expected in eastern areas, more frequent floods on the western coasts, retreating snowlines and glaciers, and changes in climatic extremes. Potential health impacts related to the supply of water include waterborne illnesses, impacts on health and well-being, and vector-borne illnesses.

Successful adaptation will not be easy, or quick. Planning, by a number of different people and organisations, will require integration of different types of information, and different methods for gathering, analysing and using this information. This paper has described two New Zealand climate change projects that aimed to provide practical 'tools' for water suppliers, health practitioners and communities, and that focused on integrating the social and technical sciences. Both projects used qualitative data collected from the Taranaki region in 2009.

Project A has produced a 'climate change, water supplies and health' booklet that uses the familiar concept of risk assessment to provide information on possible impacts of climate change on water supplies and health, and ideas for preventing, managing, responding, adapting to deal with anticipated impacts. It also encourages the users to think about their own context, and how issues overlap.

The drinking-water supply vulnerability modelling project outlined as Project B aims to determine the feasibility of assessing the vulnerability of water supplies, and identify actions that can be taken to reduce vulnerability. This risk management framework is potentially useful for application to sectors other than water supply. Again, the increasingly-used concept of risk assessment is used as the basis for vulnerability assessment.

The methods used in carrying out these two projects, as well as the findings, reveal three key steps that water suppliers, health professionals and communities can start to take now for dealing with the potential impacts of climate change; information gathering and communication, developing or using fit-for-purpose tools and plans, and ensuring uptake and dissemination of tools and plans.

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REFERENCES

Adger, N. W., & Vincent, K. (2005). Uncertainty in adaptive capacity. *Geoscience, 337*, 12.

Baker, V., Lange, M., & Nokes, C. (2010). *Literature Review on dynamics/contextual factors affecting 'Information for Action' for the Climate Change and Human Health nexus. Health Analysis & Information For Action (HAIFA) Objective 3 Report* Wellington: Institute of Environmental Science and Research Ltd.

Craigie, R. (2009). *Climate change, human health and vulnerability. A literature review. Carried out as part of the University of Canterbury Social Science Research Centre Summer Studentship*. Christchurch: Institute of Environmental Science and Research Ltd.

Danilenko, A., Dickson, E., & Jacobsen, M. (2010). Climate Change and Urban Water Utilities: Challenges and Opportunities. *World Bank Water Working Notes, 24*(April 2010).

de Loe, R., Kreutzwiser, R., & Moraru, L. (2001). Adaptation options for the near term: climate change and the Canadian water sector. *Global Environmental Change, 11*, 213-245.

Dickson, D. (2010). Two cultures but one message for climate change. *Science and Development Network Editorial, February 2010*. Retrieved from http://www.scidev.net/en/editorials/two-cultures-but-one-message-for-climate-change.html

Ebi, K. L., Mills, D. M., Smith, J. B., & Grambsch, A. (2006). Review - Climate Change and Human Health Impacts in the United States: An Update on the Results of the U.S. National Assessment. *Environmental Health Perspectives, 114*(9), 7.

Haines, A., McMichael, A. J., & Epstein, P. R. (2000). Environment and health: 2. Global climate change and health. [Review]. *Canadian Medical Association Journal, 163*(6), 6.

IPCC. (2007). *Appendix I: Glossary from the IPCC Fourth Assessment Report (Working Group II Report "Impacts, Adaptation and Vulnerability")*: Intergovernmental Panel on Climate Change,.

Klein, R. J. T. (2004). *Vulnerability Indices - An Academic Perspective: Expert Meeting "Developing a Method for Addressing Vulnerability to Climate Change and Climate Change Impact Management: To Index or Not To Index?" Bonn, Germany, 26 January 2004*.

McMichael, A. J., Woodruff, R. E., & Hales, S. (2006). Climate change and human health: present and future risks. [Review]. *The Lancet, 367*(9513), 11.

Ministry for the Environment. (2001). *Impacts Report: Climate Change Impacts on New Zealand*. Retrieved from http://www.mfe.govt.nz/publications/climate/impacts-report/impacts-report-jun01.pdf.

National Resource Canada. (2004). *Climate Change Impacts and Adaptation: A Canadian Perspective*. Ottawa: available at http://adaptation.nrcan.gc.ca/perspective/index_e.php.

Natural Resources Canada. (2004). *Climate Change Impacts and Adaptation: A Canadian Perspective*. Ottawa: available at http://adaptation.nrcan.gc.ca/perspective/index_e.php.

Patz, J. A., McGeehin, M. A., Bernard, S. M., Ebi, K. L., Epstein, P. R., Grambsch, A., et al. (2000). The Potential Health Impacts of Climate Variability and Change for the United States: Executive Summary of the Report of the Health Sector of the U.S. National Assessment. *Environmental Health Perspectives, 108*(4), 10.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, 16*(3), 11.

Taranaki Regional Council. (2003). *Taranaki - Our Place Our Future: Report on the state of the environment of the Taranaki region 2003*. New Plymouth: Taranaki Regional council.

Wood, D., Lange, M., & Winstanley, A. (2008). *Making Tools Work in Resource Management*. Paper presented at the NZWWA Conference, Christchurch.

Yohe, G., & Tol, R. S. J. (2002). Indicators for social and economic coping capacity - moving toward a working definition of adaptive capacity. *Global Environmental Change, 12*(1), 16.