

Water management in the developing town: a complex systems perspective

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Declarations

This work contains no material which has been previously submitted for a Degree or Diploma in a University or other tertiary institution. It has concurrently been submitted on this day to the Australian National University. To the best of my knowledge and beliefs, this thesis contains no material previously published or written by any other person, except where due reference has been made in the text.

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Abstract

Provision of water services is a critical strategy for addressing worldwide poverty, and this is one of the most pressing challenges of current times and is linked to population growth and climate change. Progress has been slow in achieving even the Millennium Development Goals aimed at improving coverage of adequate water services and professionals are struggling to cope with the diversity and scale of situations. Water services provision is a context-dependent process and many types of situations are very challenging, such as that of small developing towns. This thesis addresses the problems of urban centres in Pacific Island Countries and the aim is to provide formal explanations of difficulties in these locations to support recommendations that recognize local constraints and opportunities to best practice management. This is achieved largely by employing a perspective based on the science of Complex Adaptive Systems. This perspective has been chosen in recognition that water management incorporates complex interactions between social, technical and natural systems. The research is case study based, focusing primarily on Tarawa in the Pacific Island nation of Kiribati. The methodology includes historical review of the case study, and the use of historical review, as well as interviews and observation in the field as well as a cross-cutting email-based Delphi survey. This has generated qualitative and quantitative data to allow for the formulation of scientific models, an Agent Based Model describing the complex interactions involved in water service delivery; and Bayesian Network models describing the factors impacting on the chances of successful management interventions. With improved explanation of the complex situation, this has been used to support the formulation of a strategic and adaptive governance framework; aiming to introduce much needed organisational memory, and a consistent strategic direction set on the basis of the effective stakeholder interaction. By recognising weakness in capacity, it is possible to turn these into strengths by building and utilising local knowledge and commitment.

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Glossary of Terms

Adequate water services: As per the definition of improved water sources and improved sanitation by the World Health Organisations' Joint Monitoring Programme (WHO 2006) which is relatively vague but which usually requires water of sufficient quality and of sufficient quantity provided to within the household; typically via a tap, and with wastewater transported from the house via a pipe network and treated in a safe manner before disposal.

Complex Adaptive Systems (CAS): This term is used in this thesis for a special type of 'system', as described by Holland (1995); Batten (2000); Richardson (2002); Perez and Batten (2006); and Miller and Page (2007). These systems involve particular properties that make them adaptive and dynamic; and largely unpredictable. These properties are in particular: non-linear behaviour, feedbacks, path dependence and equifinality as well as self organisation and emergence. The analysis of these systems typically involves exploration of a large number of variables interacting in complicated manners, as well as breaking down populations into their individual components interacting with each other and other sub-systems; creating a distributed view of the system.

Deductive reasoning: This term is used in the thesis for a type of reasoning that is built on formal logic and is appropriate in situations where the premises are sufficient grounds to infer whether an argument is true or false. As per Batten (2000), deduction is reasoning from the general to the particular. A perfectly logical deduction yields a conclusion that must be true provided that its premises are true. Thus deduction involves specifying a set of axioms and proving consequences that can be derived from those premises.

Inductive reasoning: In this thesis, inductive reasoning is a type of reasoning which relies on incomplete information. In this case, conclusions cannot be deduced by strict logic but the premises and information act as evidence that goes to build up the case for a particular conclusion. A further description of inductive reasoning which is a cognitively complex process can be found on pages 58-59 in the book *Discovering Artificial Economics* (Batten 2000).

Level of development: The level of development, as used in this thesis, is related to economic development and the workings of key institutions, and is here used in the same sense as is done in the development of the Human Development Index by the United Nations Development Program (UNDP 2006).

System: The word ‘system’ is used in this thesis as within the discipline of Systems Engineering as described by Haimes (1998); and which holistically incorporates not only technical machinery but also people, processes, natural systems and economic factors; or in fact any factors that are important for the outcome.

Small towns: This term, in this thesis, refers to urban settlements that are in the population range of 2,000-50,000 people, as defined by Pilgrim *et al.* (2004), and that often lack resources such as finances and educated staff. It is recognised that the provision of water services and urban water management in this context is particularly challenging.

Social complexity: Refers in this thesis to viewing social systems as Complex and Adaptive Systems; and focussing on these particular features of social interactions. It thus concerns aspects such as distributed systems, non-linear feedback loops and conflicting goals; overall leading to a messy and dynamic as well as relatively unpredictable situation. Behavioural aspects and cognitive processes are key drivers in socially complex situations. A key journal in this area is the *Journal of Artificial Societies and Social Simulation* (JASSS) and applications of social complexity modelling tend to focus on policy.

Stakeholder: This term in this thesis refers to those people, or groups of people, or institutions, or organisations that have a stake in a particular decision, or in a particular operation, or who have some influence over, or who may block, the decision making process (Nandalal and Simonovic 2003).

Tactical: The term tactical is used in this thesis in the sense of a focus on strategies to achieve shorter-term goals, i.e. via projects. In other words it concerns the implementation and operationalising of goals set at the strategic level; involving knowledge management, systems analysis and stakeholder interactions.

Chapter 1: Introduction

Provision of water services is a critical strategy for addressing worldwide poverty, which is one of the most pressing challenges today and is directly linked to issues such as population growth and indirectly to climate change.

Unfortunately progress has been slow in achieving even the Millennium Development Goals aimed at improving coverage of adequate water services and professionals are struggling to cope with the diversity and scale of situations. This is particularly true in the context of small developing towns.

This thesis addresses the problems of towns in Pacific Island Countries and the aim is to provide a causal explanation of difficulties in these locations with the subsequent aim to formulate managers and policy-makers with recommendations that recognize local constraints and opportunities to best practice management which aim to promote participation, encourage flexible realizations and rely upon financial prudence.

1.1 The need for practical frameworks

With the rapid urbanisation of the world and the slow progress towards achieving the Millennium Development Goals regarding adequate water services (see Appendix 1); there is an urgent need to devise effective and adaptive strategies to narrow the gap between adequately serviced and less favoured communities.

Efforts to improve water services in developing countries are facing a number of challenges that are arguably not very well understood and for which there are only a few guidelines and operational management frameworks. This is true in the contexts of small towns in developing countries.

Guidelines for water services provision

Major international agencies such as the United Nations, the World Bank and the Asian Development Bank, have edicted a consistent range of guidelines concerning the provision of water services in developing nations. As an example, the United Nations, in their report '*Water: a Shared Responsibility*' (United Nations 2006a) have recognised that to achieve better water service provision, there is a need to design holistic and comprehensive solutions aiming at improving water governance by encouraging the active participation of all components of the civil society. Unfortunately, this laudable aspiration is often difficult to convert into practice.

Water services provision in practice

Water services provision is a context-dependent process. While available and suitable solutions in rural areas are often limited when compared with those in urban areas, developing countries face the same limitations in comparison with developed nations. In many ways, water governance in rural areas is easier because the number of people involved in operation and management is smaller, and systems are often relatively easier to comprehend.

At this scale, participatory governance is often applied, involving users and relevant components of the civil society. This is often combined with relatively simple and inexpensive technologies suitable for local conditions. At larger urban scales, engineers create technological systems, typically based on large water storages, treatment plants and reticulated networks. Customers receive water services for a fee. These systems are relatively predictable and easy to control as human influences are purposefully limited by regulatory and economic frameworks.

The challenge of water services provision in small towns

By definition, in between the two contextual areas are small towns which are urban settlements including between 2,000 and 50,000 inhabitants. They have been widely recognised as challenging in terms of water services provision (Pilgrim *et al.* 2004). Existing guidelines for small towns, like the one established by UN-HABITAT (2006), are more theoretical than practical.

In terms of demography, small towns represent a significant proportion of the world's population. By 2015 it is projected that approximately 24 percent of the world's population will live in urban areas that have a population of less than 500,000 (United Nations 2002). Furthermore, for every large town in the population range of 50,000 to 200,000 people there are ten smaller ones in the population range of 2,000 to 50,000 people (Pilgrim *et al.* 2004). Exact data is not available, but these numbers indicate that as much as 10-15% of the world's population live in smaller towns.

Politically towns tend to lack the influence of larger cities and in many instances, that of smaller rural communities. The plights of small towns often lack priority. From an infrastructure and financial point of view, there is often a lack in the economy of scale that is required to support centralised technological systems. This often means an increase the operational complexity:

These towns face special challenges in the provision of their water and sanitation services. The demand for differentiated technologies – piped water supply in the core, alternative technologies in the fringe areas – and the often rapid, unpredictable water demand and spatial growth requires planning, design and management skills that exceed “rural” community-based management approaches. But, unlike larger towns or cities, these smaller towns lack the financial and human resources to independently plan, finance, manage and operate their water and sanitation systems (Pilgrim *et al.* 2004: iii).

This means that there are real pressures on local water managers due to severe resource constraints and a strict need for holistic governance that considers a number of aspects, including systems interactions (between natural, technical and social systems), and critically those relating to people and behaviour. Therefore, the capacity to implement international best-practice for water service provision is limited; and there is disconnect between guidelines and practice that needs to be effectively bridged via appropriate frameworks. Such frameworks

would involve processes and tools for local water managers that will need to acknowledge a high level of system complexity and constraints such as limited funding and human resources.

1.2 Problem statement

As is commonly accepted, current provision of water and sanitation services in small towns in developing countries is fraught with difficulties; and implementing best practice guidelines is challenging. To be able to devise solutions to these problems, this thesis aims to find description and causal explanations of the complex dynamics and difficulties of water services provision in those locations. Subsequently, this thesis addresses the challenge of developing a practical framework incorporate best-practice management for the provision of water services in the case study. This framework aims to provide local managers and policy-makers with concepts and ideas for how to re-structure planning and decision making processes. Finally, whilst not an aim of the study per se, the hope is that the analysis tools that are developed may help local stakeholders to incorporate systems thinking, uncertainty as well as constraints and opportunities into best practice management.

1.3 Underlying assumptions

The first assumption is that complex systems models, such as Agent Based Modelling and Bayesian Networks modelling can provide adequate description and at least partial causal explanations of the context. This is backed up by the current discussion on the epistemic value of simulation and probabilistic logic (Gruene-Yanoff 2010; Pearl 1999)

Borrowing from the inductive theory building proposed by Locke (2007), another assumption underlying this study is that *it is possible to develop a governance framework through research*. However, the proper uptake of such a framework is outside the scope of this doctoral thesis; despite our recognition that the actual impact of a governance framework constitutes the ultimate validation of the theory building process itself.

A second assumption of this study is that *water management in general, and small town water management specifically can effectively be viewed as Complex Adaptive Systems*. Following Pahl-Wostl (2002a), it is considered that water management incorporates indeed complex interactions between social, technical and natural systems. Furthermore, it is intended to use sense-making concepts developed by Kurtz and Snowden (2003) for complex and uncertain contexts.

Methodologically, a third assumption of this study is that by generating an understanding via case study, *it will be possible to synthesise a range of information in order to allow the formulation of frameworks that will help improve local water managers and administrators in their professional roles* for the wider context of small towns. This is in line with the ideas of Flyvbjerg (2006) regarding the usefulness of case study research.

1.4 Thesis aim and objectives

In order to reach the goals of the thesis, this study includes six different stages:

1. To critically explore and describe the context of small town water management at a single case study location.
2. To explore the wider context, the current best practice, as well as a cross cutting analysis of urban water management in Pacific Island Countries via knowledge elicitation of a wider group of professionals with relevant expertise.
3. To develop systems representations of the single case study location that will help improve the understanding and causal explanations of the complex dynamics of this context.
4. To use causal explanations and to develop suitable tools that will likely be able to help support recommendations for local water managers and administrators.
5. To synthesise the understanding, causal explanations, and information that has been developed through the study, and provide a critical discussion and recommendations about a possible pathways towards better small town water management.

6. As a key recommendation, to develop a preliminary framework for improved small town water management in the case study location that takes into account limitations and constraints, but which at the same time considers best-practice, and acknowledges the full complexity of the task.

1.5 Structure of thesis

The structure of this thesis develops as follows: 1) Literature reviews, 2) Methodology 3) Results, and 4) Synthesis, as per Figure 1-1. The linear structure is an after construction and is not a fully accurate representation of the research process. In reality, the research process has tended to be iterative and circular. The sections of the thesis are described in the following sections.

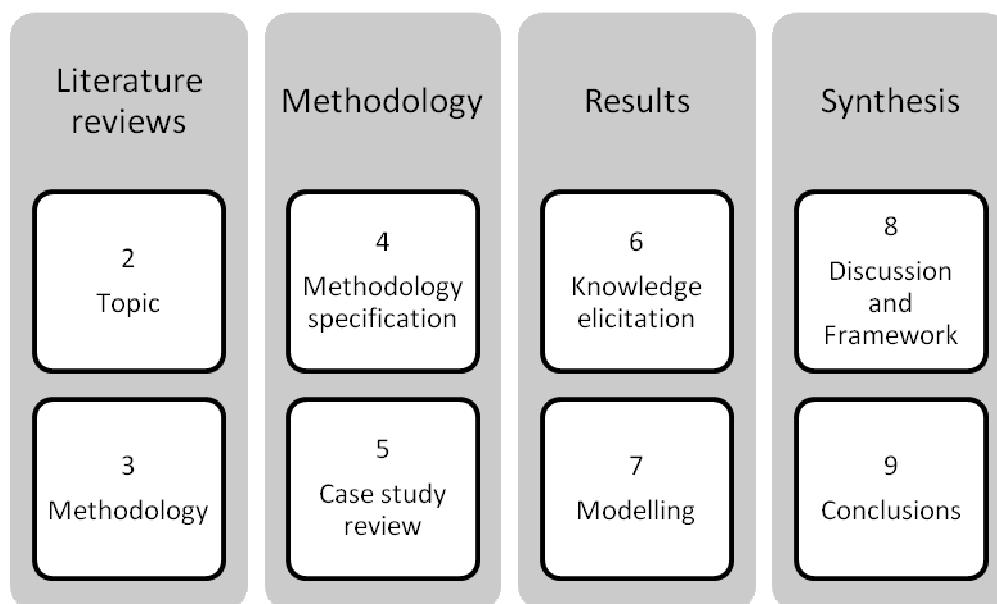


Figure 1-1: Thesis structure

1.5.1 Part 1: Literature reviews

The literature review section is split into two chapters. The first section (chapter 2) describes the context of urban water management with a particular focus on small towns. The second section

(chapter 3) describes the methodological thinking that needs to be considered and the methodological tools that appear to be suitable.

In chapter 2, the scope and challenges of urbanisation are laid out. This includes a mapping of the diversity of urban situations based on population size and level of economic development. Secondly, chapter 2 also provides a description of three perspectives on urban water governance, i.e. economic, environmental and social. These perspectives provide dynamically inter-linked viewpoints. Thirdly, chapter 2 also provides a description of frameworks for urban water management. These frameworks include sustainability principles, good governance, regulation as well as public participation and institutional decentralisation. Fourthly, chapter 2 describes specific issues of small towns in Pacific Island nations. This includes considerations relating to Small Island Developing States (SIDS); and in particular economic limitations, cultural complexity, historical background and institutional concerns.

In chapter 3, tools are identified that can generate a better understanding of the studied systems. Specifically, there is a review of knowledge elicitation techniques as well as systems analysis approaches from the complex systems science area. To support the formulation of a management framework, concepts such as social learning, post-normal science and participatory integration frameworks are also described. In this chapter, the need for participation and modelling within an integrated framework is identified. Unfortunately, none of the reviewed integrated framework approaches are perfectly suitable for this particular study.

1.5.2 Part 2: Methodology

The methodology section is divided into two sections. The first section (chapter 4) defines the methodology. The second section (chapter 5) describes the case study context via a historical review as well as an assessment of the current state.

In chapter 4, the research approach is laid out. This includes a description of the reasons for case study based research; as well as a number of criterions for choosing a case study location. By applying these criteria, a case study location is chosen: the capital, Tarawa, of the Pacific Island nation of Kiribati (shown in Figure 1-2). This chapter also includes the specifications of how

information was collected via case study based interviews and cross-cutting Delphi survey. The chapter also include specifications of the modelling; using Agent Based Modelling and Bayesian Networks approaches.



Figure 1-2: Street life in the case study location in Tarawa, Kiribati

Notes: Photography by Anne Dray.

Chapter 5 provides a description of the case study location from a number of perspectives such as geography, language, demography, distant history, culture and customs, environment and a number of challenges with aid and development. Chapter 5 also describes the more recent experiences in urban water management at the case study location, finding that there were a number of recent failures in addressing their raft of problems.

1.5.3 Part 3: Results

The result section is split into two chapters. The first chapter (6) focuses on the observations and data generated from the case study based interviews, and the cross-cutting Delphi survey. The second chapter (7) focuses on the description and results of the Agent Based Models and

Bayesian Network models that have been developed, and used to develop causal explanations.

There is also some discussion about the inferences that can be made from these models.

Chapter 6 provides a description of the results from the interviews. Interviewing is a technique that is not bound by traditional scientific constraints, but will allow for gaining a more integrated, and rich understanding of issues and factors. The understanding based on the interviews is based primarily on induction, i.e. pattern recognition. These results are hence a personal perception and interpretation of the situation in the Tarawa water supply system. However, whilst subjective the results are, to the extent possible, sense-checked by local stakeholders and experts. These results are to some extent also based on more objective observations and elicited mental models.

Chapter 6 also describes the results from the Delphi survey. The cross-cutting survey formally collected perspectives and narratives of diverse stakeholders and experienced individuals in the wider Pacific Islands region. This allows for the making of wider generalisations. The understandings based on the Delphi survey are the outcome of a designed convergent process where the multiple perspectives of a range of participants are collated, socially evaluated, narrowed down and prioritised.

Chapter 7 provides a description of the results of the ABM. The ABM allows for systems analysis whereby probes can be designed and explored using scenario analysis. The impacts of these probes and scenarios are evaluated from a number of perspectives. The ABM helps to provide an understanding of how to promote desirable patterns of behaviour in the system.

Chapter 7 also provide a description of selected Bayesian Networks. These models allow for a better understanding of the cause and effect relationships (causal explanations) in water development interventions. Such relationships are often both complex and uncertain.

1.5.4 Part 4: Synthesis and framework

In the final section, results are integrated into a non-contradictory whole. This takes the shape of theory and management framework. There is also an attempt to identify the domain and boundary conditions for this framework.

Chapter 8 provides discussion of the results of the study. The results are formally presented on the basis of themes identified in the Delphi survey. These themes are: Socio-technical issues, Boundary conditions, Policy issues and Technical issues. Each theme is discussed by exploring the results in categories of observations and model inferences. Here it is acknowledged that model inferences are context-dependent, and it is also not possible to capture the full complex and adaptive reality. Chapter 8 also describes a theory for what contributes to system complexity in these contexts. This leads on to a discussion about the implications for management strategies; in terms of potential complexity reduction, and complexity management.

Chapter 8 also describes a definition of an operational and practical management framework that is suitable to the context in Tarawa. This framework is based on a multi-scale approach which includes an operational, a tactical and a strategic level; and which includes adaptive learning cycles. The framework has been formulated on the basis of the realisation of a number of deficiencies in both the interactions between the management scales, as well as deficiencies in the tactical and adaptive capacity. It is argued that by strengthening the adaptive learning cycle, this framework can turn weakness into strength, and hence provide a manageable situation.

Finally, chapter 9 provides the final conclusions of this study and a summary of the key contributions to the global research community. In this chapter, there are recommendations for future research. Such future research relate in particular to the action based learning that is needed to fine-tune the framework. There is also a description of the framework's limits and domain of applicability.

Chapter 2: Context review

In this chapter, the context of urban water management is reviewed; in particular for small towns. Urban water management is viewed from a number of perspectives, and some key frameworks for urban water management are described. Furthermore this chapter also provides some of the background justification as to why small town water issues are critical in the big picture of poverty reduction and for achieving the Millennium Development Goals.

As the world population continues to grow, more and more people are populating an ever increasing number of towns and cities. When people arrive in cities and towns, there is a reasonable expectation that there should be adequate household water and sanitation provision. Unfortunately, as anyone who has travelled to countries such as India or Cambodia knows, that expectation is far from being fulfilled. For example, the World Health Organisation (2006) reports that in the South East Asian region, 94 percent of urban households have access to improved water services, but only 65 percent of urban households have access to improved sanitation services, and considerable variation in access to such services exists within the region. With this in mind, the scope of this literature review is on urban water governance and management.

Firstly, the scope and challenges of urbanisation will be explored, including a brief mapping of the diversity of urban situations based on population size and level of economic development. Secondly, three perspectives on urban water governance, namely the economic, environmental and social dimensions will be reviewed to reveal how these are dynamically interlinked. Thirdly, frameworks for urban water management are described, including sustainability principles, good governance, regulation as well as public participation and institutional decentralisation. Fourthly, specific issues of small towns in Pacific Island nations will be explored in relation to their economic constraints, cultural complexity, historical background and institutional concerns.

2.1 Challenges of urbanisation

Managing the impacts of increasing urbanisation was recognised as one of the key concerns internationally over 20 years ago by the United Nations' World Commission on Environment and Development, and articulated by the former Norwegian prime minister Gro Harlem Brundtland:

The future will be predominantly urban and the most immediate environmental concerns of most people will be urban ones (World Commission on Environment and Development 1987: 255).

Since Brundtland's statements, there has been an escalation in urbanisation rates, particularly in the developing regions of the world; and in 2007 for the first time, more than half of the world's population lives in cities; and this is seen as a threat to public health because the pace of urbanisation outstrips governments' capacity to provide essential infrastructure (World Health Organisation 2010).

More than two thirds of the world's population now live in Africa, Asia and Latin America and in these regions the urban population has grown more than fivefold since 1950. At the time of writing, there are 19 mega-cities in the world with over ten million inhabitants, totalling 275 million people, and a further 348 urban centres with a population over a million (UN-HABITAT 2003). The majority of these 'million cities' are in Africa, Asia and Latin America (Satterthwaite 2000a). New York was the first city to reach a population size over ten million people, during the early 1940s. In 2003, only four of the world's mega-cities were in the developed world (New York, Los Angeles, Tokyo and Osaka) while the remainder were in Africa, Asia or Latin America (UN-HABITAT 2003).

In fact, as shown in Table 2-1, approximately three quarters of the population in Europe, Oceania and North America live in urban areas; while in Africa and Asia more than a third of the population live in urban areas (Pilgrim *et al.* 2004). According to population size predictions for 2030, the proportion of the population in urban areas in all regions is projected to increase; with Africa and Asia predicted to have over half of their populations being urban based.

Table 2-1: Observed and predicted levels of urbanisation in major global regions

Region	Urban dwellers (%)			
	1950	1975	2000	2030
Oceania	61.6	72.2	74.1	77.3
Europe	52.4	67.3	73.4	80.5
Asia	17.4	24.7	37.5	54.1
Africa	14.7	25.2	37.2	52.9
Northern America	63.9	73.8	77.4	84.5

Source: United Nations 2002.

As highlighted by Chakrabarty, rapidly expanding populations compound the pressures of urban management issues such as: inadequate housing and urban services (water, sanitation, transport and so on); spiralling land prices and construction costs; proliferation of slums; and pollution and deterioration of the urban environment (2001: 331). Satterthwaite, focussing on less developed areas, however recognises a similar but slightly different set of interrelated deprivations for inhabitants of urban areas:

- Inadequate or unstable income (which translates into inadequate consumption);
- Inadequate, unstable or risky asset bases: including social, human, financial, physical (e.g. capital goods, equipment, housing) and natural (for instance access to productive land and freshwater);
- Limited or no right to make demands within the political or legal system – often within a framework which does not guarantees civil and political rights – for instance the right to have representative government, the right to organise and to make demands and to get a fair response, the right to protection against forced eviction); [and]
- Poor quality/insecure housing and lack of basic services – with the very large health burden that this imposes and the high economic and other costs this also brings (Satterthwaite 2000b: 2).

It is noted that the references to water in this document (Satterthwaite 2000b) relate specifically to the lack of adequate water supply for sections of the community, and more generally to inadequate service provisions available to communities. In addition, Satterthwaite stresses the fundamental importance of institutional management as environmental shortcomings typically result from inadequate economic and political response.

It may be misleading to refer to many of the most pressing urban environmental problems as 'environmental' since they arise not from some particular shortage of an environmental resource (land or freshwater) but from economic or political factors which prevent poorer groups from obtaining them or from organising to demand them. The very inadequate access to freshwater supplies that so many of the urban poor face is a serious environmental problem for them but rarely is its cause environmental; in most cities, it is not a shortage of freshwater resources but governments' refusal to give a higher priority to water supply (and the competent organisational structure its supply, maintenance and expansion requires) (2000b: 19).

In the most temporary and least developed areas of cities, such as slums, a clear link has been established between poverty and inadequate water supply and poor sanitation provision (UN-HABITAT 2003). Linked to the nexus of issues of water, environment, poverty and slums, there is a global political recognition of urban water and sanitation issues as stipulated in the seventh United Nations Millennium Development Goal (MDG) (the MDGs are detailed in Appendix 1):

Goal 7: Ensure environmental sustainability

1. Integrate the principles of sustainable development into country policies and programmes; reverse loss of environmental resources.
2. Reduce by half the proportion of people without sustainable access to drinking water.

3. Achieve significant improvement in the lives of at least 100 million slum dwellers, by 2020 (United Nations 2000).

Despite decades of awareness and agreement of the importance of action needed to ‘ensure environmental sustainability’, there has been very limited progress towards this particular goal to date. A recent United Nations report argues that despite considerable attention given to water developments, little has been achieved on the ground and notes the following shortcomings (adapted from United Nations 2006b: 44-45):

- Worldwide, 1.1 billion people still lack access to safe drinking water;
- Good governance is essential for managing our increasingly stretched supplies of freshwater, and indispensable for tackling poverty but unfortunately the commitment to good governance is often poor;
- There is no blueprint for good water governance... but it is known that it must include adequate institutions – nationally, regionally and locally – strong effective legal frameworks and sufficient human and financial resources;
- Local participation, transparency and solutions that are suitable in the context of diverse local circumstances are needed;
- Many governments recognise the need to localise management but fail to delegate adequate powers and resources to make it work.

Whilst these issues are not confined to urban contexts, it is clear that constraints to progress relate specifically to insufficient governance and inadequacy of institutions. This resonates with observations by Satterthwaite (2000b) and Chakrabarty (2001).

2.2 Key dimensions of urbanisation

Urban contexts vary considerably depending size of settlement, economic activity and other development types. Firstly, the size of an urban settlement is important because of its

constrained ability for utilising economy of scale (Pilgrim *et al.* 2004), and because a city and its production base may grow to exceed the capacity of freshwater sources to supply enough water on a sustainable basis (Satterthwaite 2000b). Secondly, the level of human and economic development, as indicated by for example the Gross Domestic Product (GDP) or the Human Development Index (HDI), in an urban area has an impact on the amount of available human and financial resources (Pilgrim *et al.* 2004).

Some further factors that impact on the urban water sector are described in Appendix 2. In an effort to compare and contrast urban areas of relevance to this thesis, towns and cities from different regions have been mapped on the basis of size and development status (Figure 2-1). It is noted that there is some bias in Figure 2-1 towards the edges of the figure and no representations from certain categories, i.e. towns in the LIE category or in the UMIE category. The urban settlements in this diagram represent the locations referenced in articles used in this chapter.

2.2.1 Urban size

For the purposes of water and sanitation management, Pilgrim and colleagues (2004) have categorised urban areas, as shown in Table 2-2. It can be deduced from demographic data that as many people live in towns and smaller cities as there are people that live in bigger cities (United Nations 2002). In fact, as of the year 2000, approximately 27 percent of the global population live in cities and towns with a population of less than 500,000 people (United Nations 2002: 6). In urban areas of less developed regions, approximately 24 percent of the population are projected to live in urban areas with a population less than 500,000 in 2015 (United Nations 2002: 6). In contrast, in urban areas in developed regions, approximately 43 percent are projected to live in urban areas with a population less than 500,000 by 2015 (United Nations 2002). In Asia and Africa, towns are the most common type of urban settlement (Pilgrim *et al.* 2004). In terms of frequencies in the occurrences of towns, Pilgrim and colleagues (2004) have found that for every large town there are 2-3 medium-sized towns, and approximately 8-10 small towns.

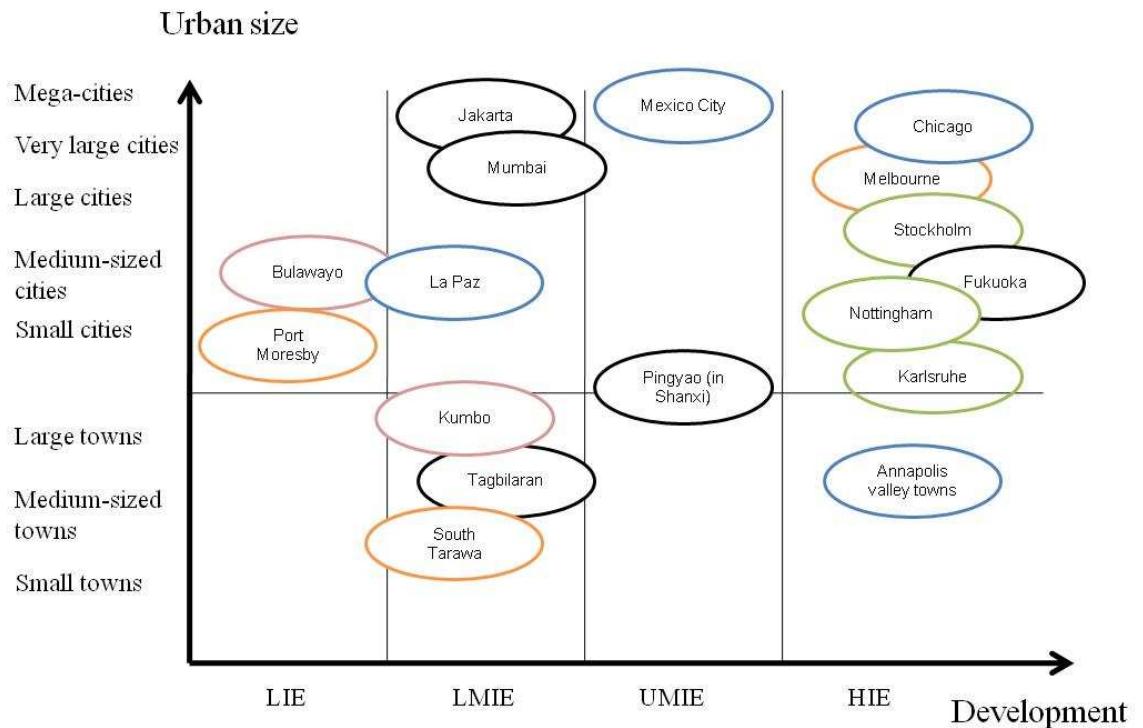


Figure 2-1: Mapping of urban areas based on two key dimensions

Notes: The ovals in Figure 2-1 represent urban areas mentioned in the references in the literature review, and the colours represent the respective regions in which the urban area is located, i.e. black represents the Asian region; blue represents the American region; green represents Europe; orange represents the Pacific region, and purple represents the African region. The development, x-dimension, has four categories: Low income economies (LIE); Lower-middle-income economies (LMIE); Upper-middle-income economies (UMIE) and High-income economies (HIE) as per national categorisations by the World Bank (2008). For the y-dimension, the size based categorisation of towns and cities is based on a World Bank sponsored report by Pilgrim *et al.* (2004). Population data has been collected from a trusted web site (City Populations 2008).

In a time of climate change when it is expected that an increasing number of people will move to cities, increasing the efforts on solving the water and sanitation issues in small towns is likely to slow the migration to slums around larger cities (Word Bank 2009: 12).

Table 2-2: Distribution of world population in a range of urban size categories

Urban size bracket	% of total population		Category*
	2000	2015	
10 million or more	3.7	4.7	Mega city
5 million to 10 million	2.8	3.7	Very large city
1 million to 5 million	11.1	13.3	Large city
500,000 to 1 million	4.8	4.9	Medium-sized city
			Small city (>200,000)
Fewer than 500,000	24.8	27.1	Large town (>50,000)
			Medium-sized town
			Small town (<20,000)
Rural areas	52.8	46.3	Village (<2,000)

Sources: This table shows the size brackets that have been developed by Pilgrim and colleagues (2004) and used for the purposes of urban water management. The current and projected percentage of population in each urban size bracket has been collected from a United Nations report (2002).

Considering the demographic importance of towns, it is apparent that improving the capacity for town water services provision is of critical importance in order to achieve the Millennium development goals as is argued also by the United Nations as a key step towards addressing worldwide poverty.

Inadequate provision for water and sanitation affects hundreds of millions of people in small urban centres and is a major constraint to the achievement of the Millennium Development Goals (UN-HABITAT 2006: 1).

It is noted that there are particular problems for (small, medium-sized and large) towns:

Water supply and sanitation services are [critical] to a town's prosperity. But service provision in towns has been extremely poor... most often characterised by sporadic government hand-outs for rehabilitation or expansion, followed by long periods of deterioration. There has been a lack

of knowledge about institutional arrangements and planning processes appropriate to towns (Pilgrim *et al.* 2004: 6).

These problems are particularly severe for small and medium sized towns that are characterised by (adapted from Pilgrim *et al.* 2004):

- Lack of resources: skilled staff, finances, information and knowledge;
- Unpredictable population growth in population in individual towns;
- High levels of uncertainty in source availability and economic capacity; and
- Close interactions between rural surroundings and urban areas.

Table 2-3: Population sizes of towns and cities mentioned in this chapter

Name	Population size
Jakarta, Indonesia	8,839,247
Mexico City, Mexico	8,463,906
Chicago, United States	8,307,904
Sydney, Australia	3,641,422
Melbourne, Australia	3,371,888
Stockholm, Sweden	1,889,945
Fukuoka City, Japan	1,414,417
La Paz, Bolivia	713,400
Bulawayo, Zimbabwe	676,787
Nottingham, United Kingdom	666,358
Pingyao, People's Republic of China	480,000
Karlsruhe, Germany	286,327
Suva, Fiji	172,948
Kumbo, Cameroon	116,500
Annapolis Valley, Canada	85,000
Tagbilaran City, Philippines	92,297
South Tarawa, Kiribati	40,311

Source: City Populations (2008)

To improve the situation for towns, some argue that generating economies of scale through regional aggregation is the only feasible solution, but this is of course in opposition to the decentralisation argument – for which significant disagreement exists (E-Conference on Town Water Supply and Sanitation 2004). There is however agreement that a new framework is required, and as discussed at a conference on small towns in Addis Ababa in 2002, water professionals agreed on the following elements of success:

Financial and management autonomy, transparency and accountability, professional support, competition, legal framework and regulation, demand responsiveness, and incentives for expansion (Pilgrim *et al.* 2004: iii).

In this first part of the chapter, the main conclusion is that small towns do not currently have an appropriate management approach for water and sanitation provision, but that there are attempts to define such frameworks by international agencies such as the United Nations and the World Bank.

The reasons for why small town water services provision is particularly problematic is due to severely limited resources, mainly in terms of finances and staff skills, but also in terms of high levels of uncertainty which partly relates to the availability of freshwater resources; as well as issues such as rapid population growth, and a diverse demographic with complex interactions that can not be aggregated and simplified in the same way as is possible at a larger scale.

2.2.2 Level of development

In addition to the size of an urban area, the level of both human development, as well as economic development, defined as per UNDP (2010), are two factors that are strongly related with the capacity for providing adequate or universal water and sanitation services.

Saleth and Dinar (2004) place economic development and policies firmly at the centre of the institutional change required to improve water supply and sanitation; on the basis of political and institutional economics. However they also point to other factors that play a role: demography, legal system, resources/environment, water institutions and the political system (Saleth and Dinar 2004).

The reasoning for the economic link is clear because water supply and sanitation relies on investments in infrastructure and services, and lacking economic resources hence jeopardises the efficient maintenance of water infrastructure as well as the potential for investments in water development projects (Saleth and Dinar 2004). Conversely, access to water and sanitation is also vital to support economic development, protect eco-system services, or any initiatives to improve human development (UNDP 2006). This shows that there is a two-way relationship between water and sanitation services, and the level of human and economic development.

It is also noted that improvements in water supply, and sanitation services took many years in the developed world and were initially very costly (UNDP 2010). This may be explained if considering the transaction costs involved with the required institutional reform (Saleth and Dinar 2004) explained through the institutional transaction cost approach (North 1990). The time lag can also be explained from the point of view of the importance of the community's ability and willingness to pay for water supply and sanitation (Pilgrim 2004). Water supply and sanitation services always need to be affordable and problems occur when institutional reform does not take this fact into account (Noll *et al.* 1998). This presents a dilemma in terms of infrastructure investments which may lock in a level of service for a longer period of time, and what is affordable at the time of investment may not be adequate towards the end of its lifetime.

Whilst little information is available on a city-by-city basis, this two-way relationship (between economic development and provision of water and sanitation) can be glimpsed in national data from the World Health Organisation (2006) displayed in Table 2-4. This data shows the common inadequacy of urban services in developing countries, as indicated by the less than 100 percent access for urban areas. Furthermore, the considerable difference in infant mortality rates between developing and developed nations serves as a proxy indicator for lack of services in combination with poverty and environmental problems.

By application of basic descriptive statistics using the data in Table 2-4, it is possible to justify the use of infant mortality rate (deaths per 1000 live births) as an indicator of human development, as there is a high but variable rate in developing nations (average 57) whilst the

equivalent rate for developed countries is low (average of 5). Human development categorisations could in fact be defined using thresholds on infant mortality rates without changing the human development categorisation. On the basis of Table 2-4 it is also possible to justify the inclusion of water and sanitation access in the concept of human development (for developing countries), as there is a strong but negative correlation rate, -0.64, between access to sanitation (column 5), and infant mortality rates (column 3). The equivalent correlation rate for access to improved water sources is -0.44. It is also noted that in the South Pacific region, Kiribati stands out as having the highest infant mortality rate and the lowest levels of water and sanitation access, and is also categorised by significantly lower levels of economic and human development than both Samoa and Fiji.

As already mentioned, human development as defined in the Human Development Report (2010) is linked with water supply and sanitation; and is also strongly linked with the level of economic development (World Bank 2008). It is noted that particular local constraints and contexts influence the vulnerability and capacity of nations for development, and the United Nations identify factors that impact considerably on the vulnerability of nations, and therefore also on cities, using the following set of categories to (United Nations Division for Sustainable Development 2007; United Nations 2008b):

- Least Developed Countries (LDC), if satisfying three criteria:
 - Low income, as per three-year average estimate of the gross national income per capita (under \$750 for cases of addition and, above \$900 for cases of graduation);
 - Weak human assets, as measured through a composite Human Assets Index; and
 - Economic vulnerability, as Economic Vulnerability Index (UNCTAD 2008: 1)
- Land Locked Developed Countries (LLDC) that face the challenges of (UNCTAD 2008: 1):
 - Poor physical infrastructure;
 - Weak institutional and productive capacities;

- Small domestic markets;
 - Remoteness from world markets; and
 - High vulnerability to external shocks.
- Small Island Development States (SIDS) that are vulnerable due to (United Nations Division for Sustainable Development 2007; United Nations 2008b):
 - Small size;
 - Remoteness from large markets (a factor in high transport costs); and
 - High economic vulnerability to economic/natural shocks beyond domestic control.

In the previous section, towns were identified as being problematic in terms of urban water management because of their smaller scale. In this section it has been found that a number of additional circumstances relating mainly to the level of economic and human development are also likely to impact on the capacity for effective urban water management.

A number of factors impact on the capacity for human and economic development, and United Nations (2008b) argue that Least Developed Countries, Land Locked Developed Countries and SIDS are particularly vulnerable.

On the basis of this, small towns in SIDS are hence faced with a double effect with particularly difficult situations in terms of urban water management, with many of the small town constraints added to the range of SIDS difficulties and constraints.

Table 2-4: Health indicators and access to improved water and sanitation

Country	Proportion of population that is urban (%)	Infant mortality rate (per 1000 live births)	Access to improved water sources, urban areas (%)	Access to improved sanitation, urban areas (%)
Selection of Developing nations				
Cambodia	17.5	97	58	53
Pakistan	33.4	80	95	92
Laos	19.7	65	66	61
India	27.9	62	96	58
Nepal	12.2	59	96	68
Bangladesh	22.3	56	82	75
Kiribati	38.6	49	77	59
Fiji	50.2	16	na	99
Samoa	22.3	25	91	100
Selection of Developed nations				
Australia	91.2	5	100	100
United States	77.4	6	100	100
United Kingdom	89.5	5	100	100
Sweden	83.3	4	100	100
Germany	87.7	4	100	100

Note: The countries in this table have been chosen on the basis of a combination of those that are shown in Figure 2-1, and those developing nations that have a relatively high infant mortality rate and poor access to improved services; as well as selected representative countries in the Pacific region.

Sources: The proportion of the population that is urban (United Nations 2002); Infant mortality rate (World Health Organisation 2006); Access to improved water and sanitation services in urban areas (World Health Organisation 2006).

2.3 Perspectives on urban water

Having identified the need for better urban water and sanitation services provision, and having subsequently explored issues surrounding how this provision relates to the size of the urban area as well as the level of development, the subsequent sections focus on a review of urban water governance and management. Urban water systems are often considered in terms of triple bottom line concepts (Hellström *et al.* 2000; Tjandraatmadja *et al.* 2005; Ashley *et al.* 2009; Sharma *et al.* 2009) involving primarily three different perspectives, i.e. the economic perspective, the environmental perspective and the social perspective. Depending on which perspective has the highest priority, the governance of water resources will be different.

Based on these opinions and statements it is clear that the three perspectives are in fact inter-related in a dynamic interplay where at least both the economic and social/institutional perspectives are partly justified on the basis of their capacity for facilitating change; while the environmental perspective is justified on the basis of avoiding unwanted change.

2.3.1 Economic perspective

The idea of water as an economic good has grown out of the academic fields of water accounting and comparative hydrology; which in turn has grown out of attempts to consider system interactions and embedded water (Falkenmark and Chapman 1989). This perspective was firmly established with the well-known Principle No.4 in the Dublin statement, an outcome of the International Conference on Water and the Environment, which clearly defined water as an economic good (ICWE 1992: xx). This was done on the basis that failure to recognise the economic value of water will lead to wasteful and environmentally damaging uses (ICWE 1992). Wolff and Gleick (2002) argue that considering water as an economic good creates mechanisms that allows water to be allocated using a combination of market and non-market based mechanisms across multiple uses in a way that maximises its value to society. Swyngedouw (2004) however also warns about the marketisation of water, and its insidious link with social power. Swyngedouw (2004) also states that there is a conflict between the centralised control typically mandated, and the local distribution of water, which has the

potential to create geographically defined economies of water, with huge consequences for social outcomes. In urban settings, charging for water using tariffs at market based prices is often justified on the basis that charging water users for their use is a critical mechanism for providing the water utilities with funds to operate and manage the system (Jouravlev 2004). The self-financing principle has long been a guiding principle in the Caribbean and Latin America, in particular since the 1980s (Jouravlev 2004). Self-financing is also a common theme in the discussion around small town water management (Pilgrim *et al.* 2004) and the United Nations (2006b: 14) considers appropriate financing and incentives structures as contributing to a critical enabling environment for moving towards the more integrated water management approach that they promote. Self financing principles are often bundled with privatisation of water utilities, where water users are often referred to as customers; as exemplified by Noll and colleagues (1998). Historically in western countries, during most of the 20th century the cultural symbolism linking water and modernity, and the recognition of the essential importance, and socio-political nature, it was justified that water was managed in a collective public fashion (Bakker 2003). The move towards privatisation in England and Wales came towards the end of the 20th century on the basis of perceived ineffective public sector management (Bakker 2003). That attitude seems to have been adopted by key organisations such as the International Monetary Fund and the World Bank (Grusky 2001). During the current privatisation paradigm, best studied in England and Wales by Bakker (2003), productive efficiency has increased, labour levels have been reduced, planning is focussed on demand management, and efficiency is prioritised over social equity. As an illustration of the attitude, it is sometimes argued:

The [water] utility needs to have a strategy to provide water to all consumer groups with a service level that each can afford (social equity), while increasing the revenue base by providing as many house/commercial connections as possible (Pilgrim *et al.* 2004: 20).

Implicit in this strategy is that some households may not be able to afford to pay for water services, and will therefore lack access to adequate water supply, as observed by Swyngedouw (2004). In fact in areas with lesser access, water users pay prices as much as 10, 20 or 400 times

higher than that paid by users connected to the public utility. This is in conflict with the notion that access to adequate water is a human right (Jouravlev 2004). Based on the experiences in Bolivia, a number of lessons are listed (Jouravlev 2004: 39):

- There is a need to be flexible about the principle of complete cost-recovery in certain cases, especially in poor countries where the drinking water supply and sanitation sector requires public investment including subsidies;
- The sector's regulatory framework should be strengthened in the interests of more efficient regulation. Otherwise, any weakness allows companies to impose conditions that eventually affect users;
- Social participation, public access to information and transparent management of services and of the resource itself are clearly fundamental;
- Conflict might have been avoided if the process had included more participation, dialogue and consultation between all those involved.

A difficulty with the concept of water as an economic good is that water is an unusual economic good with many different uses, and this is because it is renewable and fugitive, i.e. water flows in a cycle with little of the total water in storages (Batten 2007). It is also difficult to set up trading schemes or markets for water because the price to weight ratio typically means it is uneconomical, except in the case of bottled water (Batten 2007).

In a more recent application of the economic perspective, the concept of 'virtual water' has been introduced. The idea is that whilst water in itself is not economically worthwhile transporting, the products that are created using water, such as food, can be transported at a profit. These products can be seen to have embedded water and this 'virtual water' allows for water interactions at a national, regional or global scale (Pahl-Wostl 2002a). Subsequently, Hoekstra and Chapagain (2007) have explored the patterns of virtual water use and its footprint, in various countries for the period 1997-2001. They identified important factors contributing to a significant footprint that include: the consumption volume and pattern, climate and the type of

agricultural practice. This concept may better allow for incorporating issues such as food security, equity and ecology into water management.

2.3.2 Environmental perspective

The environmental perspective has arisen out of new demands on the urban water and wastewater sector from the community (Berndtsson and Jinno 2008). Such new demands concern increased recycling and reuse of all resources involved, as well as energy, to tackle real and potential resource deficiencies and to lower emissions. It also involves better management of the environmental quality, as well as additional benefits from the urban water system such as urban amenity and recreation (Berndtsson and Jinno 2008). Because of this challenge the urban water sector have responded with activity in redesign of systems and new technologies (Biggs *et al.* 2009; Gikas *et al.* 2009; Tjandraatmadja *et al.* 2009; Cook *et al.* 2009); new planning frameworks (Lundie *et al.* 2005; Sharma *et al.* 2008, 2009, 2010) and a change of mindsets and definitions (Marlow *et al.* 2010; van de Meene *et al.* 2009). It also involves considering current waste as a potential resources, for example stormwater can be considered a potentially valuable and typically overlooked domestic and industrial water resource (Niemczynowicz 1999).

Whilst urban water management has historically been mostly concerned with issues relating to public health and providing sufficient water volumes, modern communities demand more in terms of minimizing the impact on the environment. This introduces a new dimension into urban water management, which is here referred to as the ecological perspective. Falkenmark describes the ecological perspective as follows:

The ecological perspective involves attention to terrestrial ecosystems and their involvement in local run-off generation, and to aquatic ecosystems and their dependence on uncommitted environmental flows of adequate quality.

When certain highly appreciated local ecosystems have to be protected, their particular water determinants have to be identified. The long-term resilience of the overall system has to be properly analysed and secured for the benefit of coming generations (2003: 10).

In other words, this perspective extends water governance to include non-human actors. It is often argued that ecological issues need to be taken into account within urban water management, typically on the basis that too much water is being taken out of the natural systems, and that too much polluted water is discharged (Terpstra 1999). Such ideas are typically framed in terms of sustainability, in a tradition that goes back to the Brundtland report in which ‘sustainability development’ was defined as:

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development 1987: xx).

The importance of the environmental dimension in the water sector has been reinforced by the statement of the Millennium Development Goals (see Appendix 1). It also aligns with the work of practitioners such as Varis and Somlyody (1997). They argue that urban water management is strongly interconnected with, if not a component of, urban planning and environmental management; that is, it needs to consider both the socio-cultural context as well as the natural environment.

Clearly, pollution is an important environmental problem related to urban water management. For example, urban areas are sometimes located near rivers and in such cases are affected by upstream activities, and often extract water, such as in the case of Bulawayo, Zimbabwe (Gwebu 2002) which affects downstream volumes. Sometimes they dispose of waste into the same rivers, as is also the case in Chicago, USA (UNDP 2006), hence affecting downstream water quality. Similarly, Jouravlev (2004) observes that in Latin America the wastewater discharges from urban areas are often located only a few kilometres from the intakes of other cities, and this is argued to be insufficient for natural decomposition and dispersion. In China, water has been diverted from the Shanxi and Hebei provinces towards urban areas such as Pingyao, and as a consequence Chinese authorities are mediating in water related conflicts between farmers, municipalities and industry (UNDP 2006).

Another important environmental concern that relates to urban water management is the exploitation of groundwater. Many urban areas depend on groundwater as their water resource and subsequent pollution of this source impacts on the quantity and quality of the groundwater.

This happens both as:

1. Groundwater quality or quantity is affected due to changes in land cover and due to non-point source pollution (Frumkin 2002); and
2. Groundwater is extracted, pumped and supplied via pipes to urban customers, such as to households (i.e. public good extraction), or by industrial or commercial operations (i.e. point source extraction).

Most cases in the literature describing the first type of groundwater issue relate to the developed world; as exemplified by the case of Annapolis Valley in the United States which includes six towns where industrial effluent and run-off from urban centres threaten groundwater supplies (Timmer *et al.* 2007). A similar situation has been shown in Nottingham, UK, where significantly elevated levels of nitrate in the groundwater were found to be related to wastewater and solid waste disposal (Wakidaa and Lerner 2004). A similar situation is described for Karlsruhe, Germany, as found by a pilot study of a groundwater monitoring network (Trauth and Xanthopoulos 1997).

The second type of groundwater issue is described in the literature, primarily on the developing world, where it is common to rely on declining levels of groundwater for urban water supply. This is the case in northern China where groundwater provides about half the urban water supply and where most groundwater levels are in decline (Zaisheng 1998). Another example of this is in Kerala, India, where point-source water extraction by a soft-drink company has depleted the aquifer and consequently dried up several wells, negatively affecting farmers and peri-urban dwellers (UNDP 2006). In similar circumstances in Mumbai, India, point-source groundwater extraction by industry has provoked protests by farmers when wells have dried up (UNDP 2006).

Jakarta, Indonesia, suffers from both types of groundwater concerns as the groundwater has become salty due to over-extraction and canals are so polluted by inadequate sanitation and point-source pollution from industry that their contents are worse than what is in sewer pipes in developed countries (Varis and Somlyody 1997). Despite this, a large number of households in Jakarta rely on groundwater and polluted water from canals for their daily needs (Varis and Somlyody 1997).

Another example where both types of groundwater issues occur is South Tarawa in Kiribati where groundwater is extracted for the purposes of public good from shallow catchments in peri-urban areas, (White *et al.* 2005) with related socio-political tensions (Dray 2007). At the same time, considerable pollution occurs at the sites of the groundwater catchments, and as in Jakarta, a large number of households rely on polluted, and in some cases chlorinated groundwater, for their daily needs (White *et al.* 2008).

One difficulty in considering environmental and ecological issues in urban water management is that water resources in some circumstances can be considered to be common pool resources and as such are prone to social dilemmas where the incentives of individuals are in conflict with the common good and this can lead to degradation of shared resources (Hardin 1968; Ostrom 1990). Whether common pool resource systems can be managed using an economic management approach is highly questionable given the ‘tragedy of the commons’ as described by Hardin (1968), and the potential management frameworks as proposed by Ostrom (1990, 2004). Instead, for these types of resources, there is often a need for allocation and negotiation, as well as enforcement and multi-layered governance (Ostrom 1990, 2004). It is possible that in the urban setting, political process, regulation and government enforcement is a better strategy, but this is likely to depend on context.

2.3.3 Social perspective

The social perspective of urban water systems is primarily focussed on the acceptance of water services (Po *et al.* 2004; Marks and Zadoroznyj 2005; Marks 2006; Hurlimann and MacKay 2006; Hurlimann 2007, 2009; Hurlimann and Dolnicar 2009); the systems ecological

perspective (Söderberg and Åberg 2002); the systems transitions perspective (Pahl-Wostl 2002a; Brown 2005; Moglia *et al.* 2010); or from the point of view of new technologies (Moglia and Sharma 2009). For example, Brown argues that:

It is now reasonably well accepted that unless new technologies are socially embedded into the local institutional context, their development in isolation is insufficient to ensure their successful implementation in practice (2005: 1).

Similarly Pahl-Wostl argues that:

When one considers processes of transformation and change, the human dimension is of particular importance. Institutions and rule systems may cause resistance to change but can also enable and facilitate necessary transformation processes (Pahl-Wostl 2002a: 1015).

In contrast to the economic perspective which focuses on allocation and supply decisions being made on the basis of economics, in the social perspective water is often considered to have a very high social and non-monetary value in our societies as it contributes to and enables important social functions; this is the social value of water. Falkenmark describes the social perspective as:

The social perspective involves meeting human needs in terms of safe household water, water-dependent food production, and—in view of present techniques' deficiencies – water-polluting income generation activities. Securing societal acceptance of necessary trade-offs is essential by effective ways of stakeholder participation in planning and decision making. It also involves the challenge to motivate people to accept or abide to the laws of nature and to put in more (rather than less) effort to realise development aspirations (2003: 10).

For example, in early urban history, the driver for urban water management was hygiene and sufficient supply (Mays *et al.* 2007). Brown (2005) describes how in Australia, the focus has

been on public health, sufficient supply and flood control, but more recently also on pollution control. Even more recently, there has been a shift towards sustainability in the urban water sector, focussing more on ecosystems as indicated by an increasing body of work (Otterpohl *et al.* 1997; Lundin *et al.* 2000; Bai and Imura 2001; Pahl-Wostl 2002a; Lundin and Morrison 2002; Bracken *et al.* 2004; Brown 2005; Palme *et al.* 2005; Panebianco and Pahl-Wostl 2006), in what seems to indicate how the shifting paradigms reflect the shifting expectations of society.

With the addition of the social dimension into sustainable urban water management, partly motivated by the needs generated when introducing new technologies, a number of research groups have been exploring this issue, mainly in Australia and in Sweden. In Australia, Leviston and colleagues (2006) have focussed on whether a given water supply system is acceptable to community members. Taking this perspective, they identify a number of factors that contribute to community acceptance of water servicing options such as: community trust, perceptions of equity and fairness, risk perceptions, perceived outcomes, subjective assessment of outcomes and personal values. Similarly, but using a slightly different perspective, Söderberg and Åberg (2002) describe a framework for assessing socio-cultural aspects of an urban water development with an application in Stockholm, Sweden. They have done this in order to help embed urban water initiatives into the larger community and take a systems ecology perspective. Doing this, they focus on the capacity and adaptability of the organisation providing water services, as well as the motivation, ability and opportunity of the households. Hurlimann (2007) and Hurlimann and McKay (2006) have used experiences from Adelaide in Australia to focus on the social acceptability of recycled water, identifying factors similar to those described by Leviston and colleagues (2006), but also identifying a number of physical and practical characteristics of critical importance such as: water colour and odour, salt content of water, availability within water restrictions, pressure, and nutrient levels. In another paper, (Hurlimann 2009) revisits this theme, discussing the perceptions about using recycled water and the impacts on acceptance, arguing that providing information and engaging with the community is a critical issue.

Similarly, Marks and Zadoroznyj (2005) started their explorations with a study of social factors relating to water recycling. They based this on four case studies in the US and in Australia using

face-to-face interviews as the main research tool. The focus of this study is primarily on the issue of trust. Initially they argue that in the modern era, water has been delivered by what they characterise as ‘abstract systems’ that are little understood by customers and users of these systems have little control over them. This is however changing with the introduction of decentralised systems such as residential reuse. They further argue that this in turn creates new problems relating to public health risk, and related basic trust in the household water supply. They further identify a number of factors that impact on the social dimension, such as the scale of development and the transparency of governance. They also introduce the concept of a ‘social mood’ to describe the community’s attitude to a water service delivery, and this includes factors such as environmental impact and personal values, social and collective capital, as well as health risk concerns. In another paper, Marks (2006) discusses the issue of public participation, where she characterises this according to factors of respectfulness, type of inclusion and the power relations. She also argues that a number of practices can play a key role, such as keeping homeowners informed, updating plumbing plans, and monitoring of compliance with rules, regulations and standards.

Using a different perspective, Attwater and Derry (2003) have explored the use of a community of practice where professionals and individuals with a common interest meet regularly and work within an action research framework in the Naiad development in Sydney Australia (CRC for Water Quality and Treatment 2009), for managing the risks involved with a water recycling scheme; recognizing that this is strongly interlinked with risk communication and stakeholders’ risk perceptions.

As expected, the socio-cultural context is an important consideration for urban water management also in developing world contexts, and this is argued by Einsiedel, who states in relation to urban water management in Asia that: ‘We should have devoted more time and effort to studying the local culture before launching city consultations’ Einsiedel (2005: xx). In a similar vein, Varis and Somlyody (1997) argue that water developments are likely lead to failure if solutions that have worked in industrialised nations are simply transferred to low and middle income nations with drastically different socio-cultural settings.

The South Pacific Applied Geoscience Commission's guidelines for rainwater harvesting in the Pacific Island countries (South Pacific Applied Geoscience Commission 2004), argues that any development program needs to consider the local context, in particular in relation to whether systems are affordable and if people are willing to pay for them, and what funding mechanism is appropriate. Similarly this report also states that the design and size of a system needs to be considered in the local context. Similarly, and reinforcing this, a report by UNDP (2006) states that the expectations regarding water utilities can not be considered in isolation but in relation to the wider political climate and structure (UNDP 2006).

Another social value consideration comes from the gender perspective, which is often perceived as important in water contexts, and a common belief is that lack of access to water reinforces gender inequalities (UNDP 2006). This is exemplified by the Dublin Statement's principle number three: 'Women play a central part in the provision, management and safeguarding of water' (ICWE 1992: xx).

In terms of women's roles, social and cultural norms influence the division of labour in households and women tend to spend more time collecting water than men (UNDP 2006). To indicate the variation between cultures, data from urban areas in Africa show that the time spent collecting water in urban areas is almost equally distributed between women and men in Ghana, but in Benin and Guinea, women spend up to three times more time on this task (UNDP 2006). This is despite the fact that all three countries are located in West Africa, and Ghana and Benin are virtually neighbours. It is possible to speculate that this difference depends on the location of urban stand-pipes, availability of water within the households, the adequacy of the quality of water for various water use purposes, and the division of labour within the households.

Ivens argues that gender perspectives need to be incorporated into water policy and that the debate needs to move past simply a matter of access to water, as this does not necessarily increase gender equality. Based on the success of participatory approaches in case studies in India, Pakistan and Bangladesh, she suggests that such approaches should be considered in the design and implementation stages of water governance (Ivens 2008).

Another area of discussion concerns the interactions between culture, politics and water. Whilst, presumably because of the sensitivity of issues, it is difficult to find literature describing the importance of culture and politics in water projects, or the influence of corruption, it is the author's observation that it appears to be something that is widely discussed by water professionals, which was also indicated by the recently created Water Integrity Network:

The WIN stimulates anti-corruption activities in the water sector locally, nationally and globally. It promotes solutions-oriented action and coalition-building between civil society, the private and public sectors, media and governments (Water Integrity Network 2008: xx).

To give an idea of how such issues may influence water projects, a paper by Page (2003) describes how culture and the political environment played a crucial role in the failures of a water management project in the town of Kumbo in Northern Cameroon, where the narrative of the success of a project was found to be a fabrication in order to further political agendas. This narrative was further supported by the international funding bodies in order to pursue their own goals. That locals reinforced the story as the failure of the project was perceived to bring shame upon the reputation of the town and the culture (Page 2003).

Similar complexities due to local politics are described in a paper by Dray and colleagues (2007) based on experiences in the Pacific atoll town of Tarawa, Kiribati. In this study, several projects with conflicting agendas surrounding the institutional arrangements on how to protect and extract water from groundwater reserves in the peri-urban fringe of Tarawa, brought development to a halt and a subsequent stalemate position ensued.

These experiences point towards the importance of not only understanding the local culture, but also understanding local politics. It is also important to realise that urban water developments not only need to take local politics into consideration but that they also themselves generate politics and competition for jobs as well as finances and other resources and have the potential to generate inequities as well as challenge existing power structures.

2.4 Frameworks for urban water management

As previously outlined, the way one thinks of water depends on the perspective that is chosen. For example urban water and access to it, can be considered a public good, a tradeable good, a common pool resource and sometimes even a human right. Whilst each of the views may be justified depending on the context, it is also obvious that there are inherent conflicts between the concepts, such as between considering water as a public good, and considering water as a human right. This makes water management sometimes highly contentious.

On the practical side, a number of management frameworks and themes have emerged that attempt to find practical solutions to water related problems in the urban setting. These often involve incorporating multiple perspectives, goals and constraints in a single strategy. A few of these frameworks and themes will be described further.

2.4.1 Sustainability principles

A number of people have explored how sustainability principles can be embedded into urban water management and governance, in what is broadly referred to as Sustainable Urban Water Management. In one of the most succinct definitions of Sustainable Urban Water Management, Rebekah Brown and others consider the following six points to underpin Sustainable Urban Water Management (adapted from Brown *et al.* 2007 on the basis of a literature review on the fundamental philosophy of Sustainable Urban Water Management):

- There needs to be a consideration of all parts of the water cycle as an integrated and interconnected system;
- There needs to be an acceptance of the multiple purposes of water use, and flexible and multiple solutions;
- Context is important, and therefore all perspectives need to be considered (environmental, social, cultural, political and institutional);
- Public participation in planning and decision making is critical;

- Programs, projects and policies need to be considered over long time frames by a common vision; and
- An interdisciplinary approach is required.

Based on interviews with water professionals in Australia, a suggested definition of sustainability in the urban water sector is:

For a water utility, sustainability is practically achieved when all its activities, both internal to the business and across its supply chain, achieve net added value when assessed across each of the triple bottom line outcomes (financial, social and environmental) over the medium to long timescales, considering all costs and benefits, including externalities (Marlow and Humphries 2009: 120).

In terms of activity in the area of Sustainable Urban Water Management research, for instance, (Makropoulos *et al.* 2008) explore future scenarios towards sustainable urban water management. Falkenmark and Chapman (1989) integrate sustainability issues into comparative hydrology for both urban and rural settings. Pahl-Wostl (2002a) discusses the importance of social learning in order to reach sustainability in the water sector. Rogers and colleagues (2002) describe pricing mechanisms for reaching sustainability goals. A number of authors (Krebs and Larsen 1997; Lundin and Morrison 2002; Bracken *et al.* 2004) describe the requirements and criteria for sustainability in various technical components, such as drainage and sanitation systems. Berndtsson and Jinno (2008) describe a case study in Fukuoka City, Japan, in terms of sustainability in the urban water sector and draw conclusions that the system is functional, but in terms of ecological performance it is inadequate. They suggest that a number of improvements could be made, such as the merging of the water and wastewater departments in the local municipality, as well as investments in new technologies that are both technically feasible and economically viable.

There is also an increased shift internationally towards Integrated Urban Water Management and Water Sensitive Urban Design (Mitchell 2006) which attempts to combine environmental

goals with efficiency goals. However, it is worth mentioning that there are considerable difficulties in the application of, for example, Water Sensitive Urban Design (Nancarrow *et al.* 2004) and Integrated Urban Water Management (Brown 2005), which seem to indicate a social dilemma. It is however noted that almost all of this work has been carried out in developed country contexts, which probably reflects the lack of priority given to environmental issues in the developing world. However, it also raises questions regarding how useful and functional the current knowledge in sustainable urban water management is in the context of developing nations.

At least some of the reasons for difficulties in applying Integrated Urban Water Management and Water Sensitive Urban Design are that such attempts to consider social and environmental dimensions, at least in the Australian context, are strongly related to institutional inertia as these new practices often challenge existing decision making structures and institutions (Brown 2005) and because they fail to consider needs and preferences of the community (Nancarrow *et al.* 2004).

2.4.2 Governance

Governance, or the act of governing, has been the topic of many researchers and professionals interested in the management of natural resources. These include those proposing adaptive management (Folke *et al.* 2005; Fazey *et al.* 2005; Olsson *et al.* 2006); greater public involvement in decision making (Crase *et al.* 2005; Blackstock *et al.* 2006); local or distributed management of common pool resources (Ostrom 1990, 2004); appropriate water pricing (Dinar 2000); or institutional reform (Saleth and Dinar 2005) or the transaction cost of reform (North 1990).

Water governance in general refers to the allocation of water; or in other words as to who gets what water, when and how (Water Governance Facility 2009). This is inherently linked to expansion of water supplies, which typically relies on a combination of infrastructure and technology and/or removing water from the environment. Other inherently linked issues relate

to equity, efficiency, institutions, roles of government and the community, water quality and economics (Water Governance Facility 2009).

In water contexts, institutions of governance involve primarily water law, water policy and the water organisation (Saleth and Dinar 2004). In the urban water sector the sustainability paradigm is largely supported but Harpham and Boateng (1997) argue that the paradigm of ‘good governance’ in urban water is a strong alternative and that environmental damage tends to occur only when there is inadequate governance. Hugely influential organisations such as the World Bank or IMF have policies to promote good governance that include water privatisation (Grusky 2001). Swyngedouw (2004) however argues that privatisation is problematic because modern governance of cities has brought water squarely into the sphere of money and a complex set of power relations; and notes that in many cases urbanisation leads many marginalised groups to have to struggle to access water and sanitation.

Harpaham and Boateng (1997) have reviewed the notion of good governance amongst various actors and found that the focus varies greatly. For instance, the World Bank has a strong focus on Public Sector management and accountability whilst the Organisation for Economic Co-Operation and Development prioritises democratisation. Others again focus on issues such as equity, economic liberalism, legal framework and efficiency. These factors can, taking a systems perspective, be important boundary conditions for urban water management that impact indirectly on the solution space that is feasible in a given location.

2.4.3 Regulation

Regulation is another common theme within urban water management, and the Human Development Report lists features of successful regulatory bodies in a number of countries, of which the political independence, information sharing with the public, and public participation, as well as the regulatory bodies’ investigative authority and penalty power are crucial (UNDP 2006). Makropoulos and colleagues (2008) also list regulation as a common and cross-cutting driver for urban water management; in particular when it comes to widening the scope to include environmental and social concerns.

This is reinforced by experiences in Fukuoka, Japan, where regulation has been critical for the introduction of new environmentally friendly technologies (Berndtsson and Jinno 2008); and in Australia for the increased application of ‘smart-water design’ (Crase *et al.* 2008). In a developing context, in China, regulation is used to protect urban groundwater supplies (Zaisheng 1998). In another developing context, in Nairobi, Kenya, regulation has been strengthened in terms of increasing the consideration of conditions in informal settlements where there was previously no clear mandate (Gerlach 2008).

2.4.4 Public participation and institutional decentralisation

A recurring theme so far has been about public participation and as can be seen, public participation and sharing information with the public is seen as a critical component within good governance (Harpham and Boateng 1997) and regulation (UNDP 2006), for dealing with gender issues (Ivens 2008), supporting sustainable urban water management (Brown *et al.* 2007) as well as for developing contextually sensitive urban water solutions (South Pacific Applied Geoscience Commission 2004; White *et al.* 2008). The usefulness of public participation has been acknowledged by funding agencies, as indicated by the Dublin statement (ICWE 1992: xx): ‘Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels’. While many handbooks on public participation have been written, particular mention ought to be given to the handbook funded through the European Commission on participation in water management (HarmoniCop 2005), albeit not specifically written with urban water issues in mind. A word of warning is however given by Botchway (2001) that participation is sometimes seen as a kind of magical ‘missing ingredient’ that would ensure sustainability and success, irrespective of structural, administrative and political pre-conditions necessary for the participation to function.

Another common and related theme in the literature is about institutional decentralisation, such as distribution of responsibility, which is thought to increase public participation and improve good governance (Parker and Serrano 2000). Reforms to increase institutional decentralisation have happened in a number of locations, such as in Morocco (Doukkali 2005), South Africa (Backeberg 2005), Ghana (Botchway 2001) and Sri Lanka (Samad 2005). Case studies of

decentralised responsibility are discussed by Botchway (2001) concerning a rural region in Northern Ghana and by Gwebu (2002), who describes a case study in a large city, Bulawayo, in Zimbabwe. These two case studies are described in more detail in Appendix 3.

Gwebu (2002) makes a number of points, such as the fact that local authorities tend to have better information and greater incentives to act to ensure continuity of adequate water services and that grass root initiatives can be very powerful in appealing to national and international opinion and gaining wide support.

In the case study described by Botchway (2001), institutional decentralisation was motivated by a belief that it would increase participation, which was in line with funding agency rhetoric. However, Botchway states that the project's concept of participation was managerial and technocratic and this may be the core reason for the project's failure. Also, the term community and village were loosely defined in the project and insufficient consideration was given to the fact that communities and villages are not homogeneous but there are existing power structures and varying levels of wealth. Therefore, this term directs attention away from the internal politics of the village and the critical issue of distribution of the wealth. Botchway argues that communities may have entered into a new kind of dependency, due to diluted responsibilities, and are having to rely on external assistance for maintaining their pumps. Finally, Botchway suggests that participation under the banner of decentralisation should not lead to the state avoiding its responsibility to provide essential services.

2.5 Tarawa in the context of the South Pacific

So far, general issues of urban water management have been reviewed from a number of different perspectives. It has become clear, that urban water issues are often considered to be relatively straightforward when viewed from an engineering perspective. However, once social and environmental concerns are considered, matters of urban water management become increasingly complex and context dependent. Finally, identification of water management in small towns as a sub-sector tends to be characterised by low availability of resources and highly

complex in terms of management (taking a Complex Systems perspective as described in chapters 3 and 4). The aim now is to narrow the focus and consider the particular context of Tarawa a small town within the context of urban and other issues in Pacific Island nations.

In general it is noted that due to rapid population growth in cities in PICs, the need for sustainable development in urban areas is a critical issues for PICs in the 21st century (Connell and Lea 2002). However, urban and environmental planning are not traditional activities in most parts of the PICs (Lea and Connell 1994) and in fact there has been weak urban management throughout the Pacific, and high level of inconsistency in methods for planning and management at both the national and regional levels (Storey 1998). Not surprisingly, the typical situation is that provision of access to basic water, sanitation and road infrastructure cannot keep up with the demand for services (Connell and Lea 1998). One of the particular difficulties of urban management in PICs relates to socio-cultural sensitivities relating to customary land ownership and traditional decision making processes (Storey 1999). As a whole many PICs are vulnerable in terms of fragile environments, limited land resources, basic resource shortages, and the risks associated with climate change; whilst management capacity is constrained by weak economies, problematic land ownership, and institutional weaknesses (Cocklin and Keen 2006). The same authors argue that there is a need for institutional reform, better planning, improved urban resource management, as well as regional cooperation (Cocklin and Keen 2006).

The South Pacific region is dominated by urban settlements that can be considered to be small towns by Pilgrim and colleagues (2004) with a population less than 50,000 people. These towns are often of critical importance as rural populations increasingly choose to migrate to urban areas (Jones 2003). Many of these urban areas are cities that are referred to as primate cities have the greatest share of the population growth in rapidly growing formal and squatter settlements in peri-urban zones (Jones 2003).

Table 2-5: Major urban areas in the South Pacific region, and their populations

Urban area	Population
Port Moresby, Papua New Guinea	254,158
Suva, Fiji	172,948
Noumea, New Caledonia	91,386
Honiara, Solomon Islands	78,279
Lautoka, Fiji	52,742
Nadi, Fiji	42,712
Port Vila, Vanuatu	42,511
South Tarawa, Kiribati	40,311
Apia, Samoa	37,237
Papeete, French Polynesia	26,017
Nuku Alofa, Tonga	23,658
Rarotonga, Cook Islands	14,153
Kolonia, Federated States of Micronesia	5,681
Funafuti, Tuvalu	4,492

Source: City Populations 2008

The three main thematic issues identified in the lead up to the 3rd World Water Forum in Kyoto in 2003, which are perceived to limit the ability of Pacific Island nations to manage their water sectors, include (Asian Development Bank 2007):

- Being small island countries with a number of vulnerability concerns;
- Having serious constraints on finances, facilities and human resources limiting the ability for adopting efficient management paradigms, as per the small town dilemma; and
- Recognizing that water governance is highly complex due to the specific socio-political and cultural practices.

To address these concerns in the water sector, a Regional Action Plan has been developed (South Pacific Applied Geoscience Commission and Asian Development Bank 2003). This plan, however, provides only high level advice rather than a management framework. Therefore,

it can be argued that there is a need also for a framework of management that can effectively operate in this type of context. The interest of the South Pacific Applied Geoscience Commission (SOPAC) and the Asian Development Bank (ADB), as well as the focus during the 3rd World Water Forum, indicates the importance of managing the water resources and water services in the Pacific Island Countries (PICs).

2.5.1 Small Island Developing States

In the literature, it has been identified that urbanisation in the South Pacific region is related to a particular set of issues, of which some are related to the fact that countries in this region are Small Island Developing Nations. The PICs are characterised by large cultural diversities and extreme isolation of their scattered islands. There are three main cultural regions in the South Pacific Islands: Micronesia, Melanesia and Polynesia (Figure 2-2).

Most the southern Pacific region including: Kiribati, Nauru, Tonga, Vanuatu, Tuvalu, Solomon Islands, Samoa, French Polynesia, Federated States of Micronesia and Fiji, are referred to by the United Nations Division on Sustainable Development (2007) as Small Island Developing States (SIDS) and are characterised by:

- Small populations;
- Lack of resources;
- Remoteness;
- Susceptibility to natural disasters;
- Excessive dependence on international trade;
- Vulnerability to global developments;
- Limited opportunities for economies of scale;
- High transportation and communication costs; and
- Costly public administration and infrastructure.



Figure 2-2: Map of the South Pacific regions

2.5.2 Small town management gap

It has previously been identified that there are a number of particular challenges relating to urban water management for small towns. In light of this, it can be seen in the non-exhaustive list of Pacific Island towns in Table 2-5, many of the urban settlements in the South Pacific region are in the population range (2,000 to 50,000 inhabitants) indicating the management gap as identified by Pilgrim and colleagues (2004).

Table 2-6: Percentage of populations in urban settlements

Country	Cultural region	Population (2004)	Urban proportion (2005) (%)
Niue	Polynesia	1,671	36.7
Tuvalu	Polynesia	10,396	57.0
Cook Islands	Polynesia	14,346	73.3
Palau	Micronesia	20,023	68.2
Marshall Islands	Micronesia	55,559	66.7
Kiribati	Micronesia	90,411	50.2
Tonga	Polynesia	98,991	34.0
Federated States of Micronesia	Micronesia	109,393	30.0
Guam	Micronesia	165,922	94.0
Samoa	Polynesia	182,507	22.5
Vanuatu	Melanesia	209,918	23.7
French Polynesia	Polynesia	251,895	51.9
Solomon Islands	Melanesia	460,862	20.9
Fiji	Melanesia	822,885	53.2
Papua New Guinea	Melanesia	5,935,005	14.5

Source: United Nations Statistics Division (2007).

The level of urbanisation differs considerably between the PICs, ranging from 14.5 percent in Papua New Guinea to 94 percent in Guam (see Table 2-6). Generally speaking, the region of Micronesia has a higher proportion of the population in urban settlements (average of 62%), while the countries in Melanesia have a relatively smaller proportion of their populations in urban settlements (average of 28 percent). Melanesia is also home to some of the largest urban settlements in the region (i.e. Port Moresby, Noumea, Suva, and Honiara). In Kiribati, approximately half of the population lives in the urban centre of Tarawa.

2.5.3 Geography and geology

The geography and geology of individual islands is critical in terms of the availability of freshwater (Burns 2002). The island types range from high islands to low islands, but also from

atolls (Woodroffe and Biribo 2010) to volcanic islands and raised limestone islands (Burns 2002):

- High islands primarily consist of rugged volcanic mountains surrounded by fringing or barrier reefs. They may also have a fringe of low-lying coastal plains surrounding the mountainous interior (Burns 2002: 114-5);
- Atolls are ring-shaped reefs that occur in mid-ocean, often in linear island chains or archipelagos (Woodroffe and Biribo 2010). They consist of limestone reef deposits laid down on an underlying volcanic cone (Burns 2002: 114-5); and
- Raised atolls are uplifted coral atolls that consist almost entirely of limestone and dolomite, some rising 60-70 meters above sea level (Burns 2002: 114-5).

Based on the ability for collection of water, different islands rely on different types of water resources, and Burns lists the following categories:

- Rainwater based on rainwater collection systems, and this is particularly utilised in islands such as Tuvalu, the northern atolls of the Cook Islands, and some of the raised coral islands of Tonga;
- Groundwater from natural aquifers, perched or basal; the volume of freshwater lenses is roughly proportional to the width and surface area of an island and is influenced by factors like rainfall levels, permeability of the rock beneath islands, salt mixing due to storm or tide-induced pressure;
- Surface water in the form of ephemeral and perennial streams, springs, lakes, and swamps, is found mainly on high islands in PICs (Burns 2002: 117-8).

The atoll states (Kiribati, the Marshall Islands, Tokelau and Tuvalu) have water supplies that are particularly vulnerable due to susceptibility to depletion and salt intrusion (Barnett 2001).

Falkland (1999) describes that on many small coral and limestone islands, the basal aquifer takes the form of a ‘freshwater lens’ (or ‘groundwater lens’) which underlies the whole island, as shown in Figure 2-3.

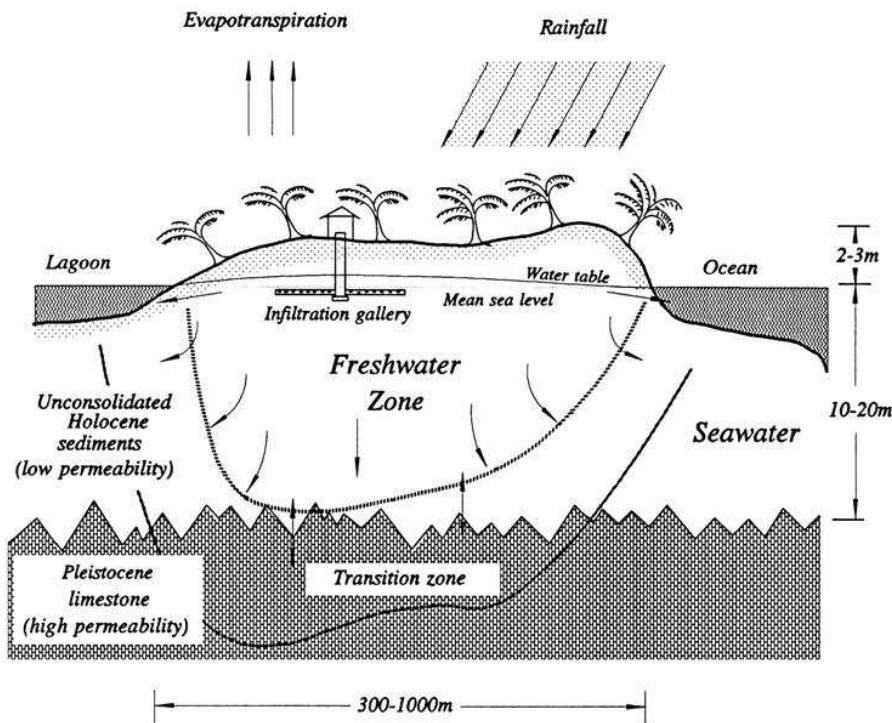


Figure 2-3: Cross-section of a small coral island showing features of a freshwater lens

Source: Falkland 1999

Falkland also mentions that non-conventional water sources are occasionally used, especially during droughts. These sources are desalination, importation, non-potable water sources (i.e. seawater, brackish water and treated waste water) especially for toilet flushing and bathing; and substitution (i.e. coconut juice). Desalination occurs among other locations at Nauru, South Tarawa in Kiribati, Kwajalein Atoll in Marshall Islands, and in Tuvalu and Papua New Guinea as emergency supplies during droughts. Descriptions of main freshwater resources and uses are shown in Table 2-7.

Table 2-7: Main freshwater resources and uses in PICs

Country	Main freshwater resources	Main freshwater uses
Tuvalu	RW (primary), GW (limited), D (emergency)	WS
Marshall islands	RW (from airport catchment and buildings), GW, D (emergency)	WS
Cook Islands	SW, GW, RW	WS, T
Niue	GW, RW	WS
Palau	SW, GW, RW	WS
Guam	SW, GW, RW, D	WS
Federated States of Micronesia	SW, GW, RW	N/A
Kiribati	GW, RW, D (limited)	WS
Tonga	GW, RW, SW (limited)	WS
Samoa	SW, GW, RW	WS
French Polynesia	SW, GW, RW	WS, T
Vanuatu	SW, GW, RW	WS
Fiji	SW, GW, RW, D (tourist resort only)	WS, T, H, I
Solomon Islands	SW, GW, RW	WS
Papua New Guinea	SW, GW, RW	WS, M

Source: Falkland 1999

Notes: SW = Surface water, GW = groundwater, RW = rainwater; D = desalination. WS = water supply to communities, T = tourism, H = hydroelectricity, M = mining.

2.5.4 Historical background

Much of the urban institutional, administrative and legislative structures in the PICs are a legacy of the colonial era. In fact, initial urbanisation was often a direct consequence of colonisation:

Most of the current towns and cities [in PICs] began as centres for the colonial administrators, followed by missionaries and traders who took on commercial, wholesale, agricultural and community functions. During the twentieth century, there was a gradual population increase in the towns in PICs but it was only in the 1960s that urban growth accelerated and the economic base of towns rapidly diversified. For some PICs, increasing urban growth was an outcome of independence, with many towns and cities reinforced as growing urban centres as a result of independence and statehood (Jones 2003: 1).

Decolonisation was a late process for many PICs with independence gained by Samoa in 1962, Nauru in 1968, Fiji in 1970, Papua New Guinea in 1975, Tuvalu in 1978, Solomon Islands in 1978, Kiribati in 1979 and Vanuatu in 1980 (Jones *et al.* 2002). Thus, many of the Pacific nations still attempt to find a balance between traditional cultural institutions and the legacy of colonial administration. This dichotomy of institutional structures is perhaps most palpable in urban settings where traditional institutions are often inadequately prepared for dealing with the challenges of high population densities; in particular in a situation where there are tensions between legal and administrative systems inherited from colonial rulers and pre-existing traditional customs (Jones 2003).

2.5.5 Economic strategies

Economically, most PICs are faced with limited opportunities for economic growth due to their small size, limited natural resource availability, small labour force and very small GDP. Furthermore, in small island economies such as those in the PICs, there are very high costs involved with the transport of goods (Tisdell 2006).

In such circumstances, the MIRAB economic approach, based on “Migration (of factors of production), Remittances/Aid (financial transfers), and Bureaucracy (non-tradable production)” to economic development is usually in operation (Bertram and Watters 1985). In practice this approach postulates that islands export labour and diplomatic services (UN votes, etc.) in exchange for a standard of living based mainly on corresponding remittances and aid from patron countries (Oberst and McElroy 2007).

In the PICs, there are also other economic approaches, namely PROFIT and SITE, which focuses on a dynamic private sector and the role of tourism respectively (Oberst and McElroy 2007). PROFIT examples would include tax and insurance havens, offshore banking centres, and duty-free manufacturing exporters (Oberst and McElroy 2007). SITE examples are characterised by tourist islands with significant foreign investments (Oberst and McElroy 2007).

Kiribati employs the MIRAB approach but this however means heavy reliance on foreign aid and migrant workers, relying on the goodwill of foreign nations for aid and migration options. Despite many jobs being available in public administration, such an approach often leads to high levels of unemployment which is problematic in urban areas where subsistence living is difficult due to high population densities (Thomas 2003). Tisdell (2006) also notes that foreign aid to PICs is falling, and hence less support for bureaucracies and jobs in public administration.

Kiribati also has the highest trade deficit in the PICs with a trade balance of -89.2% in 2003 (Tisdell 2006). Its GDP per capita is only rivalled by the Solomon Islands and Papua New Guinea in the PICs (Tisdell 2006).

Furthermore, in PICs the community is often unwilling to pay for services, as for instance in Samoa where water services are considered a ‘divine right’; and privatisation of water services has had limited success (Asian Development Bank 2000).

Availability of technical and planning staff is often a problem for water utilities in places such as in Kiribati (Government of Kiribati 2000) and human resources are generally scarce in PICs (Asian Development Bank 2000a) while there is little coordination between government departments and agencies (Asian Development Bank 2000a). In most PIC locations, over-

burdened staff, lack of data and skills deficiencies is thought to contribute to poor planning (Jones 1996).

2.5.6 Interconnected social and environmental problems

Urban problems in PICs are often worse in areas with fragile atoll environments where the opportunities for agriculture are small, such as in Kiribati, the Marshall Islands and Tuvalu (Jones 1996). There are also many social concerns relating to urbanisation in PICs (Asian Development Bank 2000a):

- Urbanisation is seen by the community as much more than an economic issue; but rather in terms of social needs, place of custom, extended family, social safety net and local life.
- Urban families tend to become alienated from their village roots.
- Without adequate employment opportunities the pressure on urban informal and subsistence living sectors is high.
- Urban isolation and lack of land for gardening in urban areas is aggravating poverty.

Many of the people now born in urban areas are second or third generation urban settlers (Jones 2003). All in all, urban dwellers tend to increasingly loose their rural subsistence safety net, but gain in terms of the social life in the cities (Thomas 2003). To mitigate this risk there is a strong need to maintain the ecosystems and environments, such as lagoons, surrounding the urban areas. Unfortunately, poor systems for sewerage collection and disposal have a tendency to ruin such environments, as in the case of Tarawa in Kiribati where there are concerns about shell fish, reef fish and other marine resources due to pollution from human and animal waste (Thomas 2003). The extent of poverty varies across the Pacific (see Table 2-8) but the poorly resourced nation of Kiribati has as much as 51 percent of the population below the basic needs poverty line.

Table 2-8: Extent of poverty in PICs

State	Population below basic needs poverty line (%)	Reference year
Cook Islands	12	1998
Marshall Islands	20	1999
Samoa	20	2002
Tonga	23	2001
Fiji	26	1990/91
Tuvalu	29	1994
Papua New Guinea	38	1996
Federated States of Micronesia	40	1998
Timor-Leste	40	2001
Vanuatu	40	1998
Kiribati	51	1996

Source: City populations 2008

2.5.7 Land ownership issues

Land issues are important in PICs and Jones (2003) explains that there are three common types of land tenure: customary or native lands, freehold lands as well as state or public or crown lands. Considerable difficulties stem from complex issues of customary land ownership and approximately 80 percent of land in PICs has been estimated to be under indigenous control (Jones 1996). Locations such as South Tarawa relies for water supply on groundwater from catchments that are on customary lands and therefore these need to be protected from pollution, such as occurs with habitation (Metutera 2002). Such issues are difficult and often in conflict with traditional culture, as described by Metutera of the Public Utility Board in South Tarawa:

In Kiribati, community consensus and participation on certain issues, such as land and development projects, are necessary and much patience and time consuming groundwork is required before successful implementation is achieved. Land is a very sensitive issue as it is the pride of families to own a piece of land, acquired from their ancestors (Metutera 2002: 10).

Jones (2003) explains that balancing traditional customary rights with issues of public interest are at the heart of many attempts of improving governance and institutional arrangements for urban management in PICs. Thomas (2003) points out that the judgments made in land-courts are often ignored due to lack of administrative capacity to enforce decisions.

2.5.8 Institutional concerns

The literature has shown that urban water management in small towns in PICs is difficult due to land issues, socio-cultural complexity, skills deficiencies and lack of resources such as information and finances. In the area of urban management in general, Jones (2006) also indicates that there is a limitations in the management and planning processes:

Limits to planning are further exacerbated by the prevailing socio-political context of ‘insularism’ reinforced by geographic remoteness which gives rise to a slow pace of administration and a lack of bureaucratic innovation. In addition, intense face to face personalism and family kinship ties can reduce opportunities for ‘objective’ decision making, inhibit the tackling of issues and reinforce the status quo. Strong partisan politics and restricted employment opportunities can generate insecurity, policy caution and poor institutional memory (Jones 1996: 4).

Additionally, Jones (1996) explains that there is poor coordination and integration between agencies and local government is typically weak and under-resourced. Jones (1996) also identifies as critical deficiencies, the lack of explanatory and predictive frameworks, the lack of consensus on social, environmental and economic goals, the lack of basic field data, and the poor understanding of the attitudes and behaviours of the urban populations.

White and colleagues (2008), based on experiences in Tarawa, also point out that management paradigms coming from the developed contexts are often inadequate and that management paradigms need to rely more on local capacity and community management.

2.6 Review summary

In this chapter small town water issues have been identified as a considerable challenge for urban managers and communities. This challenge has been acknowledged via the formulation of the Millennium Development Goal number seven which focuses on the nexus of poverty, access to water, environment and food security. Progress towards this goal has so far been poor. Urban water issues are multi-faceted with a range of implications and influences. Several perspectives on urban water management may be used, such as the social, economic and environmental perspectives, and a number of frameworks for managing urban water systems are emerging based on sustainability principles, good governance, regulation and public participation. A common discussion in this field relates to water as a public good or an economic good, and the recent wave of privatisations of public water management.

These challenges are not limited to large cities and developed countries, but in fact more severe in the context of smaller towns in less developed contexts. There is a globally acknowledged management gap for towns, where resource constraints makes traditional urban water management unrealistic. In the case of the case of Pacific towns, which face a high level of social complexity, severe resource constraints, isolation and difficult cultural transition pose difficult concerns. The reality is that many urban systems are in a poor state; and from the point of view of urban water, relatively poorly mapped and understood. There appears to be a high level of social complexity relating to economic limitations, interconnected social and environmental problems, landownership issues and institutional concerns.

At a systems-level complexity and uncertainty leads to difficulties in successfully implementing management strategies. Exactly where the complexity and uncertainty comes from remains to be explored but there is a nexus of unclear and contentious political reality; extreme resource constraints causing considerable uncertainty and risk in the operation of the highly interactive systems; actors adapting their behaviour to ever-changing conditions; and an urgent need for appropriate institutions.

Chapter 3: Methods Review

This chapter provides a review of methods that are appropriate in order to achieve the goals and objectives of this study. Firstly, some of the thinking and foundation of this study is laid out, guiding the review of methods. Subsequently, methods are reviewed that can generate data and information; and modelling approaches are reviewed that will help to provide an understanding of the complex interactions of the system, as well as the retrospective causal relationships. Finally, frameworks are reviewed that may help support the learning process that is required in order to help the stakeholders for this study, i.e. local water managers.

In the previous chapter, a number of important challenges were identified in terms of finding an appropriate management framework for urban water management in Pacific towns, and how this has relevance for the wider context of water management in under-resourced, messy and socially complex situations that are common in towns in developing nations. In this chapter, there is a review of suitable methods and approaches that will help to provide data and improved understanding of the situation in small town water governance contexts. It is assumed that these types of activities will help in the formulation of tools and frameworks that can be used by local water managers. In approaching the tasks of this study, it is noted that the studied systems exhibit tendencies of being in what Kurtz and Snowden (2003) describe as the un-ordered domain of complex relationships (see citation below). This in turn has considerable implications for the choice of research methodology.

Un-ordered domain: Complex relationships. This is the domain of complexity theory, which studies how patterns emerge through the interaction of many agents. There are cause and effect relationships between the agents, but both the number of agents and the number of relationships defy categorisation or analytic techniques. Emergent patterns can be perceived but not predicted; we call this phenomenon retrospective coherence. In

this space, structured methods that seize upon such retrospectively coherent patterns and codify them into procedures will confront only new and different patterns for which they are ill prepared. Once a pattern has stabilised, its path appears logical, but it is only one of many that could have stabilised, each of which also would have appeared logical in retrospect. Patterns may indeed repeat for a time in this space, but we cannot be sure that they will continue to repeat, because the underlying sources of the patterns are not open to inspection (and observation of the system may itself disrupt the patterns). Thus, relying on expert opinions based on historically stable patterns of meaning will insufficiently prepare us to recognise and act upon unexpected patterns. (Kurtz and Snowden 2003: 469)

In fact, assuming a complex, adaptive and socially messy reality in the studied systems, there is a need to be wary and to make sure that our assumptions, theories and inferences are grounded in reality rather than to jump into generic conclusions. Kurtz and Snowden (2003), in the formulation of the *Cynefin* framework, in fact recommend a number of approaches for sense-making in these types of systems, i.e. 1) analysis of history; 2) use of narrative techniques; 3) use of multiple perspectives; 4) exploratory systems analysis; and 5) the use of an adaptive approach where interventions are used as probes. To identify a suitable portfolio of sense-making tools, a number of knowledge elicitation techniques are reviewed, but also a number of suitable systems analysis options from the area of Complex Systems Science such as Agent Based Modelling and Bayesian Networks. It is acknowledged that these are hardly mainstream approaches, and may be difficult to embed into a management framework.

It is also noted that whilst the above is useful for generating an understanding of our system, the ultimate end-goal is not just to gain understanding per se, but in fact to formulate a management framework. Therefore, there is also a need to review some of the concepts and issues that need to be considered in such an approach. In the sections below, it is argued that a management framework needs to integrate participation with systems analysis and will need to include concepts such as social learning and post-normal science.

What has been identified so far in the review is that an important consideration in water management is the issue of participation. For example, the Dublin statement reads:

Water development and management ought to be based on a participatory approach (ICWE 1992: Principle No. 2).

Specifically, for the Pacific Island's' water sector, this is reinforced in the Regional Action Plan on Sustainable Water Management which has as a key message:

A high quality participatory framework should be adopted at the national level to allow for open participation of communities in sustainable water and wastewater management (South Pacific Applied Geoscience Commission and Asian Development Bank 2003: 18).

However, it is noted that existing participatory frameworks for water management have been developed for a different scale, and for developed contexts (HarmoniCOP 2005); and in fact participatory modelling frameworks have already to some extent failed to gain traction in the target context (Dray *et al.* 2007). Therefore, a new participatory framework needs to be formulated which better suits the context.

Participation within an integrated assessment framework is also warranted from the systems analysis perspective, as the systems under study involve large numbers of individuals and communities, whose interactions with each other, the urban infrastructure and the environment generate macro level patterns that can not, for the most time, be predicted. As argued by Batten (2000) participants in the system in turn use a combination of inductive and deductive reasoning to make inferences and identify patterns; making them adaptive, creative and inherently unpredictable.

As previously mentioned, modelling is another key strategy for understanding these systems, and this type of activity has been made plausible with the progress of Complex Systems Science. Agent Based Modelling and Multi Agent Systems are important approaches in this type of endeavour. At the heart of such models is the attempt to understand and model human

cognitive abilities, which Maturana and Varela (1980) consider to be inherently circular, subjective and paradoxical. Additionally they argue that:

[People and] ourselves operate in multiple ‘worlds’, particularly socio-cultural ones; and that a ‘world’ is moulded by contextual factors intertwined with the very act of engaging with it (cited in Perez 2006: 42).

This particular problem in combination with unpredictability means that validation of these types of models and metaphors is problematic. As argued by Perez (2008) in a recent paper, post-normal science provides a new scientific posture partly resolving this issue where participants provide the role held by peer-reviewers in traditional science. This process is critically important in order to generate validity and acceptability of models amongst stakeholders. This in turn is critical for allowing models to become important tools in decision making, and hence in a management framework. Another key recommendation concerns the fact that social learning is the most important aspect of transformation processes (Pahl-Wostl 2002a) which are desperately needed in the target context; and social learning would therefore be an important concept in our management framework.

In summary, to generate a better understanding of the studied systems, knowledge elicitation techniques are reviewed, as well as systems analysis approaches from the complex systems science area. To allow the formulation of a management framework, this chapter includes the review of concepts such as social learning, post-normal science and participatory integration frameworks.

3.1 Information collection

As argued by Bammer (2005), it is important for developing an understanding of complex environmental problems to collect information and perspectives from a wide range of sources; and this includes both qualitative and quantitative information. Therefore, the information and knowledge elicited is often qualitative in nature and a number of approaches exist for undertaking qualitative research, such as grounded theory.

Glaser and Strauss in their seminal work on grounded theory (1967) provide a method for generating theories, primarily about people's behaviours, based on qualitative data and a combination of inductive and deductive thinking. According to grounded theory (Glaser and Strauss 1967; Kelle 2005):

- Everything is considered to be data which can be used by the researcher to generate concepts, including emails, lectures, conversations, books etc, etc;
- All data is coded to extract concepts, which are classified and this is an iterative and ongoing process as the theory sharpens and new concepts emerge;
- All concepts are narrowed down by selecting the core variable, and this is further refined as learning improves.

In other words, by extracting the mental models (i.e. concepts) of others, the qualitative researcher uses a formal procedure to create his/her own mental model of the system. This is in line with social learning theory (Bandura 1977, 1986), where it can be said that individuals have mental models that are evolved and socially constructed through interaction with their environment (social and physical). These mental models in turn determine the decisions made by both organisations and individuals (Bandura 1986) and methods can be adopted to elicit the mental models of individuals, such as for example via Global Targeted Appraisal and Individual Activities Surveys as applied by Dray and colleagues (2006b); or Interviews and Focus Group Discussions as applied by Kayaga (2008); or Interviews as applied by Brown (2005); or Delphi Survey as applied by Rixon and colleagues (2007b).

In this review, there is a focus on Interviews and the Delphi Survey as knowledge elicitation techniques. Both approaches are qualitative research methods that generate qualitative information and are related to grounded theory practice.

3.1.1 Interviews

The method of undertaking interviews is one of the most commonly applied approaches for collecting information in qualitative research and while the process is time consuming, the process provides rich and contextual descriptions, even though the results are dependent on the

skills and aptitude of the interviewer (Byrne 2001). Within the qualitative research areas, it is used in case studies (Flyvbjerg 2006), in action research (Carr 2006), in grounded theory studies (Glaser and Strauss 1967) and in ethnographies (Myers and Newman 2007). Myers and Newman (2007) however note that the reporting on how interviews were undertaken is often poorly described. Interviews may be undertaken in a structured, semi-structured or unstructured manner (Cohene and Easterbrook 2005). It is also noted that the interview process can be very rewarding in terms of the individual learning for the researcher (Byrne 2001).

The structured interview is carried out by using a number of pre-defined questions, and in a semi-structured interview the interviewer adapts to the situation (using what is referred to as ‘tactics’) and delivers the questions in a more exploratory and dynamic manner (Cohene and Easterbrook 2005). Tactics employed in semi-structured interviews may be the inclusion of narratives, the use of scenarios or role-playing, card sorts, free listening or paired comparisons and providing the participants with more options for communication (Cohene and Easterbrook 2005). In unstructured interviews there is no pre-defined agenda providing much more freedom in terms of the topics that may be covered (Cohene and Easterbrook 2005). It is noted however that Byrne (2001), who comes from the perspective of medical research, provides a different definition of these concepts, making the distinction only between structured and unstructured interviews, where the definition of the structured interviews stays the same but the definition for the unstructured interviews is when you ask open questions. Byrne’s (2001) definitions are clearly less encompassing of the range of interviewing options. Myers and Newman (2007) however add another category, the group interview where one or more participants are interviewed by one or more interviewers; and this may be structured, semi-structured or unstructured.

Another approach is provided by Dick (2002b) who suggests carrying out the following stages:

1. Building rapport: providing an introduction of who you are, what you are doing, who gets the information and what the purpose of the interview is.

2. Ask an opening question without being specific; as far as possible simply introduce the topic and invite a response.
3. Keeping the informant talking for about 45 minutes to an hour without asking specific questions.
4. Towards the end of the interview, ask probing questions, and ask for a summary of the key points.
5. Write up the interview while it is still fresh in memory; and bullet points are adequate rather than a detailed report.

Dick (2002b) then suggests that this process is carried out for a selected number of participants and where the selection criteria provide maximum diversity and involves all interests. The interviewer also keeps track of agreements and disagreements in the responses and towards the end of the interviewing series, the interviewer can use the disagreements to challenge the interpretations made by participants. Dick (2002b) makes the point that with this process, information is coming from the participants and not the interviewer (and is hence participatory), and through probing questions, it involves the participant in the interpretation. By focussing on the disagreements in interpretations, the process is also dialectic by identifying differences in the participants' mental models.

There have been a number of published studies using interviews in the urban water sector. Brown (2005) interviewed 60 experts across multiple sectors to explore impediments to sustainable management in the Sydney water sector. Kayaga (2008) used interviews as a tool within a soft systems methodology to undertake performance measurement in the Uganda water sector. Who Kayaga has interviewed or how he has interviewed them is however not described in the article. Marlow and Humphries (2009) have interviewed water sector professionals in Australia to explore how sustainability issues can be operationalised within asset management. These were recorded and carried out in a face-to-face fashion where participants could choose either a structured or semi-structured approach. Probing questions were used to seek clarity but not to invite participants to make interpretations. Dray and colleagues (2006b) used an initial survey for selecting relevant groups and in this way identifying leaders or active community

members who were then selected for semi-structured interviews. The semi-structured interviews had three parts: 1) inviting participants to interpret photos, 2) cognitive mapping (i.e. mind mapping), and 3) using a card game. Based on the results of the first round of interviews, an Individual Activities Survey (a structured interviewing technique) was carried out asking questions about behaviour and activities.

Myers and Newman (2007) also point out a number of pitfalls in interviewing, such as:

- Using ambiguous language providing ambiguity in interpretations and consequently in responses;
- The tendency to steer the interviews and thereby skewing the information, and sometimes even socially constructing the results in the process of interviewing;
- Providing a bias in interpretation towards responses of those participants that are articulate or perceived as important;
- It may be difficult or even impossible to gain entry to all levels of an organisation; or all relevant potential participants;
- There may be a lack of trust, meaning that the participant may not divulge sensitive information;
- There may be insufficient time, meaning that the results are often incomplete or truncated.

Myers and Newman (2007) also stress the importance of ethical standards, i.e. getting permissions, respecting people and fulfilling commitments to individuals and organisations. They also note that structured interviews are suitable for well-defined problem areas, while unstructured interviews are preferred for topics with high levels of uncertainty and ambiguity; and semi-structured interviews are suitable for the areas in between (Myers and Newman 2007).

3.1.2 Delphi method

An interesting method for group knowledge elicitation that has been applied in the natural resource management context (see Rixon *et al.* 2007b), among other contexts, is the Delphi method which has been described as follows:

Delphi may be characterised as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem (Linstone and Turoff 2002: 5).

Okoli and Pawlowski (2004) describe a remotely conducted Delphi survey (e.g. web based survey) as follows:

1. Selecting panellists; which involves
2. Developing a knowledge resource map and a spreadsheet, and then;
3. Populating this spreadsheet with names as potential participants;
4. Ranking participants based on a relevant criteria; and selecting appropriate panels based on the range of participants' backgrounds;
5. Categorising and inviting participants (target size is 10-18 per panel).
6. Collecting data using questionnaires and sending these out by mail or email
7. Brainstorming – identifying a range of issues and factors concerning the topic at hand;
8. Narrowing down – inviting the participants to select a smaller number of issues in order to reduce the number of issues to something manageable; and
9. Ranking – inviting the participants to rank the issues in order to reach a ranked list of issues for each panel.
10. Within each iteration, it is useful to ask participants to validate the process, interpretations and the results; as discussed previously this invitation to participate in the sense-making is important for extracting the mental models of the participants;

11. Analysing the results; identifying agreements and disagreements within each panel and thereby providing a list of mental representations of the problem.

Historically, the Delphi method was originated by a number of studies undertaken by the RAND Corporation in the 1950s, and it has been applied within a large number of areas for such as: forecasting; identification of a research topic; specification of research questions; identification of a theoretical perspective for the research; selection of factors of interest; preliminary identification of causal relationships; and the creation of a common language for dialogue (Linstone and Turoff 2002; Okoli and Pawlowski 2004).

Delphi survey is a qualitative research approach that generates rich datasets based on narratives and examples provided by participants. Then, a Delphi process explores patterns in responses and allows participants to validate patterns identified by researchers. The Delphi method can also be applied within the Action Research area (Dick 2002c), and in this case the expectation is that the participants decide to take action based on the understanding that has been gained. For instance, in an ideal case, the Delphi method may start a constructive discussion about possible water development projects that will address the factors identified through this study.

The Delphi method was deemed to have the following advantages over more traditional questionnaire-based approaches by providing (Okoli and Pawlowski 2004):

- A typically higher response rate;
- More opportunities for validation and follow up on responses; via
- Direct validation of the researcher's synthesis and classifications by participants; and
- The ability to explore and clarify ambiguous responses;
- Fewer limitations because there are less concerns about statistical significance of results;
- Better ability to explore the diversity in responses and identify disagreements, which may help in focusing research questions;

- Providing a common language to emerge from the interactions between diverse stakeholders and this may allow for further cross-boundary discussion and discourse;
- Allowing issues to emerge instead of being prescribed, as is the case when using a questionnaire.

Okoli and Pawlowski (2004) also describe how the Delphi method is related to a word in French, bricolage, which means ‘to use whatever resources and repertoire one has to perform whatever task one faces’. The Delphi method achieves this because of its flexible nature, and is hence a good starting point for finding the information and understanding that already exists.

There are a number of different methods for undertaking this type of group communication: conference telephone call, committee meeting, formal conference or seminar, workshop, email or internet (Linstone and Turoff 2002; Rixon *et al.* 2007b).

3.2 Going from qualitative data to computer models

In the context of this study, knowledge engineering provides methods to translate the collected qualitative information into models. There are two basic methods for using qualitative knowledge to design agents (Becu *et al.* 2003). The first is using theories, such as Belief-Desire-Intention (Brazier *et al.* 2002) or Consumat (Janssen and Jager 1999; Jager *et al.* 1999), as frameworks that can be populated and used as computational models. These methods are based on cognitive models, often on the basis of concepts from sociology or psychology, representing sub-systems such as a knowledge base, goals, cognitive processing, and how decisions and behaviour are generated on the basis of this. The second method is via eliciting stakeholders’ knowledge and to translate this into a conceptual model which can be translated into computational models. This approach is thought to better capture the diversity of cognitive processes and systems representations that agents’ possess.

In the first approach, the qualitative information feeds into the modelling framework by simply being an ingredient used for populating existing structures whilst in the second approach, Figure 3-1 shows how the qualitative information informs the conceptual model which in turn is used

to develop the computational model. It can be argued that by using the second approach, much of the richness of the qualitative information about stakeholders' perceptions can be captured (Becu *et al.* 2003). Additionally, in situations where limited computational and cognitive capacities cause individuals to apply 'bounded rationality' using 'fast and frugal heuristics' (Gigerenzer and Todd 1999), the second method would appear superior in modelling human decision making. However, an advantage of the first approach is that models can be directly linked to theories in fields such as sociology, economics and psychology. The first approach also does not require as much effort in terms of knowledge engineering.

Knowledge engineering is mainly about the second type of model development described in Figure 3-1 and in this case, once qualitative information has been collected, it feeds into the task of creating conceptual models either formally, such as by using grounded theory, or informally by a combination of deduction and induction by the model builder (Siau and Tan 2005); and it may also be done with only personal agreement on the conceptual model, or with common (i.e. group) agreement on the conceptual model (Siau and Tan 2005).

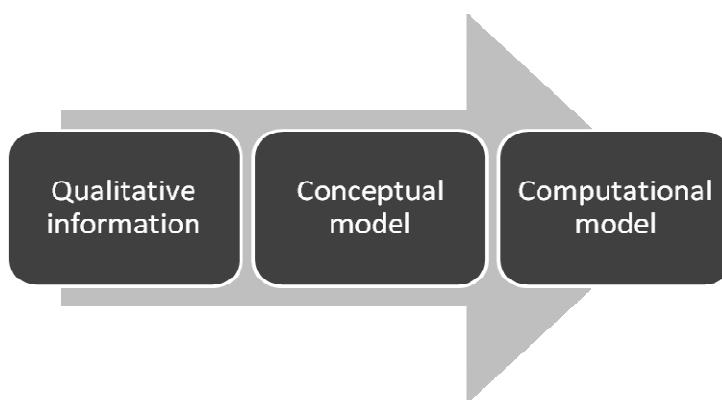


Figure 3-1: Second approach for eliciting and using qualitative data to develop models

In other words, with a typically low transaction cost, while a modeller may create a model independently using only his/her own intuition, deduction and induction; at the other end of the spectrum, a conceptual model may be generated based on a formal and documented process where a group voice is elicited and where it is assumed that the group is more likely to agree on

the language, and underlying assumptions and structures; allowing it to be used for collective decision making, as per the Companion Modelling framework (Barreteau 2003a).

3.2.1 Mental models

A key part of translating qualitative information to models is the representation of cognitive processes and human decision making. A common view in the modelling of human decision making is that each person has a different mental model, a systems representation, which is used to guide decisions and behaviour. Dray and colleagues describe what seems to be a common posture of this area:

We recognise the epistemic construction of knowledge and believe that the nature of individual representations is socially constructed through people's interactions with their physical and social environment. We agree on the fact that these adaptive mental models can be partly elicited through Knowledge Engineering-based techniques and translated into conceptual models [and], we assume that social groups carry collective representations (collective frames) of their environment and that these mental models can be partly elicited from wisely selected representatives (Group Voices). We argue that individuals belonging to the same group share the same representation, but their behaviour is driven by personal motivations and tacit knowledge. Thus, they can temporarily dismiss part of the shared representation (Dray *et al.* 2006b: 2).

Carley describe the ‘mental models’ as including definitions, procedures, examples and so on, and that they are ‘internal symbolic representations of the world or aspects of the world [and individuals] use these mental models to negotiate their lives, determine which actions to take and construct the social world’ (Carley 1997: 535). She also makes the point that individuals adapt their mental models over time, and that they can also have multiple mental models utilised in various contexts (Carley 1997). It is also argued that individuals are not fully aware of their own mental models, and that they are in fact unobservable as they exist only in the mind employing tacit and unarticulated knowledge (Carley 1997). This seems to be in line with the popular science theories laid out by Gladwell (2005) in regards to how individuals are largely

unaware of much of the processes and representations which people use for making decisions, in particular in relation to what is often referred to as intuition. In relation to the use of mental models in complex decision making situations, Gladwell also argues that too much information, rather than only the most significant information, can often interfere with the accuracy of judgments.

Groups and teams may also have shared mental maps, although this appears to be more contentious and ambiguous in terms of the exact definition (Carley 1997). Definitions concern how information is shared, the degree of sharing and the awareness of sharing. Searle (1995) describes the intricate and complicated processes of how social reality and social facts like money and sports, in essence group mental models (social facts), are constructed and reinforced. This is largely outside the scope of this literature review. This area of philosophy is often referred to as social constructionism.

3.2.2 Conceptual models

An important intermediate step between mental models and computational models are the conceptual models. Carley describes a concept as follows:

A concept is a single ideational category. A concept can be a single word such as ‘organisation’ or ‘process’, a composite word such as ‘information system’, or a more complex phrase such as ‘democratic and equal participation’ (1997: 538).

There are different types of conceptual models, such as Causal maps, Semantic maps and Concept maps (Siau and Tan 2005) while Carley (1997) uses the term Cognitive maps. The term *Cognitive maps*, is used for the purposes of this study.

Table 3-1: Cognition and quality in conceptual modelling

Quality type	Description	How human cognition is related?
Semantic quality	Valid and complete correspondence between the conceptual model and the domain	Relates to the scope of the domain. Discrepancies between individual interpretation and participant knowledge can be used to establish approximations of semantic quality
Syntactic quality	Is the language appropriate?	Limitation in human cognition capacity demands for simple models and languages
Pragmatic quality	Is the model interpreted as intended?	Good pragmatic quality typically means interpreting a single meaning with the lowest possible cognitive effort
Physical quality	Does the model bring understanding?	Refers to two processes: externalisation and internalisation. Externalisation brings knowledge of some social actors that is not widely available into the model that then becomes widely available. Internalisation brings increased knowledge on the basis of making sense of the model.
Empirical quality	Is the model accurate?	Heavy cognition loads may cause frequent errors when conceptual models are being written or read
Social quality	Do individuals agree on interpretations?	Difference in the frames of reference is the root reason for errors in social quality

Source: Siau and Tan 2005: 352

The quality of cognitive maps represents the validity of these, and as such the types of quality described in Table 3-1 are critical. Siau and Tan (2005) base their assessment of quality on a framework for conceptual modelling which includes correspondence between:

- Domain: the context of the modelling effort;
- Model: the conceptual model;
- Interpretation: the way that the audience perceives the model;
- Language: the way that the model is expressed.

Some of the qualities of a conceptual model refer to the relationship between the above elements:

- Semantic quality: correspondence between domain and model;
- Syntactic quality: correspondence between language and model;
- Pragmatic quality: correspondence between interpretation and model;

- Language-domain appropriateness: appropriateness of language in the domain;
- Audience-domain appropriateness: the appropriateness of the audience in the domain;
- Audience-language appropriateness: the appropriateness of language for the audience.

Furthermore, the social quality refers to the social value of the model; i.e. the correspondence between different individuals' interpretations and the outcomes that they can generate on the basis of this. The empirical quality refers to the likelihood of error occurring when a model is read or written by different users, and typically relates to computer-human interaction. Physical quality refers to the extent of increased understanding that individual social actors gain from making sense of the model.

Cognitive maps, as defined by Carley (1997), are developed by eliciting and coding the elicited mental models of individuals or groups. This is described as an emergent structure which in other words is not pre-defined. As such the term cognitive map is a more generic term and is not bound by a framework in the same manner as causal maps, semantic maps or concept maps. The process that Carley describes for developing cognitive maps is via different types of textual analysis, mainly of statements. The elements of the cognitive map are concepts and relationships. There are several formal processes that are available for generating cognitive maps from a combination of qualitative and quantitative data. These are further described below.

3.2.3 Coding conceptual models

The task of Coding text into conceptual models has so far not been described. In order to code text into conceptual models, the research must make a large number of coding choices in particular in terms of filtering which parts of a text to use and which concepts to code (Carley 1997).

Polhill and Ziervogel (2006) describe a process for using textual analysis for developing a conceptual model. The type of conceptual model that they develop is an OWL ontology which can be described as a concept map. This concept map was developed in a case study in South

Africa (Polhill and Ziervogel 2006) based on data from the field work as well as three scientific papers. This was done in a number of steps which were repeated for each data source, including assembling material, classification, analysis and finally development of a knowledge representation; followed by analysis of logical consistency and refinement.

Another example of a coding process is given by Dray and colleagues which started with an initial knowledge elicitation process as follows:

Our methodology includes two sets of interviews. The first one, called Global Targeted Appraisal (GTA), is meant for eliciting Group Voices representations of the key components and processes at stake. The second one, called Individual Activities Survey (IAS), is conducted with individuals selected randomly among the different groups. It is used to validate and eventually quantify the interactions that unfold during the GTA interviews (Dray *et al.* 2006b: 2).

The above mentioned Global Targeted Appraisal (GTA) uses semi-structured interviews with selected individuals based on three exercises, semi-structured interviews using photos and card games as well as cognitive mapping based on individual's home island. The exercise also involved a more structured and quantitative questionnaire for validation; as well as analysing transcripts and to analyse this using transcript analysis in a qualitative analysis software, Qualrus (Idea Works Inc. 2002).

Whilst these efforts are rigorous, the effort required is considerable and Dray and colleagues (2006b) report that approximately 60 person-days in the field work and approximately 50 person-days in qualitative analysis is required. For a PhD student, this would mean approximately 4 months of labour alone, including at least two months of field work. While the benefits are a more rigorous description, there is an overwhelming cost and effort required for undertaking this type of task. For a PhD study where the key focus is not on this aspect, this type of activity is not feasible and therefore more informal approaches would be sought.

3.3 Complexity modelling

The view is adopted that small town water management is often characterized by complex interactions. Hence, concepts used to define complex adaptive systems (CAS) are of particular relevance for describing such systems. Table 3-2 synthesizes the main findings of the literature review on CAS. The science and philosophy needed for understanding CAS is still in its infancy but is rapidly evolving and gaining ground (Finnegan 2006). The Complex Systems Science employs a growing array of modelling approaches, such as Systems Dynamics (von Bertalanffy 1972), Agent Based Modelling and Simulation (Gilbert and Troitzsch 1999), Statistical Mechanics (Albert and Barabasi 2001), Cellular Automatons (Wolfram 2002), and Network Theory (Barabasi 2002).

The academic field of Social Complexity focuses on the particular type of CAS that involves many interacting humans. Within this area a number of methods are used for modelling behaviour and decisions, often in combination with other methods: Game Theory (Binmore 2007), Bayesian Networks (Neapolitan 2003, Castelletti and Soncini-Sessa 2007a), the Consumat model based on social psychology (Janssen and Jager 1999; Janssen and Carpenter 1999), Memetics viewing behaviour and ideas from an evolutionary perspective (Dawkins 1976, Blackmore 1999) and Kenetics extending the theory for designing agent behaviour based on the psychology tradition of Belief-Desire-Intention (Ferber 1999, Brazier *et al.* 2002).

Criticisms of complexity models have been raised by Lissack and Richardson (2001), and Richardson (2003) who point out the difficulties of modelling CAS or human behaviour, and warn against attempting to use these models for prediction. They continue to warn that models can be both used and abused, as elaborated on in a paper by Lissak and Richardson (2003). However, their examples of model abuse are from the business sector where models are used to enhance political and business agendas, and their criticisms are in fact generically valid for any model.

Table 3-2: Systems features of Complex and Adaptive Systems

CAS feature	Description	Example of relevance to context
Non-linear behaviour	Small changes in independent variables can generate large outcomes in dependent variables	Small levels of pollution can cause considerable effects on freshwater resources
Feedbacks	The dynamics of the systems is dependent on itself. Most well known are positive feedbacks typically leading to unstable dynamics, and negative feedback typically leading to stable dynamics. Complex systems typically have multiple feedbacks that are often difficult to measure	Increased tariffs in response to financial shortfalls can lead to increased levels of illegal connections, and fewer households paying their bills, and therefore a reduced income
Path dependence and equifinality	Due to the high inter-dependence, feedback and non-linearity, a particular state can be reached by an infinite number of paths, and therefore it is difficult to establish causality and make inferences about system properties	Institutional settings and decision making structures are complex and interactive; and the evolution of these are highly unpredictable
Self-organisation and Emergent properties	Simple rules and interactions lead to surprising outcomes as in the case of ant colony coordination via the use of only basic pheromones for communication; or coordination of Bali rice farmers through basic interactions	The way that individuals make water use decisions is often based on simple rules, which can sometimes cause surprising macro-level results
Adaptive behaviour	The behaviour of the system co-evolves as it depends on its components responses to each other. If the components are human beings 'the adaptation relies mainly on the individual and collective learning processes', but presumably also a number of related cognitive processes.	Water users adapt to changes in the quality and volumes of the water that is supplied. Water managers in turn adapt to the expectations of the community when deciding what volumes and quality of water to supply; and this completes an adaptive feedback loop.
Non-state equilibrium	The dynamic properties of the system are constantly changing creating ever-changing and temporary Equilibria and non-stable regions	The freshwater lenses are typically in some kind of equilibrium state that depends on its path dependent history; but this equilibrium could all of a sudden change into equilibrium in response to external forces.
Self-defeating systems	There is also a particular type of adaptive system, the self defeating system where agents in a systems have an interest in doing the opposite to what the majority does, as for example in some traffic situations. These systems are often inherently unpredictable and very difficult to manage	It is unclear whether this particular system feature exists in the studied system; but it is conceivable for example that there are benefits for landowners to behave in a way that is opposite to the behaviour of the majority.

Sources: the example of non-linear effects was found in Richardson (2002); the mention of feedbacks in von Bertalanffy (1972); the discussion of path dependence and equifinality in Perez and Batten (2006); the discussion about self-organisation and emergent properties in Johnson (2001); Perez and Batten (2006) as well as Batten (2005) discuss adaptive behaviour; and Gunderson and Schelling (2002) discuss non-state equilibrium. For good descriptions of CAS, see Holland (1995) and Miller and Page (2007).

Boulanger and Brechet (2005) have explored the relative merits of Complexity models in the area of land-use. The criteria that are used to evaluate the modelling approaches are (Boulanger and Brechet 2005), their ability to:

- Support an inter-disciplinary process; i.e. its ability to:
 - Incorporate knowledge from many sources;
 - Provide transparency, i.e. opening up the black box; and
 - Support dialogue and interpretation;
- Handle uncertainty about:
 - Model quantities, i.e. its parameters and initial conditions;
 - Model structure, i.e. the relationships between variables and functions etc;
 - Model pertinence, i.e. its granularity, scale, selection of variables, etc;
- Provide a long-term perspective; i.e. its ability to incorporate several time scales;
- Model different scales, i.e. micro and macro and onwards;
- Support participation in the modelling processes.

The types of Complexity models included in the evaluation by Boulanger and Brechet (2005) were Agent Based Modelling, Systems Dynamics and Bayesian Networks; and the results are given in Table 3-3 (a higher value means that the method is more appropriate).

Table 3-3: Evaluation results of six modelling approaches against five criteria

	Interdisciplinarity potential	Long-term, inter-generational	Uncertainty management	Local-global	Participation	Ranking
Agent Based Modelling	0.29	0.27	0.30	0.34	0.40	1
Systems Dynamics	0.29	0.27	0.08	0.11	0.20	2
Bayesian Networks	0.17	0.07	0.39	0.17	0.13	3
Optimisation	0.05	0.07	0.06	0.17	0.08	6
General equilibrium	0.10	0.21	0.08	0.11	0.08	4
Macro-econometric	0.10	0.10	0.10	0.09	0.10	5

Source: Adapted from Boulanger and Brechet (2005)

As can be seen in Table 3-3, Agent Based Modelling is the best option in each of the evaluated aspects except for in uncertainty management where Bayesian Networks has been deemed to be the best option. With this in mind, based on perceived appropriateness, Agent Based Modelling and Bayesian Networks will be further reviewed.

Agent Based Modelling usually encapsulates cellular automata and more realistic behavioural models and which has already been applied within the urban water context (Tillman *et al.* 1999, 2001, 2005) and general water contexts (as exemplified by Lansing 1996; Janssen and Carpenter 1999; Barreteau and Bousquet 2000; Perez *et al.* 2002; Daré and Barreteau 2003; Dray *et al.* 2006b). As described above it has been shown to be ideal for interdisciplinary research and participation which has also been reinforced by researchers such as Pahl-Wostl (2002a).

Bayesian Networks has been applied in the water context (as exemplified by Castelletti and Soncini-Sessa 2007a, b; Martín de Santa Olalla *et al.* 2007), and has been recommended as particularly suitable for understanding risk and uncertainty (Boulanger and Brechet 2005).

3.3.1 Agent based modelling

Epstein and Axtell (1996) in their classic book *Growing Artificial Societies: Social Science from the Bottom Up*, describe the use of social simulations using Agent Based Modelling (ABM), for

analysing social structures and group behaviours. This is a ‘bottom up’ paradigm in that instead of describing aspects of the world using macro-properties, Epstein and Axtell consider the interactions and actions of individuals. In this way, they let the macro-properties emerge rather than being explicitly modelled. The primary question that Epstein and Axtell ask is: ‘How does the heterogeneous micro-world of individual behaviours generate the global macroscopic regularities of the society?’ This is of course the global-local interaction referred to in the previous section; one of the key strengths of the approach.

In a general sense, objectives of the applications of ABM can be broadly categorised into the following categories: prediction, policy analysis, inductive reasoning about system properties, co-learning and collective decision making, developing a systems understanding and knowledge management.

- Prediction (Samanidou *et al.* 2007): using models to predict some dependent variable into the future so that typically financial gains or competitive advantage can be realised in some manner;
- Policy analysis (Heckbert and Smajgl 2005): using models to help policy makers understand implications of policy to make these more efficient and fair. A particular advantage of ABM in this area is that the method accounts for more realistic behaviour as well as understanding the impacts on a heterogeneous population;
- Inductive reasoning about system properties (Rixon *et al.* 2007a): using models to understand systems where sufficient micro-level measurement is difficult, and using the simulation model as a virtual laboratory exploring possible realities. This is particularly powerful when it is possible to re-design the actual reality to match the behaviour that is modelled, and hence creating a more predictable and presumably more efficient system;
- Co-Learning and collective decision making (Barreteau 2003): helping groups of stakeholders to understand complex interactions with each other and their environment, typically in order to identify collaborative solutions to resource dilemmas;

- Developing a system understanding (Tillman *et al.* 1999): using models as a tool in the scientific process, exploring and evaluating theories; often in the social science area where such process tools have previously been somehow lacking;
- Knowledge management (Dignum 2006): using models to embed knowledge and information in an accessible manner to multiple stakeholders.

Gilbert and Troitzsch have written a very useful reference book to guide the undertaking of social science through computer simulation:

With complex models, especially if the specification is nonlinear, such analytic¹ reasoning can be very difficult or impossible. In these cases, simulation is often the only way. Simulation means ‘running’ the model forward through (simulated) time and watching what happens. Whether one uses an analytical technique or simulation, the initial conditions, that is, the state in which the model starts, are always important. Often, the dynamics is very different depending on the precise initial conditions used (1999: 16).

In particular, the ABM methodology is good at modelling *emergent* phenomenon. Emergent phenomenon is described as follows:

Emergence occurs when interactions among objects at one level give rise to different types of objects at another level. More precisely, a phenomenon is emergent if it requires new categories to describe it which are not required to describe the behaviour of the underlying components. An individual atom has no temperature but a collection of them does (Gilbert and Troitzsch 1999: 11).

Hence, this links it back to an essentially thermo-dynamic view of the world, which is signified by interactions between different scales. Or as described by metaphor: in an ABM model of a society, the individual is the atom and their individual characteristics and interactions give rise to macro-properties like the temperature and entropy of thermodynamics.

¹ This refers to models for predictions (of macro-properties) based on reasoning, such as logic or mathematics.

It is however acknowledged humans are more unpredictable than atoms. In fact, attempts to understand our cognitive abilities using the same cognitive abilities are inherently circular (Maturana and Varela 1980). Socio-cultural worlds are strongly contextual and individual people operate in multiple such worlds (Maturana and Varela 1980). Serious attempts in neoclassical economics to define human behaviour have been met with criticism from different angles; relating to the use of heuristics (Gigerenzer and Todd 1999); the evaluation of rewards (Gintis 2000); and dealing with uncertainty (Tversky and Kahneman 1981). In parallel with these more modern theories of behaviour, there is an entire area of scientific endeavour in neuroscience that is still very much exploring surprisingly complex inner workings of human brains, including those relating to feelings and emotions (Johnson 2004). Suffice to say that atomistic representations can never fully capture the complex inner workings of humans, but that it has the capacity to embed at least those representations of human behaviour that can be formalised in mathematical or computational language.

Despite its limitations, atomistic computer metaphors of humans have been surprisingly successful. As an example, Lansing and Miller (2003) describe how social structures and practices have emerged in Bali rice farming communities from only local dynamics and interactions (Lansing and Miller 2003). Indeed, the approach (as described by for example Ferber 1999) has proven to be successful in explaining the emergence of many phenomena based on simple and intuitive local rules of interaction and has even been able to explain widely diverse systems that previous research paradigms has failed to explain, such as racial segregation in cities (Schelling 1978), bird formations (Reynolds 1986), distribution of wealth in societies (Epstein and Axtell 1996), spread of HIV (Wilensky 1998), dynamics of electricity markets (North *et al.* 2002), or village formations of the Anasazi Indians (Diamond 2002). However, as previously hinted in the previous section, there is also appropriate criticism of this approach (as described by Lansing 2002 and Richardson 2003). Lansing writes:

One does not need to be a modeller to know that it is possible to ‘grow’ nearly anything in silico without necessarily learning anything about the real world (2002: 2).

Whilst Lansing argues for caution in application of ABMs and a more scientific critique, he also agrees that models are often particularly useful for understanding coupled human and natural systems and that they support inter-disciplinary inquiry.

On a similar line of scientific critique of the ABM approach, Richardson (2002) points out that there are infinitely many ways of representing the same phenomenon (equifinality), and that it is not sufficient validation of a model that an actual phenomenon can be predicted in a computer simulation. Consequently it needs to be recognised that while ABM opens up new possibilities for modelling human interactions, the approach also has limitations. It is important to realise that without backing up this tool with rigorous processes, facts and data, it provides little more than a computer game. Validation of computer simulation models has proven to be a difficult task, but one alternative approach is being done as part of the Companion Modelling framework (Barreteau *et al.* 2003) where the validation is through an evaluation with actual stakeholders, supporting and generating a socially accepted model of reality. Naturally, this type of validation is limited to situations where the stakeholders are available for discussion and evaluation.

Technically, ABM is based on a foundation of object-oriented programming which is usually, but not always, embedded into an Integrated Development Environment (IDE) or a development platform (Rixon *et al.* 2005). The conceptual representation of a system is referred to as a Multi Agent System (MAS) and the simulation instance is referred to as an Agent Based Model (ABM) and Perez and Batten provide a definition of the components of a MAS:

- An environment (E), often possessing explicit metrics;
- A set of passive objects (O), eventually created, destroyed or modified by the agents;
- A set of active agents (A), Agents are autonomous and active objects of the system;
- A set of relationships (R), linking objects and/or agents together; and
- A set of operators (Op), allowing agents to perceive, create, use or modify objects (2006: 27-28)

The structure of these components, and their place within the MAS, is set up in the modelling design process, where the design output is a conceptual model described using Unified Modelling Diagrams (UML) (Bousquet 2004), which has the following components:

The class diagram describes the entities of the modelled system (classes) with their internal characteristics (attributes and methods) and external links with other classes. It corresponds to the casting of the model. The sequence diagram describes the successive actions conducted independently by different classes or interactions between several classes. It corresponds to the storyboard of the model. The activity diagram describes the intimate actions embedded into a given method. The exhaustive list of all the activity diagrams corresponds to the script of the model (Perez *et al.* 2006: 206).

Figure 3-2 shows a UML class diagram from the model by Ducrot and colleagues (2004) which focuses on the management of the peri-urban interface between land use and water resources in a case study in Sao Paolo, Brazil. The grey boxes show classes (i.e. objects), and their attributes, within the software system, and arrows show the relationship between classes. For example, each plot belongs to an Object Location, and consequently there is an arrow from the Plot class to the ObjectLocation class. Similarly, an ObjectLocation is a special case of a Spatial Entity and consequently, there is a different type of arrow showing this relationship.

In terms of the design of an ABM, Hare and Deadman (2004) have reviewed eleven case studies in Environmental Modelling contexts and have identified key design features and set up a taxonomy of Agent Based Models with the key features being described below.

The first issue relates to how social and environmental models are coupled. In other words, this relates to whether a particular model has a spatially explicit or spatially non-explicit representation. If spatial features are not important for the problem, then a spatially non-explicit model, as exemplified by the model by Janssen and Carpenter (1999) and the SHADOC model by Barreteau and Bousquet (2000) is used. If the spatial environment is important, then a spatially explicit model is used, such as the CATCHSCAPE model by Becu and colleagues (2002).

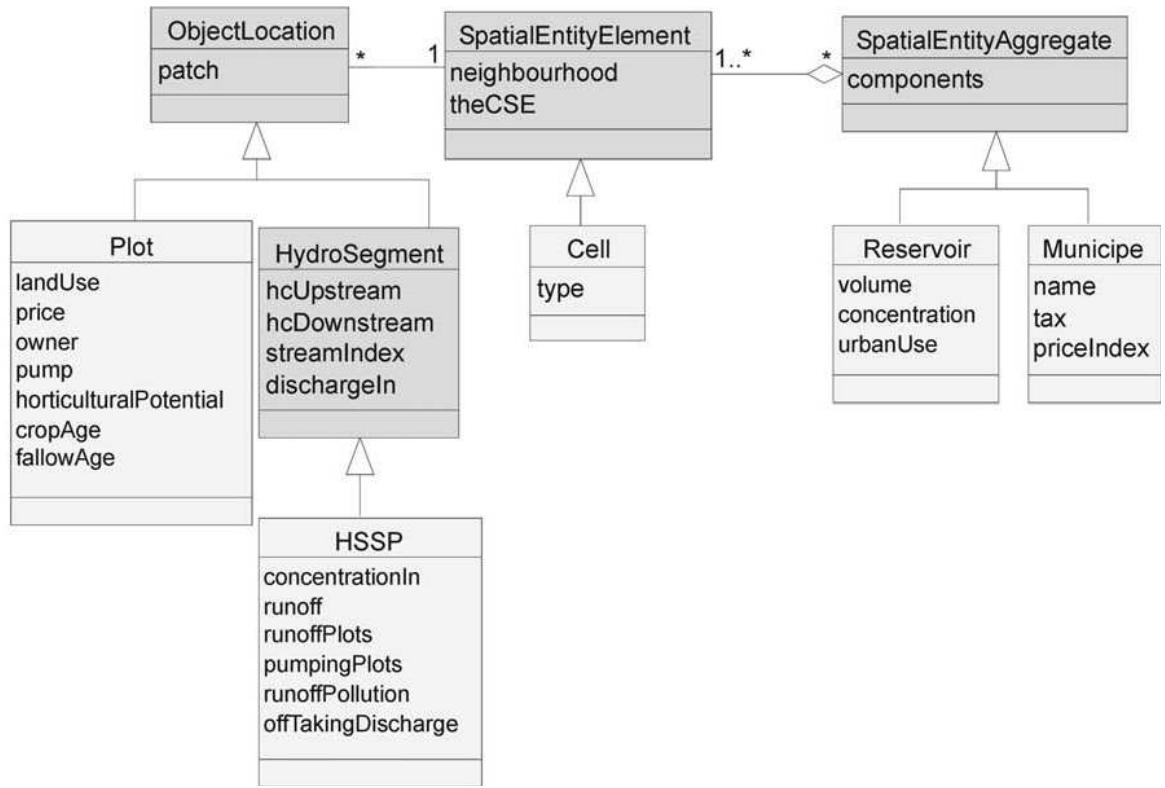


Figure 3-2: Example UML Class Diagram

Source: Ducrot and colleagues (2004)

Similarly, Figure 3-3 shows a UML sequence diagram, showing the sequence of events in the model, and how the model steps through a number of activities carried out by the various classes.

The second issue relates to how decisions are made at the micro-level by agents and this is related to what was described in the section on knowledge engineering. The types of models range from the use of the rational actor assumption where an agent maximises a utility function as per the classical homo economicus definition of classical economics which has been heavily criticised by Gintis (2000) among others; to the use of cognitive models such as Consumat (Jager *et al.* 1999; Janssen and Jager 1999) or Belief-Desire-Intention (Brazier *et al.* 2002) capturing concepts mainly from sociology and psychology; to the use of sophisticated knowledge based rule inference such as applied in the SHADOC model (Barreteau and

Bousquet 2000) or the ATOLLSCAPE model (Dray *et al.* 2006a, 2006b). Lansing and Kremerin (1994) describe perhaps another type of micro-decision making model based on simple single behaviour agents using imitation based on social interaction as the driving force for adaptation and change.

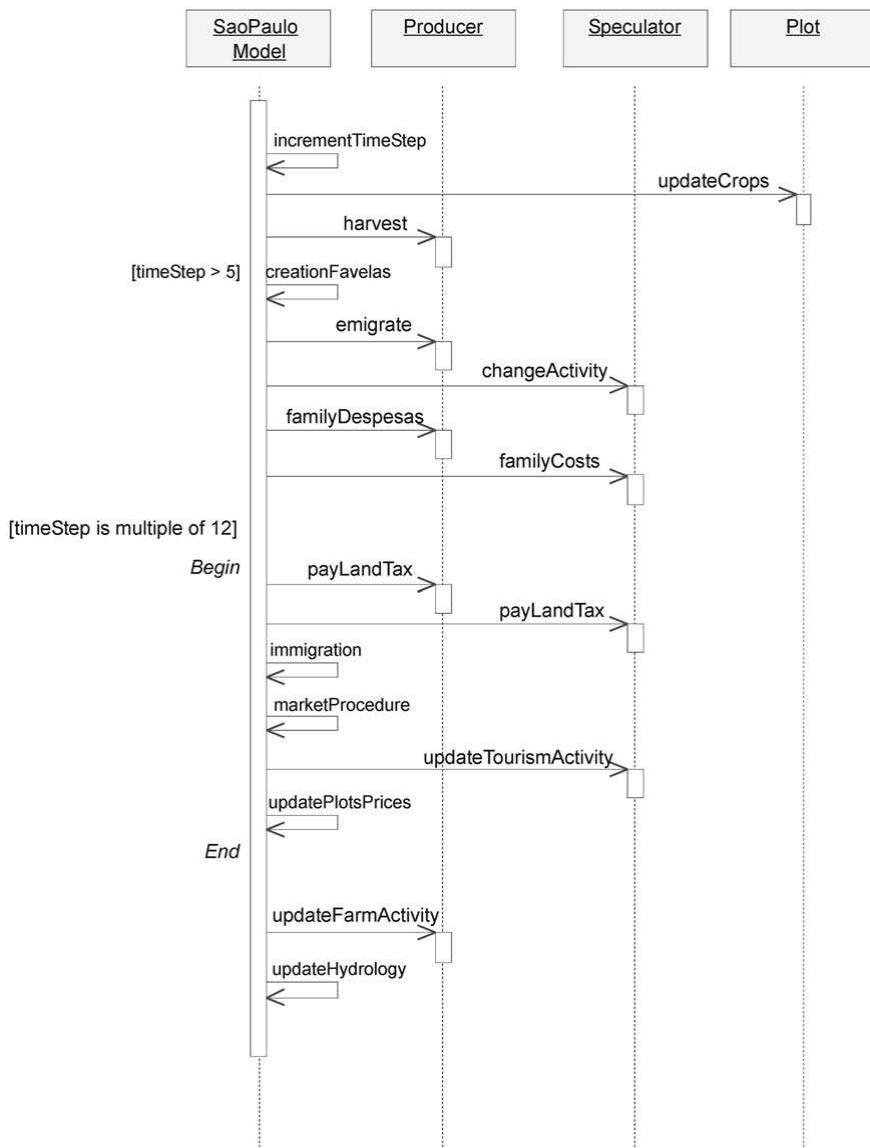


Figure 3-3: Example UML Sequence diagram

Source: Ducrot and colleagues (2004)

Thirdly, another important aspect of the design of an ABM is the level of social interaction between agents, ranging from no direct social interaction but interaction via the environment, as in the CATCHSCAPE model by Becu and colleagues (2002); to social adaptation through imitation (Lansing and Kremerin 1994); and to networks of communicating agents such as in the SHADOC model by Barreteau and Bousquet (2000).

Fourthly, Hare and Deadman (2004) also categorise ABMs on the basis of the mechanisms for adaptation; i.e. how do agents respond to policy, social interaction and environmental changes etc. The main difference appears to be whether the changes in decision making is via changing of internal attributes and parameter values, as described by Perez and colleagues (2002); or whether there are multiple strategies available from which the agent chooses such as in the Lake model by Janssen and Carpenter (1999). This appears to be strongly linked to the type of micro-level decision making as described above.

Another key issue for ABM is that of validation. The logic of simulation as a method is somehow different to that of for instance statistical modelling (Gilbert and Troitzsch 1999). For validation, both methods compare outputs of the method with observed data in order to evaluate similarity (Gilbert and Troitzsch 1999). However, due to non-linearity and unclear causality in the underlying systems, an infinite number of models are able to reproduce a given set of outputs (the equifinality principle). Consequently, similarity between model output and empirical observations is not sufficient for evaluating whether a model is an appropriate representation of reality or not. This equifinality problem can be avoided as described by Gershenson (2002) via logical arguments to dismiss theories that are incompatible with human knowledge. The problem with this is that the logical tests are based on axioms that can not be tested themselves.

By applying social validation, such as in the Companion Modelling approach, stakeholders can convince themselves that the logic and patterns represented in the model are acceptable approximations of the real system. Social model validation is also important for the developing of a sense of ownership and acceptance among stakeholders. On a final note about Agent Based

Models, it seems that the technology is now moving towards a mature stage as indicated by moves towards a community framework for Agent Based Modelling (Janssen *et al.* 2008) that would incorporate what is needed to make the ABM community more efficient and aligned with other disciplines:

- A unified protocol for describing ABMs,
- An online model archive,
- A shared library of model components,
- Shared test beds for models creating the ability for improved validation and testing,
- Better GIS-ABM integration and
- More formal and standardised training and education in ABM.

3.3.2 Bayesian Networks

Bayesian Networks (BNs) are based on what is called plausible reasoning which is in turn based on probability theory, and in particular the theory of conditional probabilities (Castelletti and Soncini-Sessa 2007a). The term Bayesian in BNs is based on the framework² by Pearl (1988) and refers to Bayes theorem³ for conditional probabilities. Using the description of BNs in these references, the framework for BNs is described below.

BNs can be thought of as a set of correlated variables, represented as nodes, and there are directed arcs between nodes that represent conditional probabilities (i.e. plausibility), as seen in Figure 3-4. No directed cycles are allowed. These nodes and directed arcs form networks classified in network terms as directed acyclic graphs; i.e. graphs where arcs have directions and where there are no cycles. These models support a number of uses, such as for making inferences about dependent variables, i.e. to make probabilistic statements about their likely values. The starting point, i.e. the graph, of a BN is simply an influence diagram showing key variables and influences, as can be identified using various knowledge elicitation techniques. There are different methods to quantify the conditional probabilities within the influence

² For further information about the mathematical framework developed by Pearl (1988) there are very useful textbooks such as the one by Neapolitan (2003).

³ For further information about Bayes theorem see Gut (1995).

diagram and thereby complete the BNs, including maximum likelihood methods and Bayesian adjustment. Various types of input data can be used, including expert judgment, output from simulation models, as well as actual estimated probabilities.

There are two types of inferences made in Bayesian Networks:

Using deductive reasoning allows the analyst to express the likelihood of an output in cases where the input is true, and in cases where the input is false. Using abductive reasoning allows the analyst to express the likelihood of the information in cases where the result would be true, and when the result is false. Deductive reasoning is most commonly used when the input is considered to be a driver or influence with respect to the result. Abductive reasoning is most commonly used when the input is an indicator or symptom of the result (Pope 2008: 2).

Boulanger and Brechet (2005) have identified Bayesian Networks (BNs) as particularly useful for understanding risk and uncertainties in planning and policy analysis in general. Similarly, BNs have been identified as particularly suitable for integrated assessments and modelling in the area of water resource planning and management, when dealing with high levels of uncertainty and complex relationships (Jakeman *et al.* 2007). In fact, Bayesian models have been used in many different water related contexts, as is clear from a relatively recent special issue of *Ecology and Society* (Volume 22, Issue 8) on BNs in water resource modelling and management. In most of the applications described in this special issue, BNs have been used to model the whole water system, but occasionally BNs have been used to model only a particular component (Castelletti and Soncini-Sessa 2007c). Bromley and colleagues (2005), Cain and colleagues (2003) and Ticehurst and colleagues (2007) have also shown through case study applications how BNs are useful for considering multiple dimensions in assessments such as environmental, technical, social and financial aspects. BNs are also useful for visualizing the outputs of more complex models (Castelletti and Soncini-Sessa 2007c) such as Agent Based or Hydrological models. Additionally, BNs are also useful for aiding decision making when they are used as Decision Support Systems (Castelletti and Soncini-Sessa 2007c). Cain and

colleagues (2003) describe how this was done in a case study in Sri Lanka where agricultural policy makers co-designed and used the model to identify problems and potential solutions for a river basin. In a similar case study in Denmark, BNs were used in an adaptive management framework of groundwater with full stakeholder involvement (Henriksen *et al.* 2007).

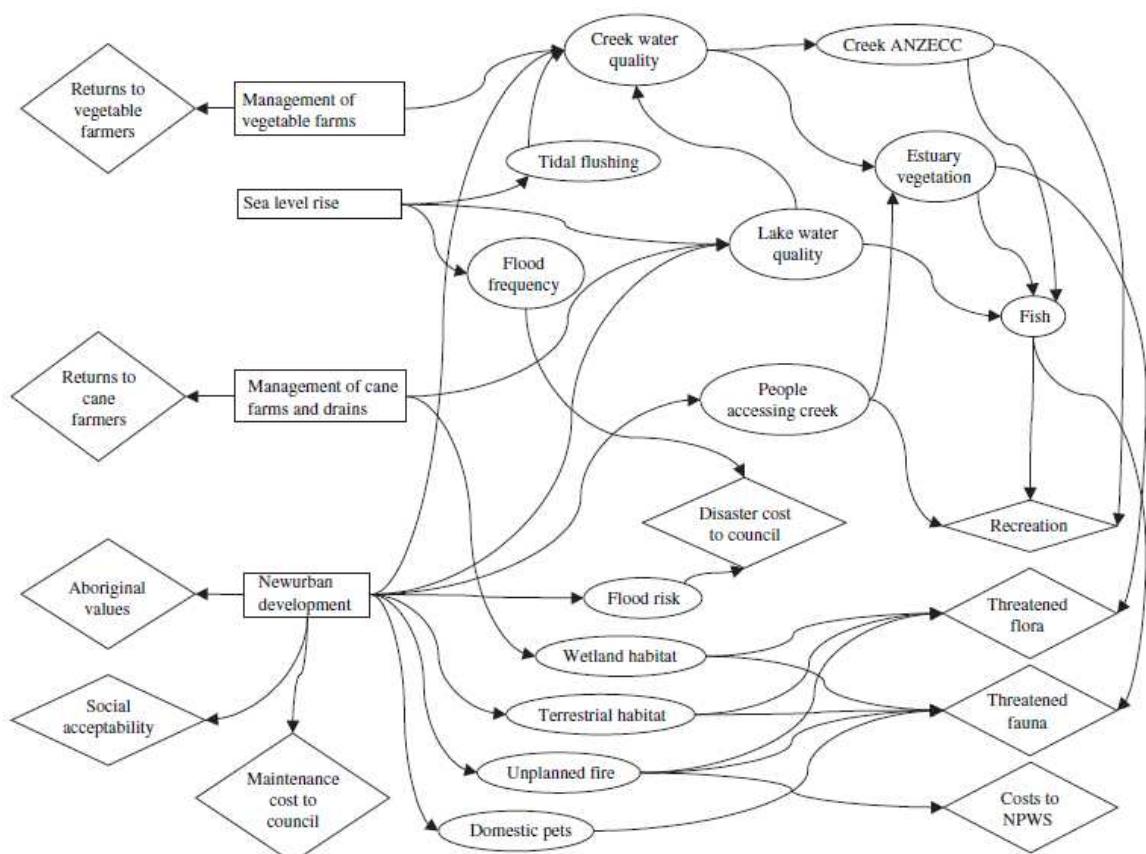


Figure 3-4: Example BN influence diagram

Source: Ticehurst *et al.* 2007: 1131.

Table 3-4: Examples of applications of BNs in urban water contexts

Description of application of BNs in urban water contexts	Reference
Combining expert knowledge and physical knowledge for evaluating the system risk of pipe bursts.	Babovic <i>et al.</i> 2002
Examining the link between land use and stormwater quality.	Ha and Stenström 2003
Simulating integrated urban drainage systems to evaluate measures to improve water quality in receiving waters.	Achleitner <i>et al.</i> 2007
Using BNs in a decision support methodology in order to optimise the number and placement of sensors for monitoring industrial waste water.	Dupuit <i>et al.</i> 2007

Table 3-5: Examples of BNs in general water related contexts

Description of application of BNs in other water related contexts	Reference
Assessing the impact of climate change on surface waters in Finland	Varis and Kuikka, 1997
Within integrated water resource management, using BNs to facilitate the consideration of economic, social and political impacts; and the active participation of stakeholders in the decision making process.	Bromley <i>et al.</i> 2005
Sustainable planning of the management of an aquifer in Spain	de Santa Olalla <i>et al.</i> 2007
Institutional analysis of interactions, actors and rules in water management in an Indian village	Saravanan, 2008
Ecological risk assessment in a catchment	Pollino <i>et al.</i> 2007
Assessing the sustainability of lakes in Australia; with a case study of Lake Cudgen	Ticehurst <i>et al.</i> 2007

Examples of applications of BNs in the urban water context are shown in Table 3-4; but BNs have also been applied in other water-related contexts, as described in Table 3-5.

The benefits of the BNs are many, as described by Uusitalo (2007) they:

- Are suitable for small and incomplete data sets and BNs have demonstrated good prediction accuracy despite small sample sizes
- Support ‘structural learning’, i.e. methods for improving the structure of the BN using computational methods
- Allow for combining different sources of knowledge and data, including expert knowledge and narrative information

- Can provide fast responses to queries once models have been set up.

On the other hand, the disadvantages described by Uusitalo (2007) are that:

- They often require discretisation of continuous variables, which is not straightforward and a potential source of errors
- It is often difficult to convert information from stakeholders and experts to a form that is suitable for BNs
- They do not support feedback loops because they are acyclic, and are hence often unlikely to accurately model the long term dynamic system behaviour.

Several of these points have related to the type of input data that is possible, giving a mixed picture. However, Bromley and colleagues (2005) considered BN as very flexible in its input requirements reporting to have been able to use all data that is available. However Varis and Kuikka (1999), who have considerable experience with BNs (Varis *et al.* 1990, 1994; Varis 1995, 1997; Varis and Kuikka 1997; Varis and Somlyody 1997), point out that while the methodology is very useful and promising, application in real cases is complicated and often long-winded as the model needs to be comprehended and accepted by many stakeholders who are typically unfamiliar with the approach. Varis and Kuikka (1999) have reported that the attitudes towards BNs vary considerably. In their experience while university students and Finnish national institutes have been generally positive to the BN approach, international institutes have been relatively conservative in their attitudes. They further speculate that the attitudes have to do with a combination of the level of methodological risk aversion and the methodological orientation amongst stakeholders.

3.4 Integration frameworks

Concepts and models within Participatory approaches and Complex Systems Science have been described independently above; but this requires the integration of such approaches into a single framework. Integrative frameworks also address criticisms of Complexity Modelling and there is an emerging discipline referred to as Participatory Modelling where models are co-

constructed with stakeholders and ‘*the final product emerges from conflicts, alliances and negotiations*’ (Perez 2006). Here models are not used for normative purposes or prediction but rather for purposes of individual and social learning, providing models as merely a mediating object (Lynam *et al.* 2002).

A number of integrative frameworks already exist as for example with Participatory Integrated Assessments, Multi-Criteria Analysis and Decision Making (MCDM), Structural Equations Modelling (SEM) as well as in Companion Modelling (ComMod). These are described below. Other frameworks such as for example the Triple Bottom Line (TBL) assessment methodology, as used by for example Maheepala and colleagues (2006) is not described in more detail, but is assumed to be sufficiently well-known and straightforward.

3.4.1 Participatory Integrated Assessments

Participatory Integrated Assessments (PIA) are described by Ridder and Pahl-Wostl (2005), including a higher level of participation from a larger number of stakeholder groups, and typically the general public. The reasons for participation are at least twofold; the first being to inform the public and the second being knowledge elicitation to inform assessments; and within local planning and decision making, to better adapt measures to local conditions. While commonly accepted principles do not appear to exist for appropriate participation, Ridder and Pahl-Wostl (2005) list the following as often applicable in PIA:

- The role of stakeholders and/or the public must be clearly defined and communicated;
- Stakeholders or the public involved should have visible direct benefits;
- The process should be transparent;
- Stakeholders involved should be representative;
- Stakeholders should be involved from the beginning of the process;
- Stakeholders should receive an adequate and timely feedback showing the results and how their inputs were used; and
- Participation should lead to learning and capacity enhancement.

It is also noted that PIA has immense ability for incorporating narrative information and multiple perspectives and is consequently preferable in those urban water situations that are categorised by high levels of complexity.

3.4.2 Multi-Criteria Analysis and Decision Making

Ellis and colleagues (2004) have described what is called a Multi-Criteria Decision Making (MCDM) process for assessing urban drainage options. These criteria are described as technical, environmental/ecological, social/community and economic cost factors. Each drainage option was evaluated by assessing its impact on each of the chosen factors, for which performance indicators and benchmarks had been decided upon. Weights were given to each option, and overall scores were then calculated providing a ranked list of options. Whilst the process is flexible and amenable to changing stakeholder interests, it does not take into consideration the diverse preferences of stakeholders in that the decision process is designed and set up by either the modeller or selected stakeholders. MCDM is suitable for assessing trade-offs between different options, albeit not when there are non-linear or dynamic interactions between factors.

When a number of weighted goal functions (such as the above factors) are optimised under constraints (limiting the feasible set of options to those fulfilling certain criteria), this is referred to as Multi Criteria Analysis (MCA), which is related to MCDM. This type of approach has been applied by Jeffrey and colleagues (1999) for selecting a combination of technology and site for urban water recycling systems in the United Kingdom. The four goal functions/attributes included in the analysis were cost, public perception, environmental impact and water savings. The advantage of this type of model is that it can consider complex relationships between factors and find optimal solutions. The disadvantage is that this type of mathematical formulation requires both modelling skills as well as data as input and that it is difficult for users and decision makers to understand the process, and hence gain confidence in the outputs. As for MCDM, the goal functions are defined by modellers or selected stakeholders and typically do not consider diverse stakeholder preferences.

Outside of the urban water context, Messner and colleagues (2006) have used what they call an Integrated Participatory Multi-Criteria Decision Support Approach (IMA), which is a hybrid between MCA, Benefit-Cost Analysis (BCA) and participatory methods. They have used this approach to resolve water allocation issues in the Spree River Basin in Germany. Here, the process starts with participatory assessment of the particular conflict situation and the institutional arrangements (both formal and informal). Following this, the stakeholders are identified and interviewed. The stakeholders in turn identify what is referred to as scenarios, which comprise a policy strategy and a framework of development. Following this, stakeholders are asked to identify indicators and criteria by which to measure the success of scenarios. At this stage, uncertainty is brought in and experts are asked to quantify likely success and uncertainty providing probabilities of results and possible ranges. From here on, MCA is used to provide information back to stakeholders, who in turn deliberate about which decision to make. Messner and colleagues (2006) report after applying this method to the Spree River Basin that:

- The method has deficiencies from a participatory point of view as:
 - It does not involve all relevant stakeholders and;
 - It dictates the method of discourse between stakeholders; however
- In terms of decision making competence it significantly increases the knowledge base on which decisions are made by inclusion of a range of information types; and
- In terms of fairness, it is a significant improvement in comparison with the MCA in the way that it includes views and interests of many stakeholders early on in the decision process;
- It is very expensive, where the estimated cost of the case study was approximately one million Euro; but potential welfare gains of a superior decision have been estimated in the range of 10-40 million Euro.

However, a similar approach albeit more structured, was applied by Marttunen and Hämäläinen (1995) for the evaluation of water development projects in northern Finland. Here, the scenarios were already defined as the development projects and the data on these projects were collected

using computer-aided interviews where interviewees (who had previously been invited to and attended a seminar) were helped to fill in a preliminary value hierarchy. Based on the information generated in the interviews, the MCA problem could be populated and the decision problem could be formalised. While this method also does not involve all stakeholders, and dictates a given discourse, the method is not at all as expensive. Also, the structured type of interview provides clear output data and stakeholders found that the structure improved communication and clarity. Participants also viewed the process as a learning process widening their perspectives, but also highlighting how differences of opinion have originated. This approach shows clear promise and is at least suitable when clear options are available and need to be evaluated.

3.4.3 Structural equations modelling

Structural Equations Modeling (SEM) is a statistical approach for identifying and estimating relationships based on a combination of quantitative/statistical data and qualitative assumptions. Syme and colleagues (2001, 2004) as well as Nancarrow and colleagues (2002) have used this approach, a technique that is commonly used in psychology and social sciences; and they have used it for exploring attitudes towards water conservation in Australian urban settings. The steps in the approach that have been applied are

- Sampling, i.e. selecting which households to interview;
- Questionnaire contents, i.e. deciding which attitudinal and lifestyle variables to include in the questionnaire, and then undertaking interviews;
- Measuring external water use for each house; and
- Developing the SEM model using the predictor variables based on the surveys, and dependent variable based on measured external water use, (adapted from Syme *et al.* 2004: 123-124).

In other words, it is not an integrative assessment methodology, but models a component of the water system. Also, this type of model is designed for prediction and is based on statistical

inference. It can take as input, correlated data from household surveys concerning attitudes and lifestyle as well as demographic factors about the surveyed population. This type of model can combine quantitative and qualitative information used to explore issues of psychology and attitudes, which can be embedded into, for example, water use prediction modelling. A first limitation of the model is that the results are specific to the surveyed population, and hence it requires representative samples in order to be generalised. A second limitation is that the identified relationships are valid at the particular time when the model was developed, i.e. it represents a static situation and may not be valid into the future. A third limitation is that it relies on linear relationships between multiple variables and is not suitable for a high level of complexity. In particular, the methodology is sensitive to high correlation between variables (Syme *et al.* 2004) and the model properties are questionable if the model is complicated (Syme *et al.* 2004).

3.4.4 Companion modelling

As mentioned, Participatory modelling combines complex systems modelling approaches with participatory methods to understand complex environments; as well as provides observation via knowledge elicitation and utilises models to support social learning. Participatory modelling has its roots in Action Research. One style of participatory modelling, Companion Modelling (ComMod) may serve as a typical example. Its posture as written by its founders is:

Based on a cycling approach, in interaction with field processes, including discussion of assumptions and feedbacks on the field process (Barreteau *et al.* 2003: 1).

With the ongoing conversation between model and field circumstances it is an adaptive approach which increases the chances of legitimacy and supports double loop learning (see section 3.5.2) by constantly challenging assumptions and beliefs (Barreteau *et al.* 2003). ComMod also attempts to make more explicit the various views and assumptions that exist among stakeholders. This provides an environment more suitable for collective decision making (Barreteau *et al.* 2003).

The cyclical process used in ComMod is described in Figure 3-5. Using knowledge engineering techniques, as is perhaps best described by Dray and colleagues (2006b), narrative information from typically semi-structured interviews are translated into associative networks (i.e. representations of mental models, as described in section 3.2.3.1), which in turn are translated into Unified Modelling Language (UML) diagrams (see section 3.3.1). These UML diagrams can be described as a design diagram for an Object Oriented computer software system. Therefore, these UML diagrams can then be translated into ABM and used to develop and run ABS (see section 3.3.1). To reach this point one would typically use an integrated modelling environment. For this purpose, the ComMod community has relied on the Cormas platform (Bousquet *et al.* 1998; CIRAD 2004).

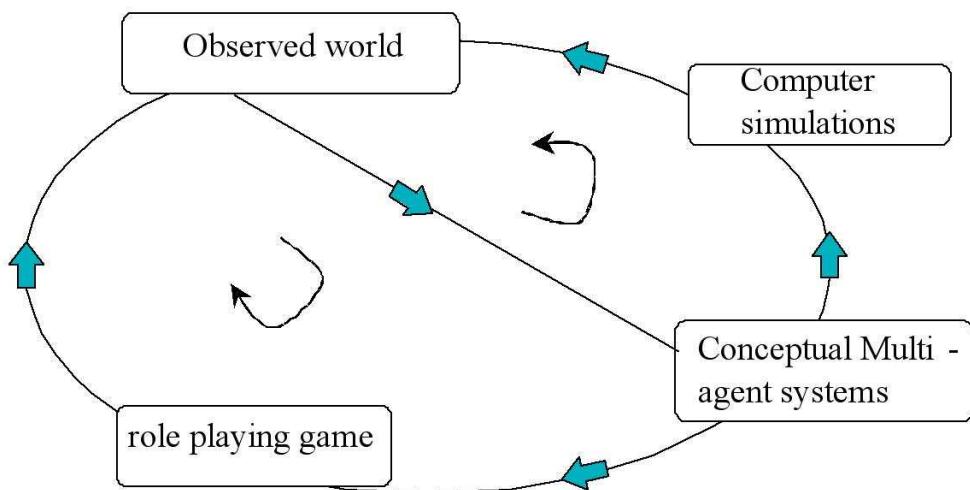


Figure 3-5: Typical cyclic framework in a ComMod application

Source: Perez 2006

The UML diagrams in fact serve an important purpose as they are used as mediating objects in model design as well as providing a link to knowledge engineering and knowledge elicitation. UML diagrams can also be used in semi-structured interviews, as well as in social evaluation as it helps to improve the transparency of the modelling process via critical review by stakeholders.

The vast majority of ComMod applications are based on ABM (Bousquet *et al.* 1999, 2001; Bousquet 2004; Barreteau 2003b; Barreteau *et al.* 2004; Barreteau and Bousquet 2000; D'Aquino *et al.* 2001, 2002, 2003; Becu *et al.* 2002; Perez *et al.* 2002, 2003, 2004, 2006a; Dray *et al.* 2006a, 2006b, 2007). Occasionally Geographical Information System (GIS) have been used in the process (D'Aquino *et al.* 2003); and role playing games are also a common feature (Barreteau *et al.* 2003; D'Aquino *et al.* 2003; Dray *et al.* 2006b).

In these contexts Role Playing Games are typically used within ComMod for educational purposes to model complex systems but also to support social learning (Barreteau 2003). Barreteau has provided a more thorough review of the joint use of games and models and argues:

In-between games and theatre, Role Playing Games are group settings that determine the roles or behavioural patterns of players as well as an imaginary context. A Role Playing Game is the performance of a roughly defined situation that involves people with given roles (Barreteau 2003: 21).

Role Playing Games are sometimes described as a type of social laboratory where participants can explore roles that otherwise would be risky (Barreteau 2003), and which can generate an open debate where participants feel comfortable raising differing viewpoints. A Role Playing Game also seems to be playful enough in order to maintain the interest of participants (Dray *et al.* 2006a) but this may depend on the personalities of the participants. A Role Playing Game can also provide information about strategic behaviour which occurs in reality but that is hidden; but to identify this type of behaviour, researchers typically need to review recordings of the game (Dray *et al.* 2006a). The Role Playing Game can also have the purpose of knowledge elicitation, identifying behaviour and decision making processes, as well as for social validation of used behavioural models (Barreteau 2003b).

ComMod has many useful features, such as Role Playing Games and the use of models to facilitate social learning, and the cyclic field based learning process which provides a good level of grounding in the research process. However, the types of contexts that this modelling process

has been applied to are widely different to the context of this study. Its direct usefulness would hence be unclear, but for the purpose of this doctoral study, the spirit and selected tools of ComMod are likely to be useful.

3.5 Consideration of stakeholders

In the introduction of this chapter, it is argued that there is a need for a post-normal approach to science in this study, as well as the need for incorporating mechanisms for social learning. This is particularly important in terms of the formulation of a management framework, but also for generating understanding about a system which is assumed to be in the complex and unordered domain as described by Kurtz and Snowden (2003).

3.5.1 Post-Normal Concepts

A common theme in the area of participatory methods is the idea of post-normal science (Barreteau *et al.* 2003; Bammer 2005; Perez 2006) that in turn make references to the literature by its founders Funtowicz and Ravetz (Funtowicz and Ravetz 1993, 1994; Ravetz 1997, 2004; Funtowicz *et al.* 2000) necessary. A key idea in post-normal science is that researchers bring their values, norms, culture and beliefs into the research process and that as such this introduces bias and subjectivity. Because of this bias, researchers can be questioned about their commonly perceived role as independent observers and knowledge creators. Hence, Funtowicz and Ravetz (1993) argue that there is a need to apply Post-normal ideas about science where both stakes and uncertainties are high, as exemplified by climate change, where they say that traditional science is ineffective. This is because in such issues, the peer review process needs to be undertaken by all those with a stake in the issue in a more public debate. In short, for these kinds of issues they argue for a different way that science and so called rational disciplines feeds into policy making and decision making allowing multiple plausible hypotheses. There is also a greater focus on exploration using questions such as ‘What if?’ rather than ‘How?’, ‘What?’ or ‘Why?’ in a way that lends itself more to public participation (Ravetz 1997). Within this type of thinking, the precautionary principle is important:

By contrast, the ‘post-normal’ approach embodies the precautionary principle. It depends on public debate, and involves an essential role for the ‘extended peer community’. It is based on the recent recognition of the influence of values on all research, even including the basic statistical tests of significance. It is the appropriate methodology when either systems uncertainties or decision stakes are high; under those conditions the puzzle-solving approach of ‘normal science’ is obsolete. This is a drastic cultural change for science, which many scientists will [find] difficult to accept. But there is no turning back; we can understand post-normal science as the extension of democracy appropriate to the conditions of our age (Ravetz 2004: 347).

A key theme in participatory methods is that of social learning, also described as learning in a social environment. As Pahl-Wostl and Hare (2004) identifies, social learning precedes collective decision making, and because collective decision making has been identified in the previous chapter as a key criteria for efficient urban water management, it follows that social learning is also of critical importance. Indicating the importance of the topic, social learning has recently been the subject of a special issue in the prominent journal *Ecology and Society* (Volume 12 Issue 1, 2007). There has also been considerable effort in the area of social learning in water management in the *HarmoniCOP* (Harmonizing Collaborative Planning) project; funded by the European Commission (HarmoniCOP 2005) to feed into the EU’s Water Framework Directive (HarmoniCOP 2005).

3.5.2 Social Learning Concepts

The theory of *Social learning* goes back to ideas about social cognition (Bandura 1977; 1986), where learning is a process of observation, interaction and imitation within a social environment. It has also been pointed out that within Natural Resource Management the term social learning is now more widely used to describe a number of learning styles, and in particular the original concept does not include the development of shared meanings and values that provide a basis for joint action (Pahl-Wostl *et al.* 2007). It is also argued that within Natural Resource Management (closely related to urban water management), both the governance structure and the natural environment is linked to processes of multi-party cooperation and

social learning (Pahl-Wostl *et al.* 2007). Alexander (2008) reinforces this, finding that social learning in this context often refers to multi-party problem-solving involving different agencies and diverse knowledge sources. In terms of the theory of social learning by Bandura (1977, 1986) there are four key elements:

- Reciprocal determinism: the reciprocal influences between an individual's social environment and his/her personality, cognitive skills and attitudes;
- Observational learning: the learning that happens through observing (i.e. paying attention to an incident), retaining information (i.e. having a mental representation of the incident), reproducing the incident (i.e. imitating the observed behaviour in a similar circumstance) and having the motivation (i.e. evaluating the benefits of a particular behaviour);
- Self-regulation: self-evaluations which informs the choice of behaviour; i.e. in a simple and narrow sense, evaluating (partly on the basis of self-efficacy) whether he/she can carry out, or will further develop from a particular behaviour in a particular context; and
- Self-efficacy: the individual's belief in his/her capability of carrying out a particular behaviour and achieving the goals and managing the situation. Alexander (2008) argues that 'Individuals with high levels of self-efficacy are likely to be more motivated to pursue learning based goals as they are more confident they will achieve their goals'.

A key addition to the theory of social learning has been contributed by Argyris and Schön and Argyris and colleagues (Argyris *et al.* 1985; Argyris and Schön 1996) with the introduction of the concepts of single and double loop learning, as described in the simplified Figure 3-6. These types of learning occur within individuals but also within an organisation or an institution; and the governing variables in Figure 3-6 refer to those key variables that are the foundation of the action strategies, such as beliefs, values and assumptions. The governing variables are critical for how action strategies are formulated. The action strategies are developed to achieve a certain set of consequences, and in the single loop learning the action strategies are adjusted on the basis of fine-tuning, skills development and trial and error to reach the best consequences. In the

more fundamentally adaptive double loop learning, the governing variables are questioned often leading to completely new action strategies to be explored and evaluated.

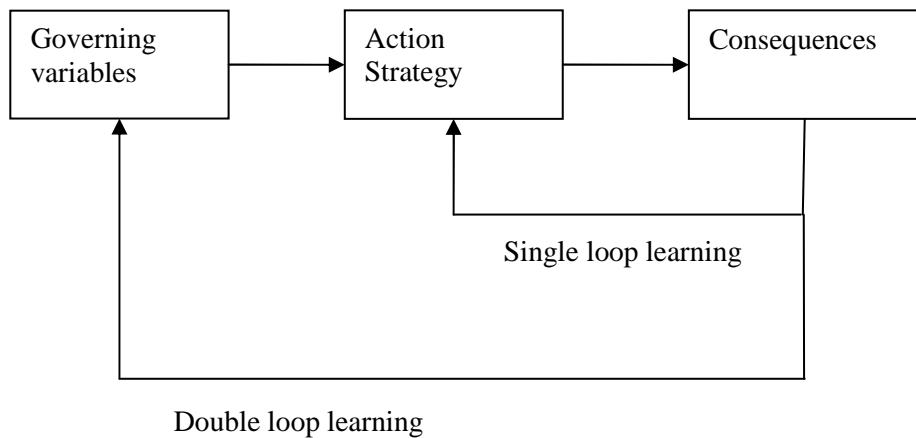


Figure 3-6: Single- and double-loop learning cycles

Source: Adapted from Argyris *et al.* 1985

While the double learning is critical in particular in situations of high stakes and high uncertainty, it is noted that the underlying theory of social learning which is based on years of research argues that the cognitive processes of individuals in organisations often actually inhibit effective exchange of relevant information that is required for double loop learning, causing a dilemma (Edmondson and Moingeon 1999).

Also, cultural factors have been shown to be important in determining the type of participatory processes that are adopted, based on a mostly qualitative synthesis and comparison of ten case studies of public participation in water management in Europe (Enserink *et al.* 2007). The identified factors are power distance (indicating essentially equality), strength of individualism, masculinity (indicating the degree to which masculine ideals of control, achievement and power are linked with perceived success), uncertainty avoidance (the level of tolerance of ambiguity

and uncertainty) and long-term orientation (the degree to which the society embraces forward thinking values). Based on these factors they propose the following hypotheses:

- A high power distance index is not conducive to public participation;
- Individualism is not a determining factor for the extent and success of public participation in a country;
- Collectivism facilitates a high degree of public participation, but this may be left to informal processes if the power distance is high; and
- A high masculinity score is not conducive to public participation. (Enserink *et al.* 2007: 8)

Similarly, Tippett and colleagues (2005) have explored social learning in the same ten case studies in Europe where the context is river basin management, and have identified factors supporting and barriers hindering social learning (probably correlated with the cultural factors identified by Enserink *et al.* 2007). Factors supporting social learning in river basin management, based on the ten case studies are (adapted from Tippett *et al.* 2005):

- Providing sufficient time to participate
- Ensuring early involvement of stakeholders
- Ongoing attention to the structures and processes of multi-stakeholder interaction; including commonly accepted ground rules, transparent communication and recording of inputs from participants
- The use of a variety of meeting types and communication tools, with an attempt to find different ways to represent technical information, makes the process more accessible to a wide range of stakeholders. (adapted from Tippett *et al.* 2005: 296)

Barriers hindering social learning in river basin management, based on the ten case studies are:

- Insufficient provision of time and resources are major barriers to social learning and often due to tight deadlines and ambitious goals.
- Failure to ensure adequate representation of stakeholders, or being unable to attract a sufficiently broad range of stakeholders and key players, can lead to decisions being seen

as lacking legitimacy. It may also lead to a lack of cooperation in implementation by those who were ‘excluded’ from the process.

- Financial, technical and resource constraints can have a negative impact on the ability of stakeholders to remain involved in the process.
- It can be difficult to maintain interest over the long timescales required to develop social learning and long-term plans.
- Lack of both trust and appreciation of the different ways that stakeholders can contribute to the success. Lack of clarity about roles, responsibilities and decision-making processes can exacerbate distrust and can lead to unmet expectations and frustration.
- Hierarchical decision-making processes can impede interaction and communication between different sectors and levels of scale. A technocratic culture, in which experts are not familiar with talking to different stakeholders in terms that they can relate to, can impede constructive communication with different stakeholders, (*adapted from Tippett et al. 2005: 297*).

Along the same line there are also some words of warning from the authors of HarmoniCOP (2005) saying that before launching into processes of social learning, the following must be accepted about the process: that it is resource intensive and so typically requires both time and money; outcomes are open and can not be predetermined; it requires sharing of responsibilities and so will not be controlled by one or a small number of key stakeholders; and it can not be imposed and while the facilitator of the process can encourage and provide a vision, it is a difficult undertaking for stakeholders to participate and this must be respected.

So what are the processes and activities that can support social learning? One contender is the use of Communities of Practice which is a method defined as groups of people who gather together around something they do and which they are passionate about, and where they meet regularly to learn how to improve what they do (Wenger 1998, 2000). This seems to encapsulate the notion of both social learning as well as single and double loop learning. Other methods and tools described in the HarmoniCOP literature (2003; 2005) for supporting social learning are:

- Geographical Information Systems (GIS), using software mapping tools to identify legitimate stakeholders, manage shared geo-spatial information, communicate geo-spatial information, collect and communicate public knowledge, perceptions and comments, and to bring people together (HarmoniCOP 2005: 45-47).
- Group Model Building, which is a methodology for facilitating the involvement of a group to develop an understanding about a system and its problems and solutions, and translate that into a conceptual model. This can be used to gain knowledge, gain common understanding, and to understand others' perspectives and constraints (HarmoniCOP 2005: 48-49).
- Maps which form a model of reality and a kind of visual language. They can be used to identify spatial phenomena, articulate and specify spatial issues, clarify issues and mechanisms, synthesise arguments and designs, consolidate findings, views, options and decisions, and to provide identify for stakeholders (HarmoniCOP 2005: 50).
- Planning Kits such as for River Basin Management, providing policy makers with tools to explore various policy options and scenarios. It can be used to specify and present measures and interventions, gain system knowledge and to structure decisions and synthesise arguments and designs (HarmoniCOP 2005: 52).
- Role Playing Games help foster communication among a set of stakeholders and make their mental models explicit. It can be used to understand others' viewpoints and constraints, explain one's views, share views on a common system, and support dialogue at a rules level (HarmoniCOP 2005: 54).
- Round Table Conferences which is an open discussion between participants where the goal is to share visions and viewpoints and give stakeholders a voice. It can help reveal and understand the diversity of perceptions amongst stakeholders (HarmoniCOP 2005: 58).
- Web Sites that allow for one-way communication, and allow interactions between stakeholders. It can be used to identify legitimate stakeholders, manage community information capital, to collect and communicate public perceptions and knowledge, and to bring people together (HarmoniCOP 2005: 62).

Many of these tools are in fact Information and Communication Technology (ICT) tools or some type of models which are used to facilitate the process of social learning and this can be referred to as Participatory Modelling which will be further described in a later section. For example, one of the Participatory Modelling frameworks, the *Companion Modelling* process, typically employs Group Model Building for developing Multi Agent Systems (MAS), sometimes incorporating maps or GIS, and usually Role Playing Games within the social learning process (Barreteau *et al.* 2003).

3.6 Review summary

In this chapter the methodological options were reviewed for understanding small town water management situations. Firstly knowledge elicitation techniques have been reviewed that generate individual learning and reliable data. Secondly, modelling approaches have been reviewed that are perceived as suitable for the problem. Subsequently, integration frameworks were reviewed but it was decided that none were perfectly suitable for this study. Principles relating to post-normal science and social learning have also been reviewed as concepts that need to be considered.

Furthermore it is accepted that the topic of study is generally information poor. Therefore, interviews have been explored as a way to generate rich qualitative information, but this information is subjective and of variable quality. Complementing interviews, the Delphi method have been explored as and approach to engage experts in a cross-cutting basis.

In the modelling area, Agent Based Modelling has been found to be more appropriate in comparison to other methods in several aspects relating to complex adaptive systems features, and its ability to support participatory methods. Bayesian network modelling has been found to be appropriate in handling different types of uncertainty and also suitable to support participatory methods.

A number of integration frameworks have been reviewed: Participatory Integrated Assessments, Multi-Criteria Analysis and Decision Making, Structural Equations Modelling and Companion

Modelling. It is noted that only the Companion Modelling approach is flexible enough to be suitable for generating the adequate understanding that is required in this study, but that it is not an appropriate method for the study. Whilst small town water management may be perceived as a resource management problem, this classification does not acknowledge all aspects of the situation. In the next chapter, the methodology for this study is defined.

Chapter 4: Methodology

This chapter provides a justification and description of the methodology that is applied in this study, and describes the underlying assumptions. It also involves the inclusion of a case study, Tarawa in the small Pacific Island Country of Kiribati as well as a description of methods for generating data and information; and methods for modelling the context of small town water governance (in the case study location), using tools from Complex Systems Science. Finally this chapter also provides a description of how all these disparate ideas, tools and approaches fit together within a unified framework.

With the literature reviews in the two previous chapters (chapters 2 and 3), it is now possible to define a research methodology for this study. This methodology is based on a combination of participatory methods and complex systems modelling, in such a way as to support social learning, and in order to identify frameworks that will allow transformation of a small town water sector towards a better and more sustainable state.

From our literature review (chapters 2 and 3) it is concluded that current water management frameworks are rarely adapted to water governance in the small towns of Pacific Island Countries (PICs) as they are often characterised by difficult constraints and barriers, in addition to a range of complex social and institutional interactions, as well as high levels of uncertainty. Based on this characterisation of the situation, it has been identified that there is a need for social learning to allow for institutional and societal transformation and, along the lines of recommendations by Pahl-Wostl (2002a), Barreteau (2003a, 2003b), Perez (2008) and others, the need for participation and modelling within an integrated framework. Whilst existing approaches are promising, such as the Companion Modelling framework, none are perfectly suitable for our particular study. Therefore, concepts from: 1) the *Cynefin* framework for sense making in situations that can be characterised as complex adaptive system, and 2) the theory of Inductive theory building for development of management theory; are used to define the methodology of this study.

Furthermore, due to logistical constraints associated with distances, languages and remarkable cultural diversity among PICs, it is decided to select one case study as epitomizing the current problems observed in a large majority of small towns in the Pacific. As per Gerring (2007), it is also noted that to undertake one case study analysis also implies, some kind of cross-case analysis or at least to think about a broader set of cases.

4.1 Assumptions and requirements

This study aims at two goals: 1) gaining better understanding of the urban water management system in small town water contexts, and 2) developing practical framework and tools for management of such systems. Below is a description of some of the assumptions and requirements that are the foundation of this study.

4.1.1 Complex and adaptive systems

A key perspective of this study comes from the assumption that small town water systems can effectively be perceived and represented as Complex and Adaptive Systems (CAS). In particular it is noted that provision of small town water and sanitation services involves interactions between social, natural and technical systems. It is hence what is often referred to as a socio-technical system.

The science of CAS concerns those systems that are neither chaotic nor ordered, but that tend to exhibit changing and emergent patterns (Holland 1995). A chaotic system is one a dynamical one where initial conditions and small perturbations may shift the system to a new pattern of behaviour; this is the realm of the butterfly effect where system behaviour tend to be of a statistical nature (Batten 2000). An ordered system, or sometimes referred to as a simple system, is more static and forces tend to be known and behaviours tend to be predictable, such as the movements of the planets around the sun; where interactions between components are only weakly interactive (Batten 2000). Emerging patterns are effects where interactions of individual and distributed components, such as atoms in a gas or individuals in a population of animals, will generate surprising and unexpected patterns at a higher scale (Johnson 2001).

Examples of emerging patterns are in the flocking of birds, the collective behaviour of ants, or the emergence of the laws of Newtonian mechanics on the basis of quantum mechanics. Socio-technical systems, such as urban water systems, are typical examples of CAS where agents tend to act in response to their environment, the built and natural environment as well as the institutional, normative and cultural settings, as well as the actions of other agents. Assuming that a socio-technical system can be described as a CAS, it should display most of the following features (Holland 1995; Richardson 2002; Perez and Batten 2006; Miller and Page 2007):

- Elements of surprise due to the unpredictable nature of the system;
- Emergence of macro-scale properties from micro-scale interactions;
- Irreducibility, or the fact that the system can not be understood by its parts alone but that the system needs to be viewed in its entirety;
- Self-organisation, or the emergence of order/complexity without inputs from the outside;
- Feedbacks and thresholds; or non-state equilibriums that change over time and which generate dynamic processes with stable and unstable regions.

In this thesis, there is a strong influence from the ideas of Kurtz and Snowden (2003) who argue that for these systems one need to relax three basic assumptions that are pervasive in the scientific study of decision making:

1. The assumption of order – that there are underlying relationships between cause and effect in human interactions and markets;
2. The assumption of rational choice – that humans make decisions based on maximising benefit or minimising pain; and
3. The assumption of intentional capability – the idea that each action is intentional and carried out to achieve a particular goal.

Hence, it is assumed that the studied system is in the un-ordered domain of complex relationships; as per the description in the Cynefin framework by Kurtz and Snowden (2003).

This system domain has been described by Kurtz and Snowden (2003) and they have formulated the Cynefin framework with the following generic principles for sense-making and management:

- Analysis of history as a way to understand systemic properties, but this is insufficient in itself as a complex system is evolutionary and dynamic;
- Use of narrative techniques, as these are able to capture and convey complexities without necessarily being bound by formalism and simplifying assumptions;
- Use of multiple perspectives on the nature of the system, because no single perspective is sufficient to fully understand it;
- Exploratory analysis in order to temporarily move to a situation where cause and effect relationships are discoverable;
- Use of an adaptive approach, where interventions are designed as probes, and analysed in retrospect in order to understand how to promote desirable patterns of behaviour.

In this thesis, there is the intent to use the Cynefin framework as a methodological template against which different research activities are mapped. This is because the Cynefin framework has the potential to provide a meta-level instruction for understanding and managing what are perceived as complex and adaptive systems. Furthermore, as per the theory of Complex Adaptive Systems, *the assumption is adopted that models of such systems tend to be unpredictable circular, subjective and paradoxical, and therefore difficult to validate. A post-normal approach to science, where participants provide the role held by peer-reviewers, is therefore warranted.*

4.1.2 Case study based learning process

As mentioned, an implication of viewing small town water systems as examples of CAS is that validation of models and theories is problematic. A type of validation can be achieved by allowing experts and stakeholders to inductively assess models, as part of the learning process, see Figure 4-1; and this is also in line with Inductive Theory Building. This cyclical learning process is similar to that used by the Companion Modelling practitioners where the process is facilitated by models within a field setting (Barreteau *et al.* 2003a). Hence, the researchers have the role of providing synthesis, whilst contradictions are provided by observations or meetings with field realities; typically offered by stakeholders and experts.

This case-based study is grounded into field reality, generating a rich body of qualitative and quantitative information. It also allows experts and stakeholders to inductively assess models and theories in use and to gradually make sense of specific and detailed aspects of the system, beyond mere generic concerns. Specifically, as per Gerring (2007) even single case studies can help support a (deductive or inductive) logical argument, in a similar way to controlled experiments, and those arguments may have broader significance to a bigger set of cases.

Similarly, it is also acknowledged that there is a need for participation in water management, but it is also argued that participation in the target context is currently problematic. Similarly, it is agreed that there is a need for social learning to be incorporated, but again it can be argued that this is currently problematic in the target context due to a messy socio-political reality.

Assumption

It is agreed and assumed that there is a need for social learning and participation in urban water management. However, it is furthermore agreed and assumed that the implementation of social learning principles and participation is often problematic in the target context; and therefore caution needs to be exercised.

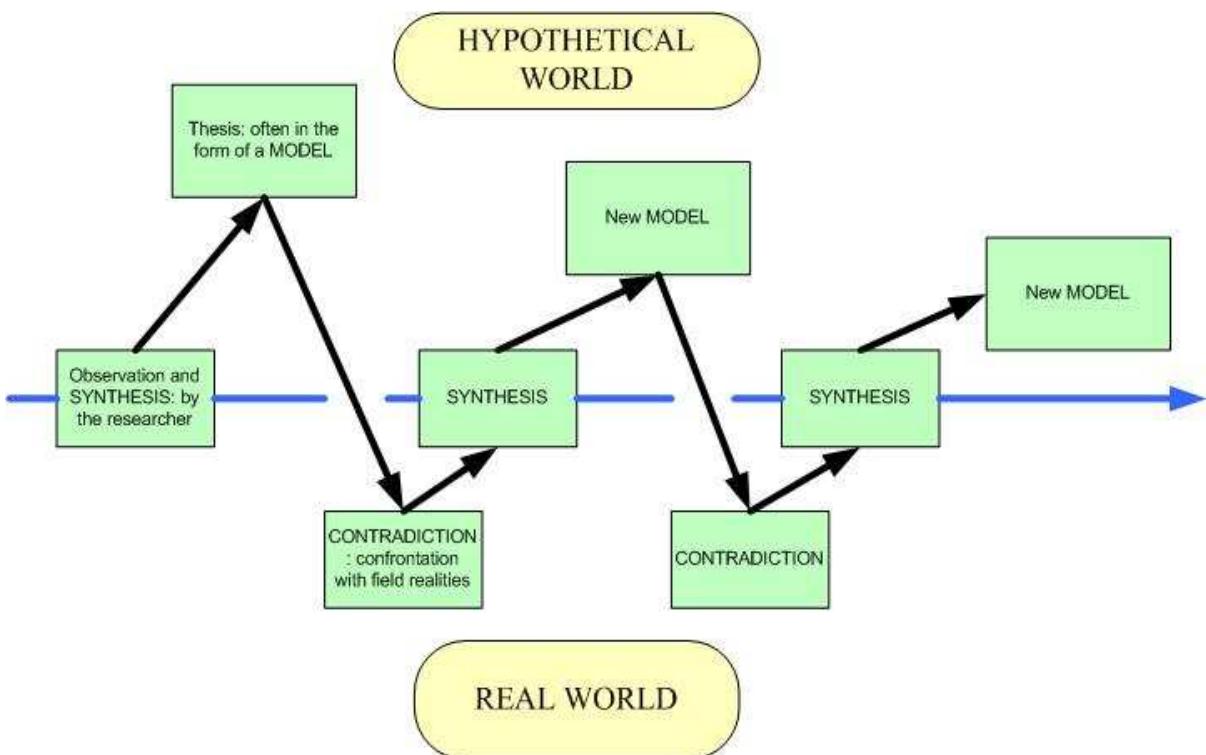


Figure 4-1: Dialectic progression of thesis, contradiction and synthesis

4.1.3 Developing management frameworks

This thesis addresses the problems of towns in Pacific Island Countries and the aim is to provide a causal explanation of difficulties in these locations with the subsequent aim to formulate managers and policy-makers with recommendations that recognize local constraints and opportunities to best practice management which aim to promote participation, encourage flexible realizations and rely upon financial prudence. A key recommendation that the thesis aims to deliver is the development a framework that bridges theory and practice in the target location, as a special case of urban water management in PICs.

Developing a framework is equivalent to governance frameworks, and this is not a traditional scientific task but is somewhat equivalent to building management theory. For example, this type of task is not an exercise that involves hypothesis testing and rigorous experiments, but one which requires synthesis and integration of a wide range of information and knowledge (Locke 2007). It is argued that for these tasks, at the theory building stage, deductive methods are premature and tend to be unproductive. Instead, Locke (2007) promotes a type of research

process, Inductive Theory Building, on the basis that it has provided the more successful theories and models in the complex area of social science and human interactions; something which is reinforced by the book titled ‘Great Minds in Management’ where leading management theory builders outline and promote this process; for example Bandura (Social cognitive theory), Argyris (Double loop learning theory), Locke and Latham (Goal setting theory).

Some key processes that are embedded into inductive theory building are to: ‘identify variables’, ‘state relationships’ and ‘clarify boundary conditions’. Key events in the approach are the observation of data which contradicts current models and the response that this generates, and examination of models by stakeholders, who may also be fellow researchers. Another element is that of elaboration which includes detective work, deduction, sense-making and exploration. A critical aspect is that of individual learning, which is maximised by immersing one self into issues. This means that there is a preference for rich and qualitative information, which sometimes comes at the expense of information reliability. The process of Inductive theory building has a number of steps as shown in Table 4-1 (Locke 2007).

Table 4-1: Inductive theory building

Methodological step	My approach
Start with valid philosophical axioms as a base	View the system as a CAS
Develop a Substantial Body of Observations or Data	Use history and knowledge elicitation tools to generate observations and data
Formulate Valid Concepts	Synthesise observations and data into appropriate categories with definitions
Look for Evidence of Causality and Identify Causal Mechanisms	Develop models to explore causality (Agent Based Model and Bayesian Network models)
Tie in Valid Concepts From Other Sources and Theories Where Applicable	Identify useful concepts in the wider research community; including by applying Delphi survey
Integrate the Totality of Findings and Concepts Into a Non-contradictory Whole	Integrate all into a coherent and non-contradictory framework
Identify the Domain and Boundary Conditions for the Theory	The framework applies to the conditions that are being studied, i.e. small town water management
Make Theory Building a Careful, Painstaking, and Gradual Process	Consider multiple perspectives, and use the critical review by stakeholders in an iterative fashion to help learning

Several of these steps are mapped against actual research methods, and will help to:

- Prioritise richness of data, such as via narratives, ahead of information reliability and apply historical review and interviews for generating a substantial body of observations and data (see chapters 3, 5 and 6 for more information);
- Include multiple perspectives by using personal synthesis and a Delphi survey in parallel in order to formulate valid concepts and identify the relationships between key variables, using a process for developing consensus amongst and between experts and knowledgeable stakeholders (see chapters 3 and 6);
- Take a CAS perspective and apply methods from the Complex Systems Science toolbox, such as Agent Based Modelling and Bayesian Networks (see chapters 3 and 7 for more information) in order to look for evidence of causality and identify causal mechanisms between key variables.

In terms of the data and inferences that are used in this study, there is a need to strike an appropriate balance between information reliability allowing for deduction and richness of information allowing for induction. Both aspects are necessary at different stages, but often contradictory within a reality that is constrained by time and finances. Hence, in a rapidly evolving system it must be accepted that anyone operates in an unknowable reality, and it is argued that premature deductive reasoning:

Demands, premature theorising and often leads to making up hypotheses after the fact – which is contrary to the intent of hypothetico–deductive method (Locke 2007: 867).

Experience has shown that induction is more suitable at stages of theory development. Therefore, in this study, there is a tendency towards richness of information rather than reliability of information. Future studies are invited to question the various conclusions that are drawn, typically using quantitative methods and that is part of the logico-deductive scientific process.

Assumption

It is assumed that Inductive Theory Building is an appropriate approach for the development of practical management frameworks and tools in the target context. Therefore, the focus of this study is on this type of theory building rather than deductive theory testing. As such, there is a preference for rich and qualitative information, and this sometimes comes at the expense of information reliability.

4.1.4 Context requirements

Using case study information that is already available by drawing on the information reviewed in terms of urban water management in small towns in the Pacific Island Countries, it has been identified that there is a need for a framework that:

- Can deal with situations of a high level of complexity such as those that relate to socio-technical interactions and systems trade-offs;
- Allows a combination of social, economic and ecological perspectives to be embedded in governance;
- Is suitable for situations of high stakes and considerable uncertainty;
- Has the potential to unlock social dilemmas when appropriate;
- Can support the evolution of appropriate institutions and institutional memory;
- Is sensitive to the local context, culture and environment, in particular in relation to new technologies; and
- Is feasible in contexts of modest resources; in terms of skilled staff, finances or facilities.

4.2 Case study selection

Despite its obvious usefulness, case study-based research is often discredited due to its inductive nature and relentlessly faces the following list of misunderstandings:

Misunderstanding 1: General, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge;

Misunderstanding 2: One cannot generalise on the basis of an individual case; therefore, the case study cannot contribute to scientific development;

Misunderstanding 3: The case study is most useful for generating hypotheses; that is, in the first stage of a total research process, whereas other methods are more suitable for hypotheses testing and theory building;

Misunderstanding 4: The case study contains a bias toward verification, that is, a tendency to confirm the researcher's preconceived notions; and

Misunderstanding 5: It is often difficult to summarise and develop general propositions and theories on the basis of specific case studies (Flyvbjerg 2006: 221).

Along with Flyvbjerg, these misunderstandings are refuted and, instead the following stance on the use of case study research is taken:

Statement 1: Predictive theories and universals cannot be found in the study of human affairs. Concrete, context-dependent knowledge is, therefore, more valuable than the vain search for predictive theories and universals;

Statement 2: One can often generalise on the basis of a single case, and the case study may be central to scientific development via generalisation as supplement or alternative to other methods. But formal generalisation is overvalued as a source of scientific development, whereas 'the force of example' is underestimated;

Statement 3: The case study is useful for both generating and testing of hypotheses but is not limited to these research activities alone;

Statement 4: The case study contains no greater bias toward verification of the researcher's preconceived notions than other methods of inquiry. On the contrary,

experience indicates that the case study contains a greater bias toward falsification of preconceived notions than toward verification;

Statement 5: It is correct that summarising case studies is often difficult, especially as concerns case process. It is less correct as regards case outcomes. The problems in summarising case studies, however, are due more often to the properties of the reality studied than to the case study as a research method. Often it is not desirable to summarise and generalise case studies. Good studies should be read as narratives in their entirety (Flyvbjerg 2006: 224-241).

Therefore, in accordance with principles set up by Flyvbjerg (2006) the principle which has been chosen is to select a case study location in order to maximise the utility of information from a single case study. Choosing to focus on a single but extreme case study helps is thought to reveal more information that can be used to provide explanations to the difficulties of small towns in PICs, because they activate more of the systems (mechanisms, issues and actors) in the studied context (Yin 2004). This is particularly valid in situations, as in this study, where there already exists some kind of “consensus theory” about the issues of small towns, but lacking scientific explanation or evidence for that theory (Yin 2005).

In our case this means to choose a location with a maximum level of difficulty from a management perspective; meaning that a post-normal approach is warranted due to high stakes and uncertainty, and hopefully meaning that stakeholders will be motivated to deal with their problems. Also, choosing a maximum difficulty location should mean that any proposed management framework will be designed for coping with as many difficult conditions and challenges as possible.

Therefore, the criteria for selecting a case study site are:

- The town needs to be in the population range for small towns, i.e. between 10,000 and up to 75,000; but a population below 50,000 is preferable;

- There needs to be a considerable need for change; indicated by the level of poverty and environmental vulnerability at the location;
- It needs to have a high degree of socio-cultural complexity;
- There needs to be availability of data, and existing studies; and
- There needs to be opportunities to make connections and meet with key stakeholders.

Criterion number 1 is used to identify contenders, while the following criteria are used to narrow down the list of contenders.

Criterion 1: In terms of towns in the Pacific Islands within the appropriate population range, there are 8 contenders (see Table 2-7), namely: Nuku Alofa, Tonga; Nadi, Fiji; South Tarawa, Kiribati; Apia, Samoa; Port Vila, Vanuatu; Lautoka, Fiji; Honiara, Solomon Islands; or Guam, Territory of Guam.

Criterion 2: In terms of the limitation on resources, Kiribati has the highest proportion of the population in poverty (see Table 2-10) with a large number of slum dwellers. There are also reports on conflicts around water, groundwater resource depletion and serious environmental pollution. For information on this see chapter 2.

Criterion 3: In terms of socio-cultural context, South Tarawa in Kiribati has been the topic of a number of studies all indicating a high level of socio-cultural complexity and conflict. There is also an interesting dichotomy between existing bureaucracies and traditional village practices.

Criteria 4 and 5: Perhaps due to its lack of resources and high levels of complexity, South Tarawa has also been the subject of a large number of studies; including studies and reports explicitly focusing on the urban water sector.

In terms of opportunities to make connections and meet with key stakeholders, there are opportunities to build on existing and robust links with local stakeholders already established by senior researchers at the Australian National University.

Kiribati has been the target of a number of aid projects (in particular the SAPHE and KAP 2 projects), administered by the Asian Development Bank and the Australian government's aid organisation AusAID among others. Taken all together, there should be considerable opportunity to gain access to stakeholders, data and reports.

Decision

South Tarawa in Kiribati is an outstanding and practical candidate for a case study location which encapsulates what appears to be a full range of complexity and difficulty; but is also feasible in terms of availability of data and access to stakeholders. This location is chosen as a case study location.

4.3 Integration framework

The field study location South Tarawa has already been the focus of major studies and in fact, the AtollScape and AtollGame (which are further described in chapter 5) have been social learning experiences facilitated through the Companion Modelling framework. While the AtollScape and AtollGame experiences were successful in certain respects; lessons were made and recommendations were developed but there was no real change on the ground.

Based on these lessons and recommendations and on the basis of assumptions made in our previous chapter (3) it important to build on the lessons of previous experiences in Tarawa, and our first step will be to undertake a historical review of experiences in urban water supply in Tarawa, and in particular the *AtollGame* and *AtollScape* experiences.

Furthermore, based on the literature review, the framework for this study needs to:

- Provide a holistic vision of urban water management decisions;
- Enhance dialogue between policy makers and community members;

- Identify a transition pathway towards a more equitable and better adapted water governance system; and
- Improve the adaptive capacities of local institutions to coordinate flexible programmes of action.

These are considerable challenges that will involve institutional or even societal transformations. As argued by Pahl-Wostl (2002a), this requires social learning and therefore the human dimension is crucial. Building on the experiences of Kurtz and Snowden (2003) within action research; three pervasive assumptions are relaxed about individuals and organisations decision making, that are common in decision making and policy formulation:

- The assumption of order: that there are underlying relationships between cause and effect in human interactions and markets, which are capable of discovery and empirical verification. In consequence, it is possible to produce prescriptive and predictive models and design interventions that allow us to achieve goals. This implies that an understanding of the causal links in past behavior allows us to define ‘best practice’ for future behavior. It also implies that there must be a right or ideal way of doing things.
- The assumption of rational choice: that faced with a choice between one or more alternatives, human actors will make a ‘rational’ decision based on minimizing pain or maximizing pleasure; and, in consequence, their individual and collective behavior can be managed by manipulation of pain or pleasure outcomes and through education to make those consequences evident.
- The assumption of intentional capability: that the acquisition of capability indicates an intention to use that capability, and, as a consequence, actions from individuals or communities are always the result of intentional behavior. In effect, it assumes that every ‘blink’ we see is a ‘wink’. In contrast, we assume that people happen to do things by accident. (Kurtz and Snowden 2003: 462-463).

This does not mean that these assumptions are never true; but rather that they are not universally true and that the representation of reality is not simplified by assuming that they are.

Furthermore, in this study, a post-normal stance is adopted by acknowledging that in complex situations with high stakes there is a need to accept multiple plausible realities; and incorporate the review and social validation process with affected stakeholders as part of the research process.

In fact, as was found in the AtollGame experiences, the same individual may be acting according to conflicting mental models of reality depending on the context (Dray *et al.* 2007).

Additionally, like Dray and colleagues (2006a; 2006b; 2007) it is believed that individuals' representations of reality (mental models) are constructed in interaction with their physical and social environments; and that as per Becu and colleagues (2003), those mental models can be elicited and translated into conceptual models using knowledge engineering. It has also been described how such mental models, including multiple and conflicting mental models, can feed into computational models, i.e. Agent Based Models (ABMs) and Bayesian Networks (BNs).

Based on the relaxation of the described assumptions about order, rational choice and intentional capability, the Cynefin framework prescribes a number of activities for sense-making in what they refer to as the un-ordered domain of complex relationships in which patterns can be perceived but not predicted, and these are:

- Analysis of history as a way to understand systemic properties. This will help us identify and respond to general patterns, and make us prepared for any unexpected patterns;
- Use of narrative techniques. This will help to generate a richer picture of the diversity and will allow us to capture important aspects which can not be easily formalised in numbers and theories;
- Use of multiple perspectives on the nature of the system. In this way it is possible not only to identify the multiple perceptions of reality (i.e. mental models), but also to identify a greater diversity of patterns that occur in the system;
- Exploratory analysis in order to temporarily move to a situation where cause and effect relationships are discoverable. While patterns may not be predictable, they are usually

understandable using hindsight. This will help us to understand the range of possibilities, and in some circumstances to probabilistically assign more or less likely future scenarios;

- Use of an adaptive approach, where interventions are designed as probes, and analysed in retrospect. This will help us understand how to promote desirable patterns of behaviour and destabilise undesirable patterns.

It turns out that it is possible to map these sense-making activities against our reviewed methods, as per Table 4-2. This mapping forms the basis for our integration framework.

Table 4-2: Methodological guidance based on the Cynefin framework

Cynefin sense making activity	Method
Analysis of history as a way to understand systemic properties	Historical review of previous experiences
Use of narrative techniques	Survey/interviews
Use of multiple perspectives on the nature of the system	Delphi survey
Exploratory analysis in order to temporarily move to a situation where cause and effect relationships are discoverable	Bayesian Networks
Use of an adaptive approach, where interventions are designed as probes, and analysed in retrospect in order to understand how to promote desirable patterns of behaviour	Agent Based Modelling

This selection of methodologies addresses the fact that the problem of water supply and sanitation in small towns in PICs in reality is a messy problem, and that it is difficult to establish which of the Cynefin domains that this problem spans; or in other words, to what extent is the problem in the known, knowable, complex or chaotic domains.

In the known domain, literature and simple analysis will suffice in order to provide explanation of the system – this domain is covered by the literature review and Delphi survey to explore expert knowledge, predetermined practice, field guides and manuals etc.

In the knowable domain there exist stable cause and effect relationships although they may not be fully known to all actors. Systems thinking on the basis of interviews, historical review and case study review feeding into Agent Based Modelling allow exploration of this domain.

In the complex domain, the domain of complexity theory, patterns emerge and can be perceived but not predicted. These may or may not be stable, and therefore structured methods that seize upon such patterns are likely to eventually become ineffective. In this domain, Bayesian Networks that establish probabilistic causal links based on retrospectively identified patterns have a use. However such modelling needs to be done in acknowledgment that patterns may change (and hence may consider input from people who can sense more current system dynamics).

In the chaotic domain, small and seemingly random stimulus or disturbances may create large changes in systems dynamics. This generates a level of uncertainty and randomness. Whilst interviews may provide some insights into those largely undefined things that may impact on the system, the Bayesian Networks to some extent deals with the uncertainty of this domain. More importantly, this domain is dealt with by stakeholders using strategies such as control; uncertainty reduction; or shifting the domain. As a researcher, engaging with stakeholders who are critical actors in the system is a way of acknowledging this domain.

Synthesising the above, the Historical review of the case study water sector will provide the setting, and will allow us to identify patterns which have been observed in the past, providing what is referred to as retrospective coherence. It will also allow for continuity in an on-going learning experience. The interviews will provide an interrogation technique which is not bound by traditional scientific constraints, but will allow for gaining a more integrated and rich understanding of issues and factors. The Delphi survey will allow for formally collecting perspectives and narratives of diverse stakeholders and experienced individuals in the wider Pacific Islands region, and thereby allowing for making wider generalisations. Analysis based on BNs will allow for, at least temporarily, understanding the cause and effect relationships in water development interventions which are often both complex and uncertain. Systems analysis

using an ABM will allow for exploring how probes can be designed and explored using scenario analysis and the impacts can be evaluated from a number of different perspectives. This will help the understanding of how to promote desirable patterns of behaviour in the system.

The sequence of these activities also forms a natural sequence in terms of generating the data and understanding required for developing models. In other words, the historical review, interviews and the Delphi survey provide a rich and diverse information base to feed into the modelling exercises. This approach also allows the researcher to develop an understanding of the context in consideration of the steep learning curve that anyone would have that is unfamiliar with the Kiribati culture and context.

Additionally, given the remote location and the practical/financial difficulties in spending long periods of time at the case study location, the Delphi survey will allow knowledge elicitation to be carried out remotely via email. This will also allow for more general information about water supply issues in small towns in the Pacific Islands.

It is also noted that in reality, it is and has been important to iteratively respond to local circumstances and feedback, which means that methodological decisions are made during the research process. In other words, a linear sequence of activities is deceptive in that in reality these events do not follow in quite such a sequential order. The over-arching iterative procedure that is applied in this research is shown in Figure 4-2:

- Reflection: using inductive and deductive reasoning, to identify patterns and understand observations and data. An important part of the reflection is to raise new questions as well as to discuss/debate with colleagues and other relevant individuals.
- Field study: based on the improved understanding and new questions that have emerged, further ideas and information is collected from the field. This also includes evaluation by local stakeholders (i.e. water managers) of existing models or frameworks in terms of their appropriateness in light of field realities.

- Modelling: based on new evidence and questions, models are developed to allow further exploration as well as probing in a virtual laboratory. This can also be seen as theory development and hypothesising.

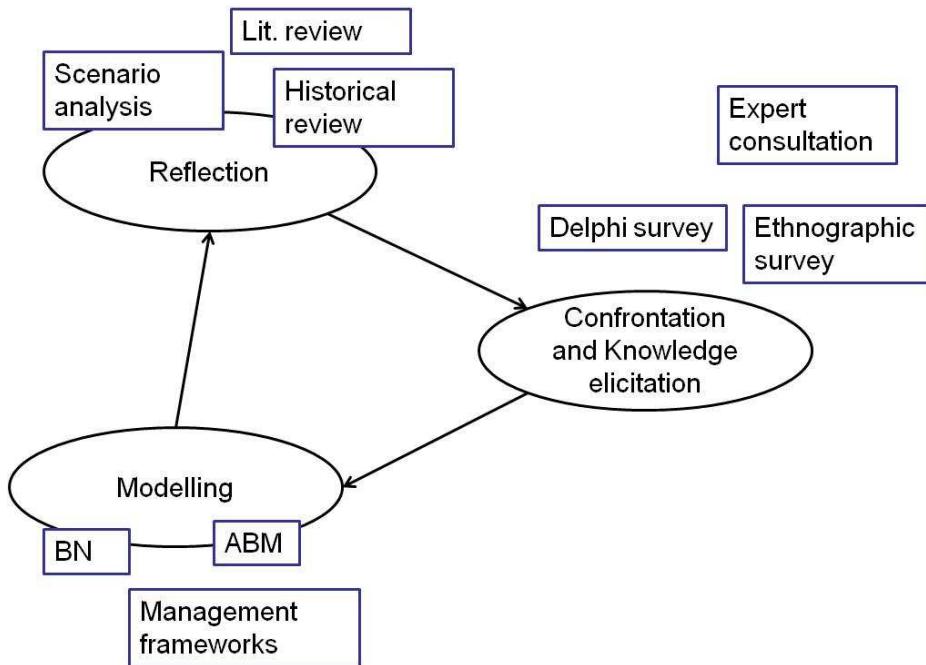


Figure 4-2: Research process as iteration between reflection, field study and modelling

Finally, it is worth noting that the goal of this study is not action but rather to develop a management framework and a transition strategy. Therefore, the problem definition is somewhat diffuse and complex; and implementing solutions are likely to be strongly dependent on political support. Because of this high level of uncertainty, it is deemed that having action on the ground as the aim is a risky strategy because research success would be dependent on political outcomes; and may generate unrealistic expectations and is therefore potentially unethical and therefore poor engagement practice.

4.4 Sequence of activities

The process of how this study was carried out is shown in Figure 4-3 showing in which order the components of the study were included:

1. The study started in May 2004 with discussions with experts and review of literature;
2. An initial and preliminary conceptual framework was developed which was used for examination by local stakeholders at the case study location during the first visit;
3. After this visit, the Delphi survey was initiated with a range of regional stakeholders;
4. A sectoral review of the situation in the case study location was initiated, and results from this review was used for examination at the second case study visit;
5. Based on results of the study so far, and the information from the second case study visit, models were being developed, the mid-term review was carried out, and a second preliminary management framework was being prepared;
6. Models and management framework were used for evaluation against field reality during the third case study visit;
7. Finally, based on all the results so far, a management framework has been developed, reaching the end of the study.

Three trips were undertaken to the field study location at the following times:

1. 28th November 2005 – 6th December 2005: Travel together with Anne Dray of the Australian National University to Tarawa, Kiribati.
2. 17th May 2006 – 27th May 2006: Travel together with Ian White of the Australian National University to Tarawa, Kiribati.
3. 27th September – 4th October 2007: Travel to Tarawa Kiribati.

Trip reports are available in Appendix 4. It is also worth noting that the sequence of this thesis of Introduction, Literature review, Methods, Results and Conclusions, is in contrast to the chosen iterative and non-linear framework where research decisions are made adaptively to local circumstances and in response to feedback from stakeholders. Consequently, when writing according to a linear and structured narrative, there needs to be some re-construction of the

order of events. Therefore, the reader should note that the linear structure of this thesis is in fact not completely representative of the actual research process.

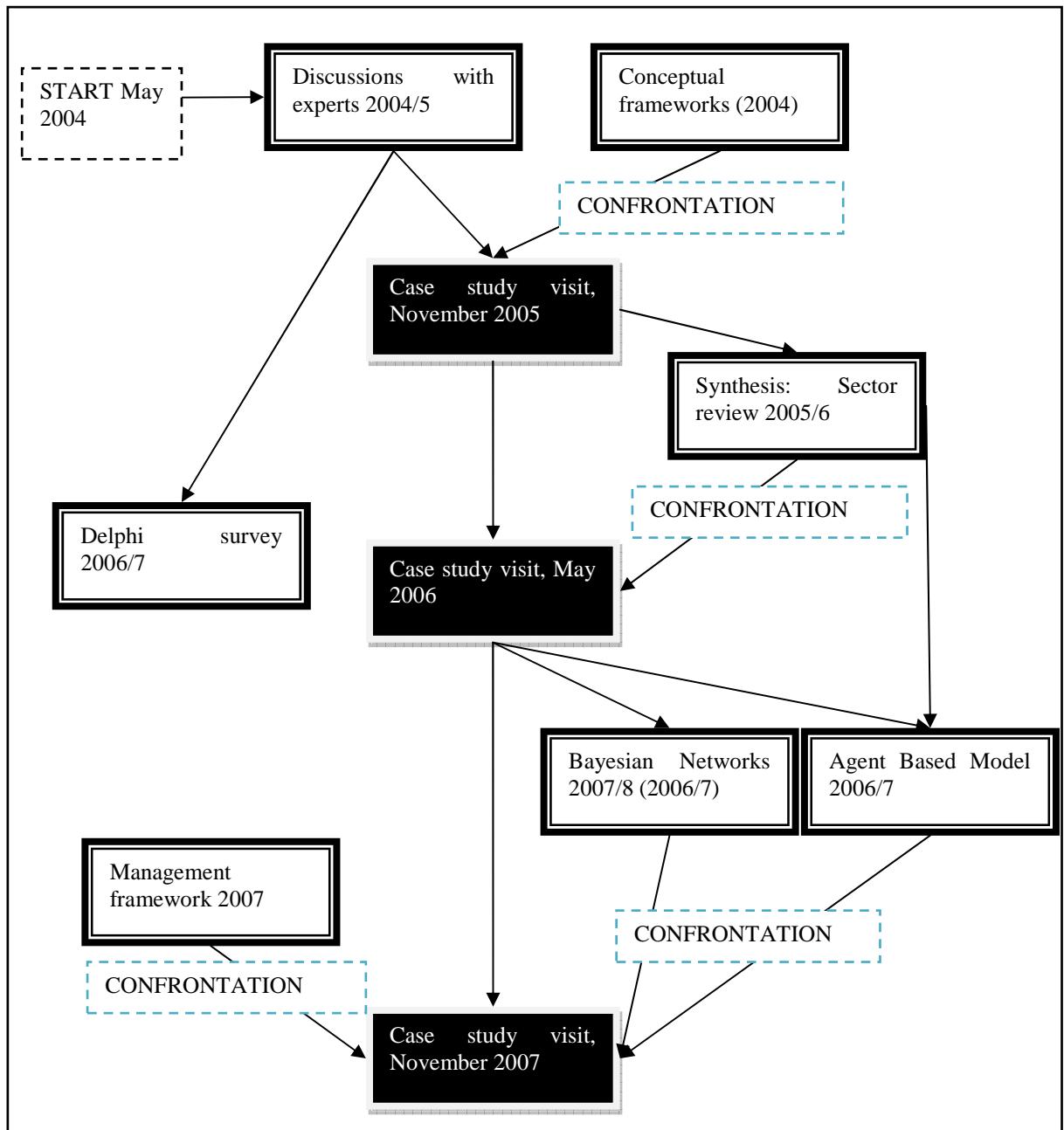


Figure 4-3: Study process and timelines

4.5 Historical review

The historical review of the South Tarawa water supply is undertaken to build on previous lessons and experiences. This Reflection stage (Figure 4-4) is based in particular on the *AtollScape* and *AtollGame* experiences by Perez and colleagues (2003; 2004) and Dray and colleagues (2006a; 2006b; 2007), but also on the successive phases of the SAPHE Project funded by the Asian Development Bank (2000b; 2003b; 2004a; 2004b; 2004c; 2008a), as well as contributors such as Falkland (1999; 2003) and White (2006a, 2006b) and colleagues (1999a; 1999b; 1999c; 2003; 2005; 2006c; 2008) of which the IHP Humid Tropics Programme Project is most worth a mention.

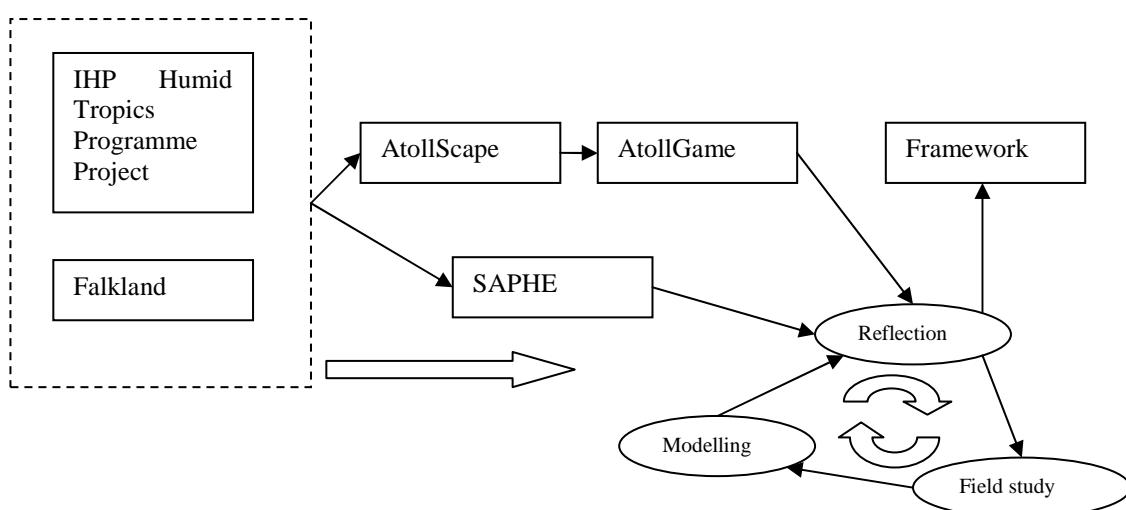


Figure 4-4: Historical context of study

Figure 4-4 shows how lessons from the IHP Humid Tropics Programme Project fed into the AtollScape, AtollGame and SAPHE projects, which in turn feed into this study's iterative framework of Reflection, Modelling and Field study by providing:

- Key concepts, discourses and themes;
- Lessons based on previous experiences;

- Identification of difficulties that need to be overcome; and
- Identification of mistakes of the past so that they can be avoided.

4.6 Interviews

Interviews have been judged as a critical tool in this study in order to collect qualitative and narrative information about the complex interactions between social, cultural and institutional dimensions of the current situation. A combination of unstructured and semi-structured interviews has been employed to collect information and elicit knowledge. Interviews are deemed to be flexible and targeted enough to allow the focus to emerge; but at the same time provide a deep understanding of complex issues. The interviews have been undertaken at different stages of the study (Figure 4-3):

- In discussions with experts during the initial stages of the study;
 - To identify key concepts, discourses and themes;
 - To test and socially validate ideas and reflections;
- During the first field trip, in order to
 - Provide answers to questions raised in the prior reflections;
 - Allow stakeholder validation of theories (answers) and frameworks. At this stage a number of conceptual frameworks had been developed;
 - Increase individual understanding of local context;
 - Get a better understanding of the AtollScape and AtollGame experiences, as this field trip was undertaken with Anne Dray of the Australian National University (Dray *et al.* 2006a; 2006b; 2007);
- During the second field trip, in order to:
 - Provide answers to questions raised in the reflection stage;
 - Allow stakeholder evaluation of theories (answers) and frameworks. At this stage a sector review had been undertaken;
 - Increase individual understanding of the local context;

- Get a better understanding of the IHP Humid Tropics Programme Project and other experiences, as this field trip was undertaken with a prolific contributor to the understanding of the Tarawa water supply, i.e. Professor Ian White of the Australian National University (White *et al.* 1999a; 1999b; 2008; 2005a; 2005b; 2003; 1999c; 2006a; 2006b; 2006c);
- During the third field trip, in order to:
 - Provide answers to questions raised in the reflection stage;
 - Allow social validation of ABM and a preliminary management framework;
 - Identify factors and assessments for the BN models;
 - Increase individual understanding of the local context.

Table A4.1 gives some of the names of those interviewed at various organisations. Usually, the process for getting interview access was to be introduced, or to introduce myself, to the head of a department or organisation, in order to set up interviews. Hence, there is a limitation both in terms of the number as well as the types of interviews carried out. Access was more straightforward in later trips. The number of interviewees in the various organisations varied from 1 (at the Office of the President) to 8 (at the Public Utility Board). With very few exceptions most of those from local organisations were I-Kiribati. The age range varied from a smaller number of young professionals in their 20s, but considerably more interviewees in their 40s and 50s. All of those from international organisations were not I-Kiribati. Approximately a quarter of those interviewed were female. The range of questions varied greatly and interviews were non-structured or sometimes semi-structured. Semi-structured interviews were carried out with the use of models, diagrams or photos to facilitate discussion and conversation.

The interviews have been a mix of unstructured interviews in the initial stages to allow topics and themes to emerge, followed by semi-structured and more targeted interviews, when issues have become clearer. The interviews have been influenced by some qualitative research tactics in the sense that:

- Interviews and discussions have been undertaken in as natural a setting and situation as possible. This also involves basic observation of discussions and note-taking;
- Efforts have been made to understand the local culture and context, and the representations of the system (mental models) that are applied by local stakeholders. This has involved both interactions with local culture, but also via reading autobiographic books about Tarawa such as that by Troost (2004), or the helpful notes on working in Kiribati culture by the Asian Development Bank (2004a);
- Adoption of a philosophy that the research process does not start with an explicit hypothesis, but that knowledge is discovered, as per ethnographer Genzuk (2003), and as such it is not appropriate for the researcher to strongly impose or steer questions, but rather to often use open language so as to let interview outcomes emerge.

It is also acknowledged that field research in this manner is a highly personal experience, in which outcomes depend strongly on the observer/researcher's individual skill, discipline and perspective. My personal cultural background as a Swedish immigrant in Australia; an academic focus on Mathematics and Physics; a number of years of working in urban water management in Australia; combined with a strong interest for history and geography would be important factors for my interpretation of the information and knowledge elicited in interviews.

The thinking of grounded theory has been adopted in the sense that everything is considered to be data which can be used by the researcher to generate concepts, including emails, lectures, conversations, books etc. Therefore, the word interview is here a somewhat loose terms which also includes observation and reading.

No recording device was used in the study, so as to make interview participants to feel at ease and the reporting of interviews has been done by writing down notes within a day in most cases, but in some cases within three days of an interview. Summaries of these have been put into trip reports (Appendix 4). Generally, no formal structure of interviews has been used, but a number

of principles/procedures inspired by the Convergent Interviewing approach (Dick 2002a), as described in the chapter 4, have been followed:

- Interview participants have been chosen to provide maximum diversity;
- A note of agreements and disagreements have been kept which are used to challenge the interpretations made by participants;
- When appropriate, introduce general topic but avoid specific questions, allowing the participant to steer the discussion.

In terms of the pitfalls identified by Myers and Newman (2007), there has been an attempt to avoid ambiguous language, however it is acknowledged that:

- It has sometimes been difficult to gain entry into organisations and identifying the appropriate people;
- Interviews have often been under some time pressure given that many participants are generally busy, and that field study trips have been limited in time. Notably, due to these constraints, there has been no access to the Department of Finance; and
- Related to the lack of time is the issue of trust as this takes considerable time and effort to gain. This is a possible pitfall in this study.

Individuals that have been interviewed range from:

- Consultants/experts with extensive experience in the Pacific Island Countries in general to Tarawa in particular; to
- Representatives of the Government of Kiribati (GoK), the PUB, the OB and the WEU (see Figure 4-5); to
- Representatives of regional organisations and/or funding agencies such as the South Pacific Applied Geoscience Commission, and the Australian government aid agency, AusAID; and the World Health Organisation.

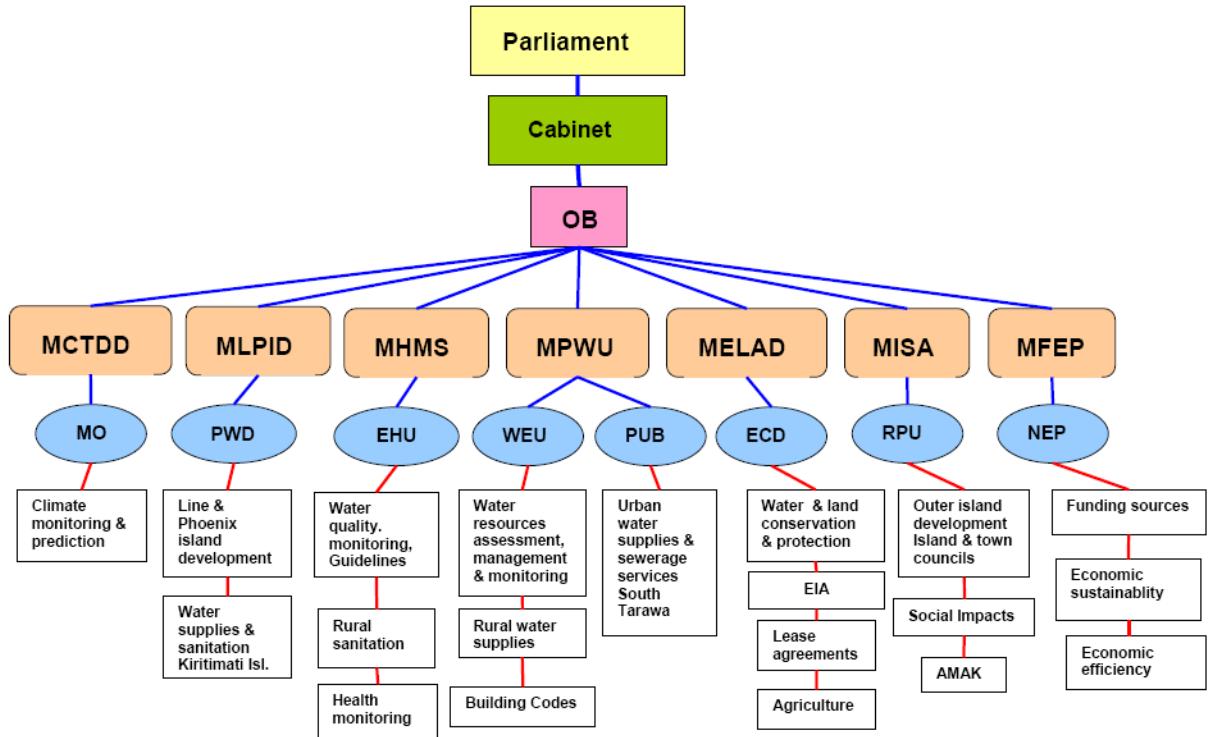


Figure 4-5: Kiribati water sector organisational and responsibility diagram

Source: Government of Kiribati 2007

The major local stakeholders in the water sector in Kiribati, apart from the community, are described in Figure 4-5 where representatives from the MHMS (i.e. Ministry of Health), MPWU (i.e. Ministry of Works), MELAD (i.e. Ministry of Lands and Environment), MISA (i.e. Ministry of Social Affairs) and OB (the Office of the President) have been interviewed. It is noted that the key gaps are in MFEP, the Ministry of Finance, as well as the Cabinet and Parliament. This lack of a representative sample is primarily due to limited access to this level, and the limited amount of time available.

The diagram in Figure 4-5 shows the organisational structure relating to the water management in South Tarawa. The diagram comes from a Government of Kiribati report published in 2007. These organisations are further described in chapter 6. The approach when attempting to socially validate any frameworks and models is to confront stakeholders with representations of such models. In the case of frameworks, such representations are flowcharts and diagrams

(represented using PowerPoint). In the case of *ABMs*, such representations are *Unified Modelling Language diagrams*, i.e. sequence diagrams and class diagrams. In the case of *BNs*, such representations are influence diagrams and tables of judgments. The process steps followed in interviews are:

1. Present the conceptual model representation using my own language;
2. Discuss how the framework or model would be used or operationalised; and finally
3. Invite comments and criticism; and
4. Take notes, and identify agreements or disagreements to use in further interviews.

4.7 Delphi survey

To complement interviews and the historical review, a Delphi survey was carried out with experts, water managers and funding agencies that were either based in or active in the Pacific Islands region. The main reason was to provide a stock-take of expert opinion on urban water issues in PICs, hence in a way supporting cross-case analysis as suggested by Gerring (2007). Hence the Delphi survey, as is aligned with the *Cynefin* framework, provides multiple perspectives on the issue of water supply in PIC towns.

Email-based Delphi survey was used to elicit the views and knowledge of experts and stakeholders, relating to the wider issue of urban water management in Pacific towns. Pacific towns are seen as representing a more difficult context than the average small town in the developing world, but are a more generic situation than that in the case study location.

The Delphi survey is a formal process similar to that used in grounded theory and is often used to establish key concepts and factors. The application of this Delphi survey is mainly:

- To select factors of interest that contribute to vulnerability of water supply services in PIC towns;

- To generate qualitative data to understand the wider context of vulnerability of water services in PIC towns;
- For preliminary identification of causal relationships in relation to barriers and enablers;
- For specification of research questions in the sense that the learning that occurs as part of the process is likely to raise new questions and uncover problem areas.

The Delphi survey was email based, employing the web survey software (SurveyMonkey 2009), in order to allow remote access to stakeholders, and this was critical in enabling the survey to be carried out with such a diverse array of stakeholders.

4.7.1 Sequences of events

The steps in the survey process are, loosely as per Figure 4-6:

1. Identification of participants, as well as invitation and setting of expectation;
2. Brainstorming; with participants identifying and describing various factors;
3. Classification of responses into a number of categories / factors;
4. Validation of the classification;
5. Selection by each participant of the most important factors; and
6. Validation by participants; if ok continue, otherwise return to step 6;
7. Ranking of the most selected factors;
8. Validation by participants; if ok continue, otherwise return to step 8;
9. Re-ranking of the most selected factors;
10. Validation of rankings by participants; if ok stop, otherwise return to step 10.

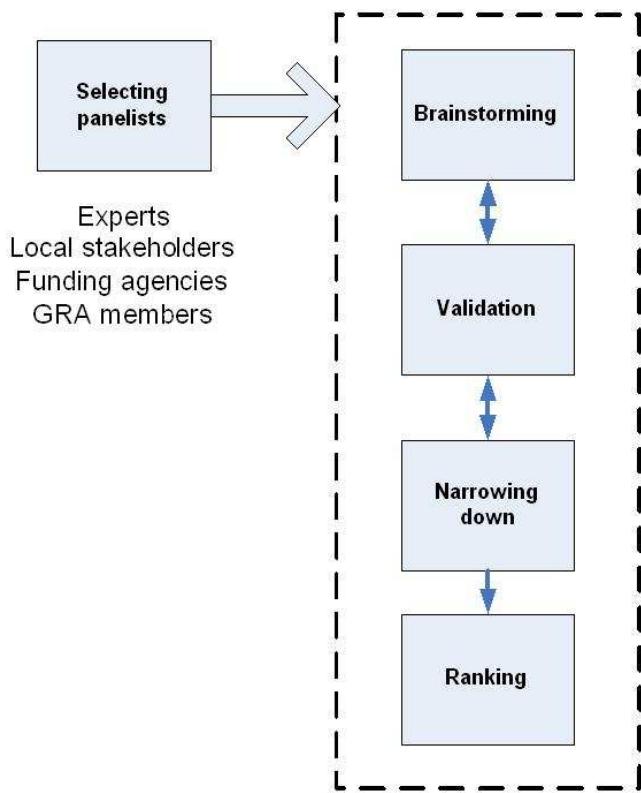


Figure 4-6: Delphi dialogue process as it is applied in this study

This process is designed so that the outcome emerges from the interactions of the participants, but it is unavoidable that there is a bias from the researcher who facilitates the process as well as provides a categorisation. To limit this bias, the process has elements of:

- Iterative participant validation of the categorisations, and rankings;
- Participants being invited to provide feedback on the process; and the facilitator adapting the process when it is found to be appropriate.

For the survey questionnaires, email was used in conjunction with the collection of responses using designed forms in online survey software (SurveyMonkey 2009).

All written communication with the participants was based on the principles of simplicity, avoiding ambiguity and clarity of language. Clear and simple communication is critical for ensuring a high response rate as well as to reduce any risk of bias by misunderstanding. Other efforts to ensure a high response rate were:

- Avoiding technical terminology to the extent possible so as not to exclude people with non-technical backgrounds;
- Support by a communication expert, to make any material as accessible as possible to participants from a non-English speaking background;
- Keeping the momentum going throughout the process which occurred over several months, by updates on progress, even when there was no questionnaire sent out;
- Making every effort to simplify forms in order to reduce the time taken to fill them in;
- Inviting participants to be critical of the process, and adapt the process when it is perceived to be appropriate to do so;
- Being clear about commitments in terms of time.

4.7.2 Selection and invitation of participants

For the purpose of this Delphi survey, participants were sought that possess cross-cutting experience with issues in the PICs urban water sectors. The Delphi dialogue traditionally starts with a mapping of knowledge hubs in the area, and subsequently maps out potential participants, which are then ranked based on a number of criteria. This process was not strictly followed but three wide categories of individuals were identified that play vital roles in water development projects: Funding agency representatives, Local stakeholders, and Experts. Naturally, there are also a number of subcategories relating to each of these Stakeholder groups, as can be seen in the Table 4-3.

The anonymity of participants in the survey needs to be ensured, but some basic statistics about them can be disclosed. Out of the 47 participants, a mere 7 were female (it is a male dominated sector); 10 came from PICs, 16 were international experts (from outside of Australia), and 21 were experts were based in Australia. 29 of the participants had extensive experience of working in the water sector in the PICs, whilst the remaining participants worked with PICs indirectly, such as for example those representatives for the Asian Development Bank, the

World Bank, the European Commission, the Global Water Programme, and the International Water Association; and a small number of international researchers on similar issues in other locations, such as in the Caribbean and in Africa. Experts with relatively limited experience in the PICs were put into a reference, base case group; a sub-category of the Experts group.

Table 4-3: Stakeholder panels in the Delphi study

Local stakeholders	Experts	Funding agencies
Water utility interests	Engineers	Development banks
Government departments or parliament	Development specialists	Government aid agencies
NGO interests	Natural scientists	International aid programs
Business interest	Socio-cultural experts	Research foundations
Household interests	Process facilitators	Donation based aid organisations
Landowner interests		Volunteer organisations
Agricultural and subsistence interests		Industry association

Ten Local stakeholder participants from PICs in the Delphi dialogue were selected on the basis of access and willingness to participate; mainly from the categories of Water utilities and Government departments. The countries represented were Kiribati, Tonga, Cook Islands, Fiji, Papua New Guinea, Tuvalu, Tonga, Samoa, Solomon Islands and the Federated States of Micronesia, with one participant from each country. Attempts were made to achieve a larger number of participants from PIC backgrounds, but this was not successful. However, given the smaller number of individuals in the world with cross-cutting experience with issues in the PICs urban water sectors, this may be acceptable.

The bias towards the two first sub-categories in the ability to identify and successfully invite participants into the process may in fact represent a common bias in the design of water development projects. The reason for having this bias in the selection in fact relies on two facts, i.e. the:

- Limited scope of the social networks of people asked to nominate participants into the other Local stakeholder group's sub-categories; and
- Reliance on the computer literacy and Internet access of the participants.

There were twenty-two participants within the Expert panel with representatives from each of the sub-categories so the Expert panel is in fact rather diverse. There were a total of fifteen participants in the Funding agency panel, with at least one participant from each of the sub-categories except for from a Volunteer organisation.

Once a number of potential participants had been identified, they were invited into the process. This was done via phone conversations and by sending a document describing the background and aim of the study, time requirements and scope, as well as the expected outcomes in realistic terms. Most of the invited participants agreed to take part in the dialogue.

4.8 Agent Based Modelling

ABMs that are implemented to allow for Agent Based Simulation (ABS) are useful for supporting interdisciplinary studies, incorporating both qualitative and quantitative information, exploring long term intergenerational issues, modelling individual behaviours, exploring the links between local activities and global behaviours, modelling diversity in populations and supporting participatory processes. In particular ABS also supports the ability to incorporate more realistic, and often adaptive, behavioural models and to model CAS. As per the Cynefin framework, the main reasons for using ABM in our study are to use an adaptive approach, where interventions are designed as probes, and analysed in retrospect. This will help us understand how to promote desirable patterns of behaviour and destabilise undesirable patterns.

ABM is here used in recognition that real world interventions and probes are complex and adaptive and therefore, the outcomes are unpredictable. It is therefore ethically preferable to explore the potential outcomes in a virtual laboratory in a computer before implementing them in reality. This is also done in acknowledgment that researchers have limited influence and resources to undertake any interventions in reality.

With the decision to apply ABM in this study, there is a need to specify our ABM further, in particular regarding the Modelling requirements; Design process; Software development environment; and Model structure.

4.8.1 Modelling requirements

I have deemed that the following requirements, based on the ABM taxonomy by Hare and Deadman (2004) are appropriate in this study:

- Space is represented in an explicit way, albeit without accurate representation. This is because it is believed that the particular spatial setup is not a critical influence on the behaviour of the system other than in a very general sense;
- Heuristic rules and imitation are used to model individual decision making. This is due to a combination of difficulty in accurately modelling rational and boundedly rational behaviour using utility functions and inferences without significant understanding of the local culture. Heuristics and imitation can incorporate insights from social psychology.
- Social interaction is through a combination of group based tasks, and a combination of local as well as global social adaptation. This is chosen because it is perceived that for the urban water system, individuals are interacting essentially anonymously to a group based task; whilst individual households do tend to adjust their behaviour and mental models in response to what they can observe in neighbours and elsewhere.

4.8.2 Design process

The design process for the ABM is inherently coupled with the Interviews and the Historical review. The mediating objects that are used to facilitate the design process and the interactions with the Interviews are Unified Modelling Diagrams. This coupling between ABM design and Semi-structured interviews is as follows (as in Figure 4-7): knowledge gained and information collected in the interviews is used to develop UML diagrams and populate the model; UML diagrams are in turn used in semi-structured interviews as part of the interviews; and finally, UML diagrams are used in semi-structured interviews for stakeholder evaluation of models.

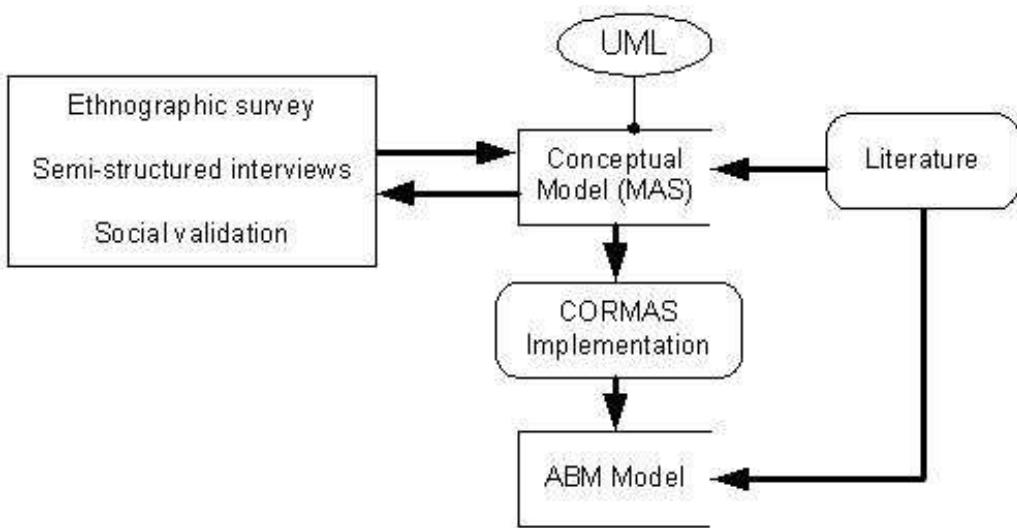


Figure 4-7: Information flows from survey to model

Therefore, in line with the Participatory Modelling philosophy that has been adopted, the ABM is viewed as socially constructed based on input from stakeholders. UML diagrams are seen as the stepping stones that can facilitate this transaction.

4.8.3 Software Environment

ABM relies on the Object Oriented Programming paradigm. Whilst ABMs in theory can be programmed in any object-oriented programming language such as Visual Basic, C#, Python or Java, as described by Rixon and colleagues (2005) there are also a number of Integrated Development Environments available as summarised by SwarmWiki (2009). Notable examples of these are shown in Table 4-4. There are obviously also other ABM Integrated Development Environments, but these appear to be the most commonly used within contexts similar to this study.

The requirements for an ABM Integrated Development Environment when undertaking Participatory Modelling is that it:

- Supports rapid development; allowing for quick turnaround when adapting models to user and stakeholder feedback;

- Is free and Open Source; allowing for handing over ownership of models; and
- Has excellent visualisation features; allowing for efficient communication.

Using these three evaluation criteria, DIAS/FACET, NetLogo, and Jack are no longer viable options because at the time of choosing, they were not free and open source. RePast, MadKit and Swarm on the other hand do not adequately support rapid development unless the research team is of sufficient size and with sufficient programming skills. This leaves one remaining option, Cormas which is selected because of the list of characteristics shown in Table 4-5.

Table 4-4: Selected ABM integrated development environments

IDE	Reference	Programming language	Free and Open source
Cormas	CIRAD 2004	Smalltalk	Yes
Dias/Facet/JeoViewer	Argonne National Laboratory 2004	Java	No
Jack	AOS Group 2004	Subset of Java	No
MadKit	MT 2004	Java, Python and Scheme	Yes
NetLogo	NetLogo 2009	Java	Free but not open
RePast	Repast 2009	Java, .NET, Python	Yes
Swarm	SwarmWiki 2009	Java, Objective C	Yes

Notes: It is noted that this table was set up at the time that the decision had to be made and that some of assessment results may have subsequently changed. However, this table does represent the information at the time the decision had to be made and is therefore consistent with the logic of choosing Cormas as an IDE. A more recent review of Agent Based Modelling platforms has been done by Railsback *et al.* (2006).

Table 4-5: Evaluation of Cormas as an integrated development environment

Criteria	Evaluation of Cormas
Opportunities for code reuse	Considerable due to the available models on the web site, and the existing AtollScape model for Tarawa.
Spatial representation	Cormas provides capability to both use cells and cellular automata (CA); and it also allows for reading in files containing cell/CA attributes (i.e. spatial layers).
Visualisation	There is excellent support for defining and dynamically visualise probes and spatial layers.
Debugging capabilities	Cormas has an efficient system for reporting errors, and debugging, albeit requiring some knowledge of features, and this knowledge is relatively poorly documented.
Suitability for prototyping and rapid development	With a large library of features, and an easy to use interface, Cormas is particularly suitable for rapid development. This is partly because memory handling, pointers and other technicalities are hidden, putting the focus on the actual models, and reducing the occurrence of bugs.
Effort required for development	Relatively little effort required. The user has to specify the agent and model actions in each step, and the initialisation; and any method out of the ordinary has to be written using the Smalltalk programming language.
Learning required	Requires some teaching and practice, and Cormas is not perfectly straightforward to learn. While extensive tutorials and users guides are available for the associated scripting language Smalltalk, there is currently limited written material for the Cormas platform itself.
Software scalability	Because of the high level languages used, and the extensive support, Cormas is excellent for small to medium size developments, but other IDEs, such as RePast in particular, are more suitable for large scale developments.
User groups and support	A users' forum is available for questions and answers concerning the use of Cormas.

Notes: Again, it is noted that this is the evaluation of Cormas at the time that the decision had to be made; and that there may have been subsequent changes. A more recent review of Agent Based Modelling platforms has been done by Railsback *et al.* (2006).

4.8.4 Model structure

The ABM model is structured in a manner which is typical for Cormas, containing:

- Model class containing
- A Scheduler implemented within the Model class as a method: step
- Alternative schedulers are implemented as different step methods
- An Initiation procedure implemented within the Model class as a method: init
- Alternative initiation procedures are implemented as different methods

- Probes implemented as methods, monitoring variables or functions of variables and can be displayed as dynamic graphs
- Spatial environment established by defining the cell class and relevant aggregates
- Social classes: in this case Landowners, Customers, Water utility, etc
- Passive classes, such as Weather and Pipe infrastructure, and Tariff structures.

Figure 4-8 describes how these components are embedded within the Model class.

Figure 4-9 shows how, within Cormas, a probe can be selected one at a time, by selection in the left part of the screen. The right part of the screen shows the chosen variable as they change with each time step. An ABM can be described in terms of its structure and components, i.e. its classes and interactions between classes; its dynamical properties; i.e. the sequence of events in each time step; and its spatial representation; i.e. the landscape in which the agents interact. These perspectives of the model are described using Unified Modelling Language (UML) diagrams which are further described in the Results section (chapter7).

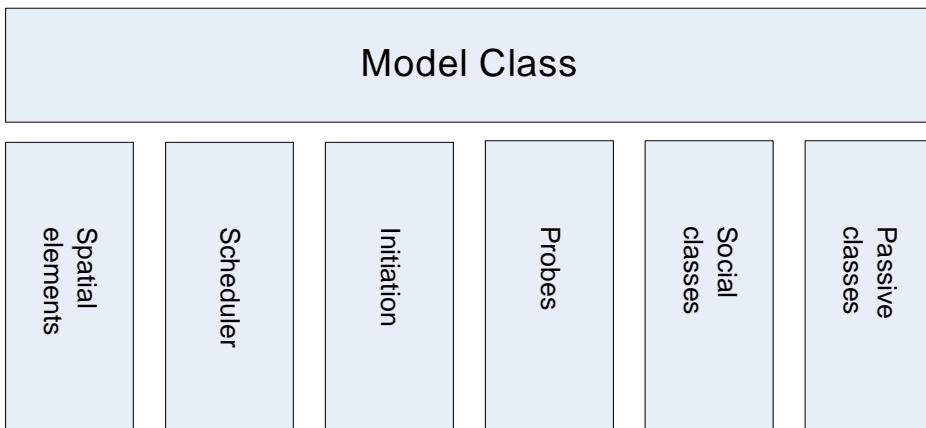


Figure 4-8: General description of a typical Cormas ABM model structure

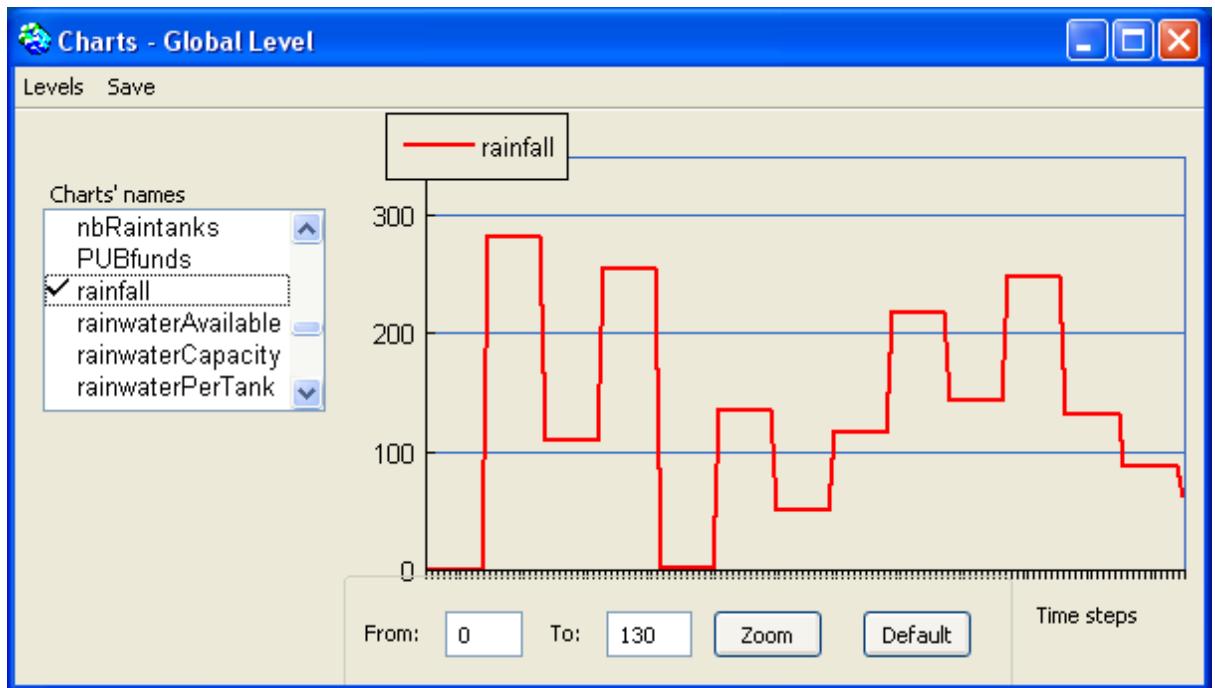


Figure 4-9: Illustration of how probes are displayed in the Cormas software

4.9 Bayesian Networks

Bayesian Networks help an analyst with inductive, abductive and deductive reasoning and are particularly suitable for handling uncertainties, and supporting adaptive management. They are also particularly suitable for combining qualitative and quantitative information into integrated assessments. As per the Cynefin framework, Bayesian Networks are used in order to carry out exploratory analysis as to temporarily move to a situation where cause and effect relationships are discoverable

In the historical review (chapter 5), it was identified that project implementations have failed for many diverse reasons. For certain stakeholders these reasons may have been obvious, but for other stakeholders they were surprising. This provides an argument for risk analysis as well as incorporation of local and expert knowledge into the planning process. Also, each particular location and context has a unique set of issues and constraints that need to be considered, and in order to learn from history, it is useful to map the factors that have impacted on the chances of success in the past. This will help improve project design, planning and implementation. These

factors are inter-connected and correlated. In this complex and adaptive situation Bayesian Networks are used in order to temporarily understand the cause and effect behind the success of interventions.

BNs are particularly suitable because they are able to incorporate local and expert knowledge in a collective assessment mode. This has made possible to incorporate qualitative information into the model building stage, and because all judgments can be included, regardless of their varying level of reliability or accuracy.

To implement Bayesian Network models, there is a need to specify the modelling requirements, design process and a software environment.

4.9.1 Modelling requirements

A number of issues need to be considered in specifying the modelling requirements:

- In the narratives about success or failure of interventions, conflicting information is often encountered, and there is therefore a need for an ability to handle multiple and conflicting hypothesis;
- Some information is more reliable than other information (for example statements in official reports by reputable experts as opposed to statements made over lunch by a government official), and so there is a need to allow for taking this diversity in information reliability into account;
- Assessments are made at certain points in time and the relevance diminishes with time. This freshness of information needs to be taken into account; and
- The structure of the cause and effect relationships is often unclear, and there is a need to allow for structural learning of models to occur in response to new information.

It is also noted that BNs do not support feedback loops, as only acyclic cause and effect networks can be modelled. This is a shortcoming of this methodology, and it is hoped that the use of ABMs will help overcome such shortcomings.

4.9.2 Design process

The design of a BN model has three main components, i.e. it's:

- Ontological component, which is the definition of terminology;
- Qualitative component, which is the definition of the causal relationships between topic domains;
- Quantitative component, which consists of judgments of the state of topic domains.

The steps that have been taken in the design of Bayesian Networks are as follows:

- Choice of scenario / hypothesis for exploration, on the basis of options (management, technology or otherwise) that, on the basis of knowledge elicitation, have been perceived as both important but also either already being considered, already being implemented or being planned for;
- Identification of ontology and topic domains (i.e. terminology) and causal relationships between topic domains using literature and trip reports; generating influence diagrams which are translated into a model structure. It is noted however that there is an element here of filtering out what is important and what is not important; providing another bias from me as a researcher;
- Choice of data sources (such as literature, trip reports and personal memory) including assessments, judgments and opinions regarding the state of the various topic domains; accepting multiple and conflicting hypotheses regarding the same topic domain. This also involves a subjective assessment of the reliability of each information source.

Validity of the BNs has been explored by analysing the risks of historical projects, and seeing whether it is possible to predict failure or success of such intervention strategies. There has also been dialogue and social validation with stakeholders in regards to the influence diagrams. The decision about which intervention strategies to analyse has been made on the basis of those that are perceived as important by key stakeholders and experts.

4.9.3 Software environment

Software environments that have been used in other BN modelling studies:

- Varis (1997), Varis and Kuikka (1997) and Varis and Somlyody (1997) used a self generated spreadsheet toolkit, ‘F. C. BeNe’, which are not widely accessible;
- Bromley and colleagues (2005) used the HUGIN EXPERT (Hugin Expert A/S 2009) software environment which is not free, but which has been widely used in many different areas ranging from climate and environment to finance and intelligence;
- Saravanan (2008) used the software tool NETICA (Norsys Software Corp. 2009) which is also a commercial software product with an impressive list of clients worldwide;
- Pollino and colleagues (2007) have used a methodology called Knowledge Engineering of Bayesian Networks (KEBN) (Woodberry 2009) and the associated support tools that are linked to this approach. This is a tool developed at Monash university and while promising it seems to be in relatively early stages of development;
- Ha and Stenström (2003) used a Neural Network software tool, Neural Connection 2.1 which would have had to be adjusted in order to help in Bayesian Network modelling;
- Ticehurst and colleagues (2007) have programmed their own software environment based on the Interactive Component Modelling System (ICMS);
- Pope and colleagues (2008) have used the software tool Sheba which has been developed at the Defence Science and Technology Organisation (DSTO) of Australia, primarily for intelligence purposes.

Based on this list, four realistic options have been identified as for BN analysis, i.e. Sheba, HUGIN EXPERT, NETICA and KEBN. Based on an initial investigation of these software tools, the criteria for assessing which tool is most suitable are as follows: quality of user interface, and ability to build large scale applications; ability to accept multiple and conflicting hypotheses regarding the state of a particular topic domain; and given the wide range of

information types that's can be used, the ability for including information about reliability of information; as well as the ability for modelling both deductive and abductive reasoning. Whilst most tools are able to capture deductive reasoning, only few tools allow for considering abductive reasoning (i.e. considering the symptoms of a hypothesis being correct).

Applying the first criteria eliminates the KEBN software environment from our list of options. The second criterion eliminates NETICA from our list as there seems to be nothing in the available documentation written about how to consider multiple and conflicting information. HUGIN EXPERT on the other hand appears to not support abductive reasoning; leaving Sheba as the only remaining option. While Sheba is not commercially available yet; thankfully, for the purposes of this study, Sheba can be used at no charge after approval from its inventor.

The following description of Sheba has been provided:

Sheba is a cross-platform software application for performing predictive analysis under conditions of uncertainty. It runs on a desktop computer and provides a framework for users to structure and analyse categorical reasoning problems. It was designed for use with strategic intelligence tasks within the National Security and Intelligence domains, and is well-suited to various competitive intelligence and decision-support applications within the Business and Commerce domains. Sheba uses the Analysis of Competing Hypotheses using Subjective Logic (Pope and Jøsang 2005) to reason about the effect on the projected outcomes created by different categories of information, even where data may be sparse. Various techniques are used within Sheba to calculate the effect of out-of-date information, and unreliable sources and observations (Pope *et al.* 2006). This enables Sheba to be used in situations where the availability and quality of the data varies to create usable assessments that are reflective of the available data, and which also highlight the uncertainty created by any lack of relevant, reliable data (personal communication, Pope 2009).

4.9.4 Model formulation in Sheba

In an overview of the Sheba software (Pope 2008), it is described how the software has been developed as a framework for structuring and analysing intelligence problems, with initial applications in the National Security Domain, but also in the Business and Commerce domain. It is also described that Sheba is a software framework for developing analytical models to represent the complexity and subtleties of real world problems. This is achieved by:

- Decomposing such problems into fragments that can more easily be understood and managed;
- Storing information relating to the relevant problem at hand, using multiple sources and considering the time aspects;
- Adding qualifiers relating to the reliability and credibility of information sources;
- Providing reasoning with uncertain and/or incomplete information using a number of analytical models;
- Setting up complete inference chains using subjective logic formalised in a probabilistic framework, from information to assessment;
- Providing output in terms of likelihoods and certainty of particular outcomes; and in this way giving measures of not only the uncertainty of outcomes but also how much is really known about the problem, and where critical knowledge gaps are.

Whilst initial applications have been in unrelated domains, it can clearly be seen how the Sheba framework may provide considerable support in the sphere of uncertain and incomplete information encountered in the urban water domain. To specify a model in Sheba, an analyst will need to provide certain information, relating to:

- Choosing, in the language of Sheba – the Hypothesis, i.e. a particular issue to explore, for example ‘successful installation, operation, performance and maintenance of a desalination

plant in a particular location operated by a particular organisation, and based on a certain technology, etc?

- Identifying the Topic Domains, i.e. the terms relevant to the particular problem, i.e. Hypothesis, relating to all factors or items of information which relates to, and including, the hypothesis, and for each topic domain possible states have been defined, such as for example if the term is ‘environmental acceptability’, the states may be ‘high environmental acceptability’ and ‘low environmental acceptability’;
- Setting up the Model, defining the relationship between the Topic domains and the Hypothesis. This is done by specifying a system of conditional probabilities (i.e. applications of Bayes’ formula):
- A topic domain can be defined as either a Symptom/Indicator or an Influence/Driver for the chosen Hypothesis;
- Each of the conditional probabilities are specified on the basis of existing information; and can be classified as Simple opinion, Probability or Bayesian and specifying, as percentage of trustworthiness, the Certainty that the estimate is judged to have;
- Linking Topic domain states, for example in the case of an Influence/Driver ‘The probability of weak ownership of technology assuming that there is a low social and cultural acceptability of the solution’. For Symptoms/Indicators the statement is reversed.
- Entering the Data sources which are to be used in the Assessment, identifying documents and other sources of information that are relevant for the Hypothesis at hand. These Data sources contain different information at different times, and with different levels of Certainty. They are entered as Simple opinions, Probabilities, or Bayesian statements referring to the states of Topic domains. Conflicting information is acceptable, and dealt with using probabilistic formalism.

- Setting up an Assessor specifying which information sources to use, which models to link up, and providing output results such as:
- The likelihoods and certainty of different outcome states;
- Graphical output containing a number of different aspects.

The layout of the Sheba software is shown in Figure 4-10, where a project is entered.

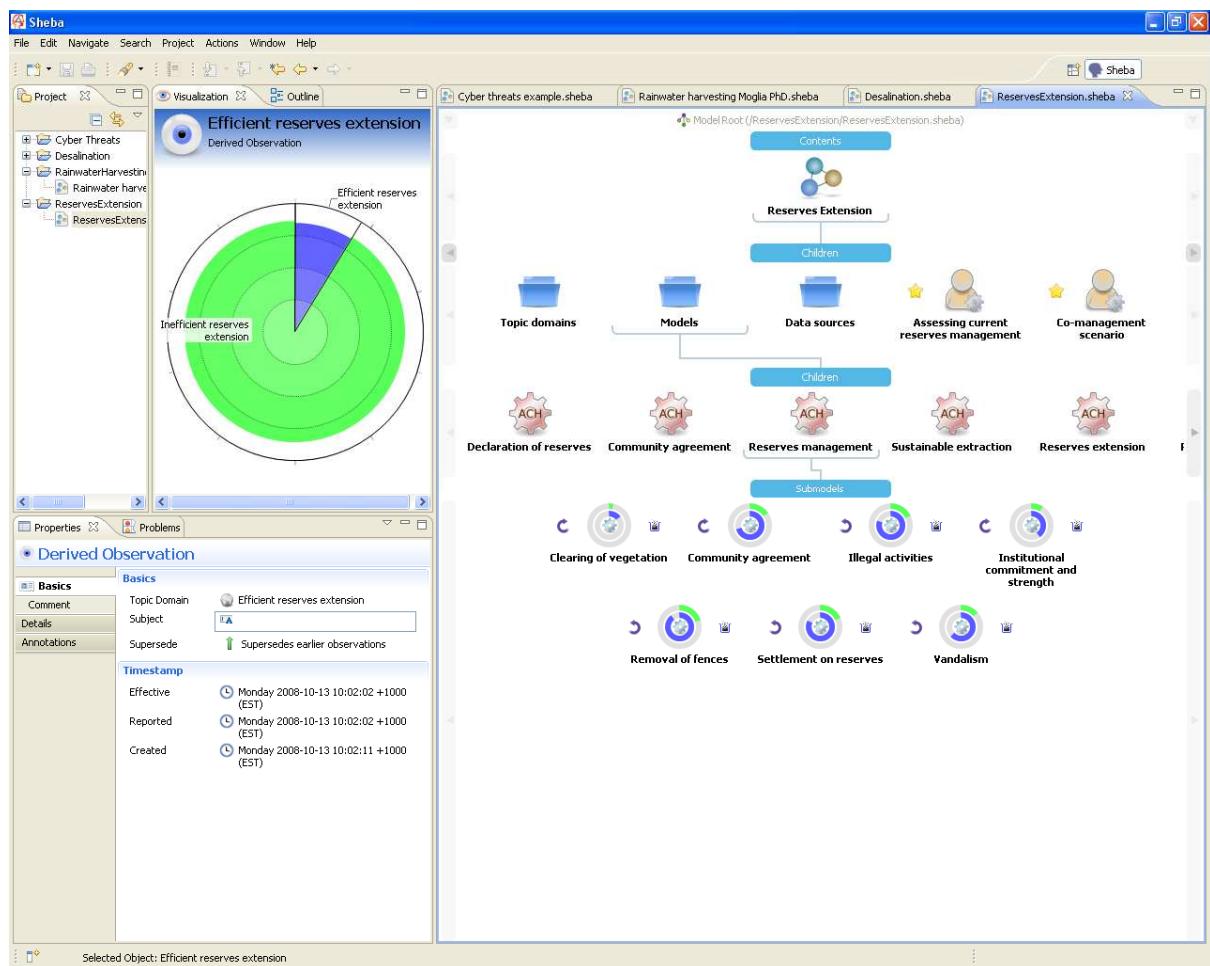


Figure 4-10: User Interface for an example BN Model in Sheba

Chapter 5: Review of case study site

To picture Kiribati, imagine that the continental U.S. were to conveniently disappear leaving only Baltimore and a vast swath of very blue ocean in its place. Now chop up Baltimore into thirty-three pieces, place a neighbourhood where Maine used to be, another where California once was, and so on until you have thirty-three pieces of Baltimore dispersed in such a way so as to ensure that 32/33 of Baltimorians will never attend an Orioles game again. Now take away electricity, running water, toilets, television, restaurants, buildings, and airplanes (except for two very old prop planes, tended by people who have no word for ‘maintenance’). Replace with thatch. Flatten all land into a uniform two feet above sea level. Toy with islands by melting polar ice caps. Add palm trees. Sprinkle with hepatitis A, B and C. Stir in dengue fever and intestinal parasites. Take away doctors. Isolate and bake at a constant temperature of 100 degrees Fahrenheit. The result is the Republic of Kiribati (Troost 2004: 15-16).

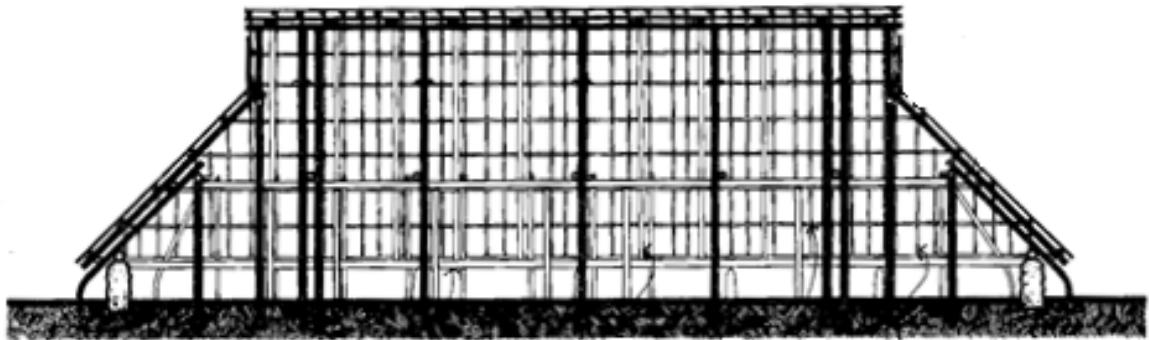


Figure 5-1: Traditional Maneaba structure, a focal point in I-Kiribati culture

Notes: Sourced from Hockings 1989: 222.

In the previous chapter it was argued that the methodology needs to be grounded in real issues within a case study environment. Furthermore, a case study location was identified, in the small atoll town Tarawa in the middle of the Pacific Ocean, which is the capital of the small nation of the Republic of Kiribati. This chapter provides a review of the case study location and hence provides qualitative data and information and another case study description is provided by Moglia and colleagues (2008a). Through this case study, key issues, variables and actors are identified; and this will support further data collection and modelling exercises. It is also worth noting that the case study location was chosen not on the basis of being a typical location, but on the basis of the particular and extreme difficulties that it faces in terms of small town water governance.

This chapter provides the background of the case study location; both in terms of context, but also in terms of the historical path of the Tarawa water system. Path dependency is an important feature of Complex and Adaptive Systems, as their states and dynamics depend strongly on their history. For example, humans, as examples of such systems, depend strongly on their personal experiences and not only on their physical and genetic makeup. In the Tarawa water system, historical events have shaped not only governance systems, but also the physical systems. From a systems perspective, history can be used as a source of data for generating understanding which can be used to populate models. From a different perspective, and thinking along the lines of the Cynefin framework, each historical development project can be seen as a probe that has generated a system response that can be analysed inductively for the purposes of sense-making.

5.1 Study area description

In this section, the field study context, Tarawa in Kiribati, is briefly described in terms of geography, language, demography, and environment and development challenges. Subsequently, a historical review of the Tarawa water sector is described.

5.1.1 Geography

Tarawa is located in the country of Kiribati which is an island nation in the Pacific Ocean which stretches across the equator, and borders the international dateline. Kiribati is culturally and geographically located in the Pacific region of Micronesia and consists of 33 islands, of which 32 are either coral atolls or coral reef islands. All these islands except one are in three main island groups (Asian Development Bank 2004c):

- The Gilbert Group containing 17 islands and most of the Kiribati population. This island group crosses the equator and lies approximately north of Tuvalu (north of Fiji) and south of the Marshall Islands;
- The Phoenix Group consisting of eight islands with a total land area of merely 30 km², and only a small population. Only two islands are populated in this group;
- The Line Group consisting of eight islands but with a total land area of 800 km². Only three islands are populated in this group.

In addition to these, the island of Banaba is also part of Kiribati. Banaba is a raised coral atoll of 6 km² which was heavily mined between 1900 and 1979 by the British Phosphate Commission (South Pacific Applied Geoscience Commission 2000), and where only a remnant population of 301 now remain. Most of the population have left because the island was damaged by mining (Hindmarsh 2002). Much of the money earned by the Government of Kiribati from the mining has been set aside in a Revenue Equalisation Reserve Fund (Australian Department of Foreign Affairs and Trade 2008) and compared to for example its neighbour Nauru, the Asian Development Bank considers Kiribati to have a history of sound fiscal management (Asian Development Bank 2002).

Tarawa lies within the Gilbert Group and geologically it is an atoll island chain, i.e. a string of closely connected sandy islands on a base of coral, with a lagoon in the centre (Jones 1997); see Figure 5-2 for geographical description.

The main islands, with descriptions on the basis of personal observation and with populated data retrieved from the 2005 census (Kiribati National Statistics Office 2006) are described below.

Betio: with a population of 12,509 it is the most densely populated island, and the location of the urban utility head offices (PUB and WEU), shops, a handful of restaurants, the wharf, the harbour, the main police headquarters, workshops, a small amount of industry, as well as a large number of informal settlements. Betio was also the site of a large scale battle during world war 2 and there are remains of this battle scattered around the island and its surrounding waters, which poses danger both in terms of explosives as well as pollution.

Bairiki: which is connected to Betio via a causeway is the location of many central government offices, the main prison in South Tarawa, a number of foreign missions and embassies (including that of Australia), a market, shops, the national arena (i.e. a grass pitch with a stand), and the households of some of the wealthier families that mainly work as public servants. Bairiki only has a population of 2,119 and is not at all as densely populated as Betio;

Bikenibeu: with a population of 6,170, it is a largely residential island that also houses the main hospital, a number of shops and government offices. This island has a relatively high population density and some of the problems that this brings, i.e. considerable pollution of groundwater and lagoon, and some reports of pervasive smell;

Eita: one of the smaller islands of South Tarawa with a population of 2,229. This island is mainly residential and is often described as very religious and conservative. Its main landmarks are a number of churches, and a large school;

Bonriki: with a population of merely 2,119 on one of the largest islands of Tarawa, this island is essentially peri-urban. It is the location of the airport and the landing strip crosses the island from one side to the other on an angle. It is also the location of the largest water reserve which has been established for the protection of the groundwater which is the main source of water for South Tarawa. Most of the settlers now live on the edge of the island, although there are also settlements on the water reserve;

Buota: this is an essentially rural island, and the main road ends at Buota. To go further one has to either wade across in low tide or use a small boat. This island is also the location of a large water reserve and as such settlers have largely been forced to live along the edges of the island;

North Tarawa: this is a number of islands including the closest islands Abatao and Tabiteuea for which it has been suggested to introduce new water reserves. In North Tarawa, the population live primarily in small villages and rely heavily on subsistence activities, although some crops are grown and sold in South Tarawa.

The settlements in urban Tarawa are highly variable in type, ranging from temporary shacks, to more traditional houses combined with more modern materials (see Figure 5-3). Worth noting is also the location of the House of Parliament on a small island named Ambo, which is located on the stretch of relatively small and mainly residential islands between Eita and Bairiki, i.e. (population as per 2005 census in brackets): Tangintebu (94), Taborio (955), Ambo (1,688), Banraeaba (1,789), Antebuka (390), Teaoraereke (3,939) and Nanikai (803).

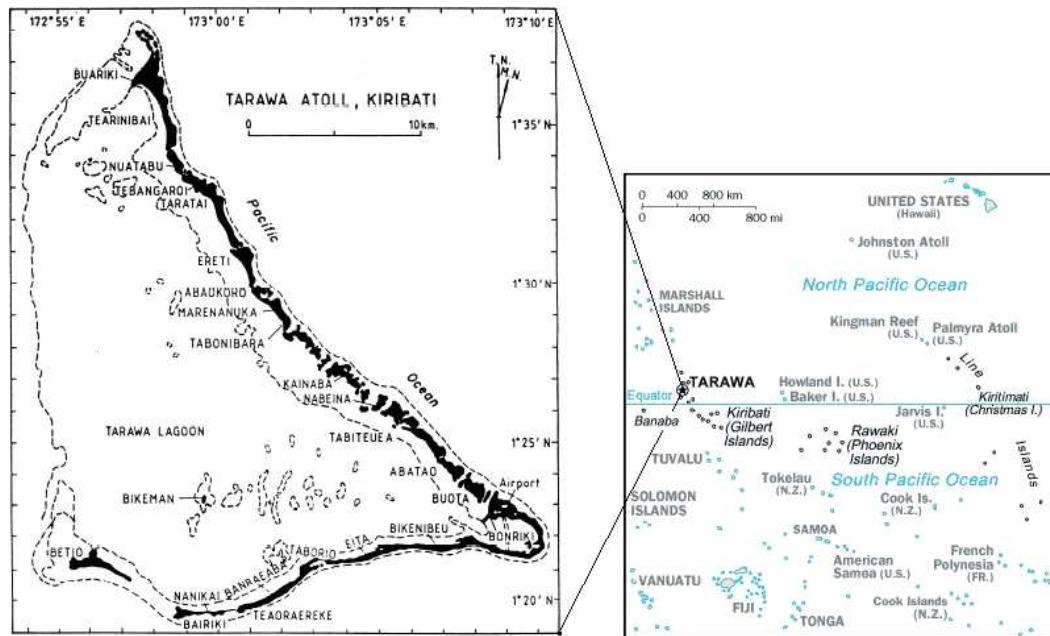


Figure 5-2: Map of Tarawa Atoll and the surrounding Central Pacific Ocean

5.1.2 Language

The language spoken in Kiribati is I-Kiribati which is an Austronesian language and a Micronesian dialect. English is also spoken by many. Nonetheless, language can be a major barrier when working as a foreigner in Kiribati (Asian Development Bank 2004). Therefore, it is recommended to involve native I-Kiribati speakers in any project in Kiribati (Asian Development Bank 2004).



Figure 5-3: Typical household buildings in South Tarawa

5.1.3 Demography

Kiribati has a national population according to the latest census of 92,553 individuals which are distributed on a number of islands as per Table 5-1. Due to high birth rates, the population is also growing rapidly and more than 35 percent of the population is below the age of 15 and Kiribati has a high population growth rate of about two percent per annum (Kiribati National Statistics Office 2006).

Table 5-1: Kiribati estimated population, land area and population density

	Estimated population in 2005	Land area (km ²)	Estimated population density
GILBERT GROUP			
Banaba	301	6.29	48
Makin	2385	7.89	302
Butaritari	3280	13.49	243
Marakei	2741	14.13	194
Abaiang	5502	17.48	315
North Tarawa	5678	15.26	372
South Tarawa	40311	15.76	2558
Maiana	1908	16.72	114
Abemama	3404	27.37	124
Kuria	1082	15.48	70
Aranuka	1158	11.61	100
Nonouti	3179	19.85	160
North Tabiteuea	3600	25.78	140
South Tabiteuea	1298	11.85	110
Beru	2169	17.65	123
Nikunau	1912	19.08	100
Onotoa	1644	15.62	105
Tamana	875	4.73	185
Arorae	1256	9.48	132

PHOENIX ISLANDS			
Teeraina (Washington)	1155	9.55	121
Tabuaeran (Fanning)	2539	33.73	75
Kiritimati (Christmas)	5115	388.39	13
LINE ISLANDS			
Kanton	41	9.15	4

Source: Kiribati National Statistics Office 2006; Extracted from Table 1A, p.16.

Approximately 90 percent of the Kiribati population lives in the Gilbert Group; however with increasing population pressure, the Government of Kiribati (GoK) has initiated a program with incentives for people to move to growth centres in Beru, Butaritari, Tabiteuea North and Kiritimati Island (Asian Development Bank 2004c). One of these centres, Kiritimati Island lies outside of the Gilbert Group. Kiritimati Island is of particular interest because it represents more than half of the land mass of Kiribati and due to its late settlement, it is relatively pristine and almost fully owned by the Government, making land ownership issues less complicated (Asian Development Bank 2003a).

Tarawa, the capital of Kiribati, has a population of about 46,000 and that represents approximately 50 percent of the national population (Kiribati National Statistics Office 2006). Tarawa is administratively divided into South Tarawa and North Tarawa. Whilst the islands of North Tarawa are essentially rural, the islands of South Tarawa are urbanised and because of their small total land area of approximately 15 square kilometres the island group has a population density of at 2,558 persons per square kilometre (Kiribati National Statistics Office 2006). This is on par with urban population densities in the developed world, and well above population densities in most Australian cities. In Betio, the most densely populated island of South Tarawa, the population density is at least 8,500 people per square kilometre; which puts

considerable pressures on natural resources such as land and water with consequent environmental damage.

5.1.4 Colonisation, Transition and Post-colonisation eras

It is believed that there has been human settlement in the Micronesian area, including Kiribati, for some 3,000 to 4,000 years (Jones 1997). During this time it is believed that a number of invasions have arrived in the Gilbert Islands, including the first Austronesian settlers from the north, to the latest migration from Samoa to Kiribati in the 14th century AD (Jones 1997). The Line and Phoenix islands were never settled (Jones 1997). Before the colonisation, most I-Kiribati belonged to clans, and there was no national identity (Hockings 1989); and clans were strongly interlinked with land ownership (Hockings 1989; Asian Development Bank 2004). Traditionally, land was gained through fighting between clans (Asian Development Bank 2004). There were different governance styles in the islands, ranging from democratic systems based on the traditional leaders (unimane) gathering in community buildings (Maneabas, see Figure 5.1)); whilst other places were ruled in an autocratic fashion in what is referred to as the uea system (Jones 1997).

After numerous encounters with European explorers, traders and whalers, and some largely unsuccessful efforts to introduce Christianity, the Gilbert Islands were colonised by the British in 1892 (Grimble 1952) when the population was considered to be approximately 26,500 persons (Jones 1997). The British colonial rule was dominated by large scale phosphate mining on the island of Banaba, west of Tarawa (Asian Development Bank 2004a). During World War II, the Japanese invaded the islands and were reportedly both cruel and ruthless to the local population (Asian Development Bank 2004a). Once phosphate deposits were exhausted in 1979, Kiribati became independent (Troost 2004). Christmas Island was also used for British nuclear testing in 1954 (Jones 1997).

The British introduced a traditional British bureaucracy and trained the locals to take the roles in administration (Grimble 1952). The colonial administration disposed of the uea system but supported the maneaba system; however they also put all villages under centralised control

(Jones 1997). This also involved a system of a local magistrate representing the government and being a judicial authority, supported by a local policeman (Jones 1997). The intention was for the magistrate to work with traditional leaders; however he is essentially seen as a representative for the colonial government, and government enforcement; and consequently the gap between traditional authorities (i.e. the maneaba system) and the government has not been effectively bridged (Jones 1997).

The Republic of Kiribati has adopted a British style government system based on 'Westminster principles', but combined with local values and issues (Jones 1997). It is also worth noticing that the institutional structure in Kiribati is different to that in Western societies in the sense that Western style bureaucracies are additions onto existing structures, as described in a key report:

The organisational structure of traditional I-Kiribati society for decision-making is the family. The Maneaba, a council of families represented by respected family elders (unimwane) addresses issues outside the family. With the arrival of Europeans came the introduction of a western government structure which included elected island councils, parliament and a president, responsible for the broader issues of education, health care, financial assistance, development projects and governance of the islands. Adapted with cultural beliefs and practices the government remains separate / external to the family and individual and reflects a 'paternalistic' role. Similarly, the local Island Councils are seen as a means through which the family can communicate with the government. In this context planning for the protection of groundwater must acknowledge the separation between the traditional and formal post-European structures (Asian Development Bank 2004a: 17).

This appears to have generated an inherent and built in tension between traditional organisational structures and post-European Organisational structures, as illustrated in Figure 5-4 and tensions over land rights can in fact be seen as a manifestation of this conflict.

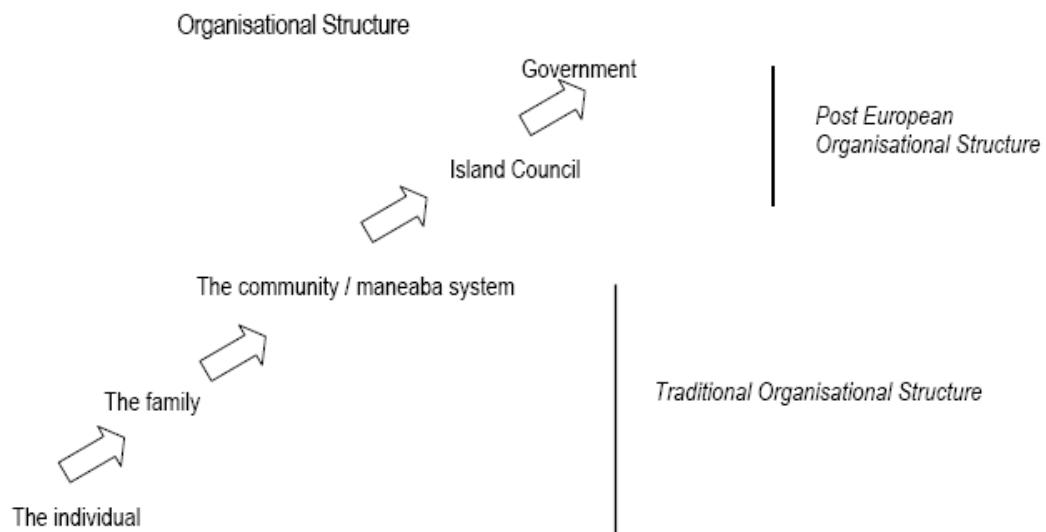


Figure 5-4: Organisational structure in Kiribati society

Source: Asian Development Bank 2004a

5.1.5 Culture and customs

The culture in Tarawa is mostly that of I-Kiribati people who have arrived from the outer islands in search for opportunities of the more urban and modern life, and in particular education for their children (Kirion 1985a). Another attraction of Tarawa is its social context with a lively range of cultural activities that include music, dancing and fishing (Onorio 1985; Kirion 1985b).

In the old traditional order, there was no sense of national Kiribati unity, but these days most I-Kiribati feel a strong national pride (Talu 1985). Kiribati society is still very much governed by traditional customs, but this is now combined with modern institutions into a unique combination (Talu 1985). The first early contacts with European visitors were Spaniards (in the 1500s) searching for new territories, followed by British (in the 1700s) but these were brief and infrequent with no major impact on I-Kiribati society (Macdonald 1982). Following the early contacts was the much more influential trade (mainly with whalers), colonisation by the British Empire, and arrival of Christian missions (Macdonald 1982).

The impact of Christian missions has fundamentally changed I-Kiribati life (Kirata 1985). Whilst some traditional beliefs remain, these have largely been replaced and given new

meanings, through the belief in a various Christian denomination (Kirata 1985). Traditional spiritual beliefs continue to be practised but less openly amongst families (Kuruppu 2009). Christian churches provide free education and women's empowerment, and an increasing level of individualism, but have also been criticised (Kirata 1985; Kuruppu 2009). Criticisms relate in particular to the demands for donations, and the social problems and increasing levels of poverty that this causes (Kuruppu 2009). In fact, Kuruppu (2009) identifies the role of religion in Kiribati as a significant impediment to climate change adaptation and adequate urban water management.

Customs and culture in Kiribati are unique and those who arrived from other places tend to be perceived as odd (Kirion 1985a). In fact, there is a concept in the I-Kiribati language, which is I-Matang that refers to Westerners (Talu 1985; Jones 1997; Asian Development Bank 2004a). This term is also used to describe ideas that come from a Western perspective, and without consideration of 'how it works in Kiribati' (Jones 1997; Asian Development Bank 2004a). Therefore, a project that is considered I-Matang will have a reduced chance of success, and consequently, collaboration with I-Kiribati people in developments should be seen as critical (Asian Development Bank 2004a).

There are a number of cultural features and customs that need to be considered in water management in Tarawa. Firstly, it must be recognised that administrations only have a short history in Kiribati and are sometimes in conflict with traditional decision making structures and practices (Talu 1985; Jones 1997; Asian Development Bank 2003c). In Kiribati, the family is the traditional core unit, and male elders are representatives for the families in a village (Talu 1985). These male elders meet in the Maneaba which is a traditional building where, among other things, decisions are being made (Talu 1985; Tabokai 1993). Such decisions often involve long discussions and are reached in a relatively democratic manner (Tabokai 1993; Asian Development Bank 2004a). Within the Maneaba, there is certain etiquette and rules and as an outsider coming to Kiribati it is difficult to know how to behave appropriately in these circumstances, especially without speaking the language (Asian Development Bank 2004a). The

debate in the Maneaba is not polarised, and the aim of the elaborate decision making process is to reach consensus (Tabokai 1993).

Other cultural aspects also need to be considered such as the fact that old age is respected in I-Kiribati culture, and that the I-Kiribati culture is male dominated (Asian Development Bank 2004a). Women's roles in I-Kiribati society are however changing, and are increasingly being asked to give advice and take responsibilities outside of their traditional spheres (Tira 1985).

Another view that is encountered is that women are more suitable than men for contributing to long term planning and management of the water supply as their traditional roles require more foresight and careful consideration (Asian Development Bank 2004a).

The context of Tarawa also needs to be considered in terms of the limited amount of employment opportunities and the fact that the majority of the community are still engaged in subsistence activities (Tofiga 1985; Jones 1997). This generally involves fishing, collection of coconuts as well as a small number of other crops, such as swamp taro, breadfruit, pandanus (for their leaves), bananas etc (Tofiga 1985). More recently, new crops have arrived such as limes, tobacco and other exotic introductions (Tofiga 1985). Households often also keep pigs and chicken, and there are a large number of cats and dogs on the Tarawa islands (Jones 1997).

There is also a local custom called *bubuti*, which is an acceptable way of sharing resources by relatives being able to take possession of material belongings without asking permission (Jones 1997; Asian Development Bank 2004a). This also means that relatives can come to live on your land and can not be refused to do so (Jones 1997). These customs and norms mean that strategies based on money that are typically used in Western developed countries are not always suitable (Asian Development Bank 2004b). On the other hand, financial issues have been identified as a key factor in the conflict over land on the water reserves; in particular in relation to the discrepancy between land lease payments and market land prices (Dray *et al.* 2006a; 2006b; 2007). This shows that money is indeed an important consideration at least for some; and this may be a reflection of a move by many families away from traditional subsistence

living. The role of money in Tarawa appears to be complicated and contentious where little can be taken for granted.

5.1.6 Environment

The most commonly mentioned environmental concerns in Kiribati are:

- Pollution of lagoons, primarily in Tarawa (White *et al.* 1999a, 2005b; Government of Kiribati 2000, 2002; Asian Development Bank 2003b);
- Over-extraction and pollution of freshwater lenses, primarily in Tarawa (Asian Development Bank 2003b; Falkland 2003; Government of Kiribati 2002; White *et al.* 2005; 2007); and
- Failure to effectively police fishing stocks, and as a consequence unsustainable harvesting of same stocks (Asian Development Bank 2002).

Additionally, the Government of Kiribati report to the 2002 summit on Sustainable Development states the following:

The inevitable problems attributed to improper management of waste and pollution is a widespread experience in Kiribati. The situation is worsening in urbanised areas where there is a high population density and the obvious problem of overcrowding and pollution evolving from many sources (Government of Kiribati 2002: 9).

Two of these issues are related to freshwater in Tarawa, i.e. pollution of lagoons as well as over-extraction and pollution of freshwater lenses.

Additionally, according to the South Pacific Applied Geoscience Commission's Environmental Vulnerability Index (South Pacific Applied Geoscience Commission 2005), Kiribati is extremely vulnerable to climate change. In fact, it is the second most vulnerable nation in the Pacific Island region, after its neighbour Nauru.

Given that the highest point of Tarawa is only approximately three metres above sea level, it is considered very sensitive to climate change. The model-based projections of sea level rise by

2099 by the International Panel on Climate Change (IPCC 2007: 45) ranges from 0.18 and 0.59 metres depending on the scenario and the model used; meaning that the Tarawa islands will not be completely inundated but may be badly affected, in particular under any worst case scenario.

The impact of sea level rise in small islands is expected to:

- Exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities.
- [Cause] deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources.
- By mid-century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods.
- With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands. (IPCC 2007: 52)

5.1.7 Development challenges

Kiribati is classified by the United Nations as both a Small Island Developing State (SIDS) as well as a Least Developed Country (LDC). This means that Kiribati is likely to have (reiterated from chapter 2):

- Low income, in the light of a three-year average estimate of the gross national income per capita (under \$750 for cases of addition to the list, above \$900 for cases of graduation);
- Weak human assets, as measured through a composite Human Assets Index;
- Economic vulnerability, as measured through a composite Economic Vulnerability Index.
- Small size;
- Remoteness from large markets (a factor of high transport costs); and
- High economic vulnerability to economic and natural shocks beyond domestic control.

Tarawa is also classified as a small town, with the following typical challenges (reiterated from chapter 2):

- “Lack of resources: skilled staff, finances, information and knowledge;
- Unpredictable population growth in population;
- High levels of uncertainty in source availability and economic capacity; and
- Close interactions between rural surroundings and urban areas.”

Additionally, the unemployment rate in Tarawa is very high with a majority of the resident workforce engaged in subsistence type activities (Asian Development Bank 2002).

5.2 Case study historical review

Historically, the water and sanitation service provision in Tarawa has been dominated by hand-outs from international donor agencies, but unfortunately the efficiency of programs has been less than satisfactory.

Kiribati has relied on international aid and donor agencies to assist in addressing water and sanitation problems. These aid and donor programmes in the water and sanitation sector have tended to be relatively short term and narrowly focused, particularly on the water and sanitation infrastructure needs and on the agendas of international agencies (White *et al.* 2008: 286).

This section describes the results of a literature based historical review of the water supply in Tarawa in the Republic of Kiribati.

5.2.1 Issues and concerns

Tarawa relies primarily on groundwater for water supply (Falkland 2003). Unfortunately access to good quality groundwater is restricted by over-population and shortage of land and for these reasons, alternative water sources are used, i.e. rainwater harvesting and desalination (Falkland 2003). Groundwater for the reticulated water supply is extracted from infiltration galleries on the islands of Bonriki and Buota (Metutera 2003).

Rainwater collection from roofs is considered merely a supplementary source of water, because, as a consequence of the limited size of tanks, in times of prolonged drought there would be insufficient water volumes unless very large and expensive tanks were installed (Falkland 2003).

In addition to extracting groundwater via infiltration galleries and the reticulation system, many households rely on extracting groundwater from domestic shallow wells (Asian Development Bank 2000b). In fact, most households have a domestic well, and six percent of households in Tarawa use domestic shallow wells for extracting water for drinking and cooking, while 18 percent of households use water from domestic shallow wells for other uses (Asian Development Bank 2000b). The households that rely solely on domestic wells are primarily in rural Tarawa, in Bikenibeu and in the squatter areas of Betio (Asian Development Bank 2000b).

Despite alternative sources, reticulated water is the main supply for most households; however the supply is intermittent and often fails to meet demand (White *et al.* 1999b). As a consequence, there is no 24-hour supply as this would lead to excessive demand and leakage (Metutera 2002). Indeed, there is often only reticulated water supply for one hour a day (Metutera 2002). Also, unaccounted for losses are estimated at 50 percent combining both actual physical losses as well as losses to illegal connections (Government of Kiribati 2002).

5.2.1.1 Freshwater lenses

The groundwater on which Tarawa relies occurs as a thin lens of freshwater floating over seawater in coral sand and limestone aquifers (White *et al.* 2007). Traditionally, communities have relied on these freshwater lenses for their water supply:

Fresh water was obtained from wells sunk to the level of the fresh-water lens. Potable water was generally available, even in times of drought, on all sections of the islets more than three hundred meters in width. There were exceptions to this, and on Onotoa, at Tebuarorae for instance, the well water was highly saline and odorous. The general availability nevertheless indicates that settlement pattern was not influenced by considerations of fresh water supply (Hockings 1989: 66).

In modern times, this situation has changed with increasing population densities, and the size of the freshwater lenses is becoming increasingly important. The critical factors determining the size of the freshwater lens and the sustainable pumping rates are the width of the island, the ease of transmission of freshwater through aquifers and the amount of rainfall (White *et al.* 2005). The freshwater in the groundwater is recharged through rain, and lost through a combination of (Falkland 2003):

- Trees and bushes that tap into the freshwater lens;
- Domestic wells and infiltration gallery pumping schemes;
- Discharge to the ocean at the lens and island margins; and
- Tidal mixing generating a thick brackish transition zones between freshwater and seawater.

This means that some islands are better suited for pumping groundwater than others, with the wider islands, Bonriki and Buota, being the primary sources of water (Falkland 2003; Metutera 2003). Groundwater is extracted in Bonriki and Buota from infiltration galleries that are shown in Figure 5-5 and Figure 5-6. It is also worth noting that during the 1960s and 1970s, freshwater lenses in Betio, Bikenibeu and Bairiki were explored and subsequently pilot infiltration galleries were installed (Falkland 2003). It was later concluded that the freshwater lenses on these islands were inadequate and reserves and infiltration galleries were abandoned (Falkland 2003).

To allow sustainable extraction of groundwater, establishing sustainable yields for different islands is of critical importance, and considerable efforts have been invested over the years, each time adjusting conservative estimates upwards. For instance, the estimate for Bonriki, the island with highest sustainable yield, was estimated in 1982 as 750 m³/day, and subsequent investigations by Falkland, based on improved information, in 1992 adjusted the estimate upwards to 1,000 m³ / day, and in the most recent investigations in 2002, under the Asian Development Bank funded SAPHE project (described in section 5.2.4.1), an estimate was given for Bonriki at 1,350 m³/day (Falkland 2003). The sustainable yield estimates for the islands in

North Tarawa in 1992 was 3,850 m³ /day, but based on improved information and analysis this was adjusted upwardly in 2002 to 4,620 m³ /day (Falkland 2003).

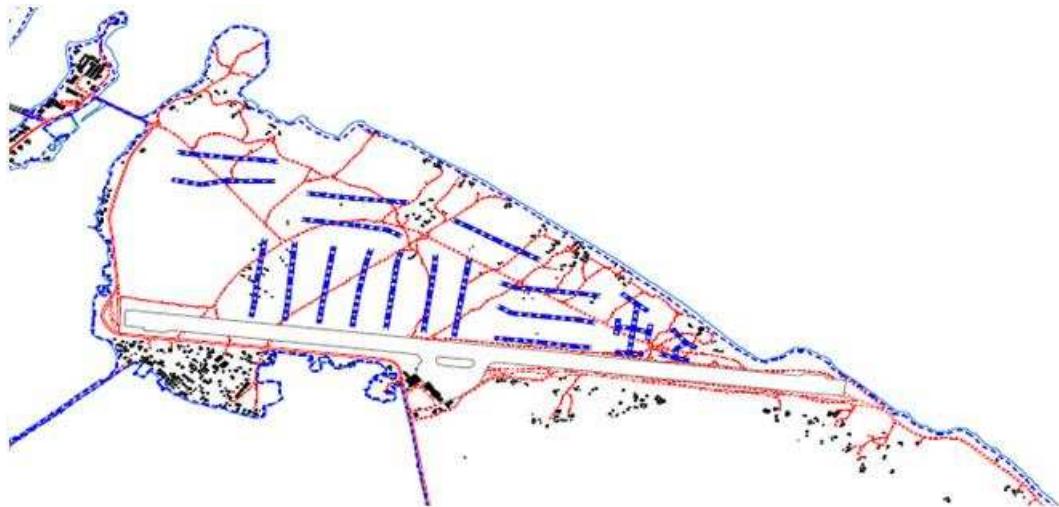


Figure 5-5: Spatial layout of infiltration galleries in Bonriki

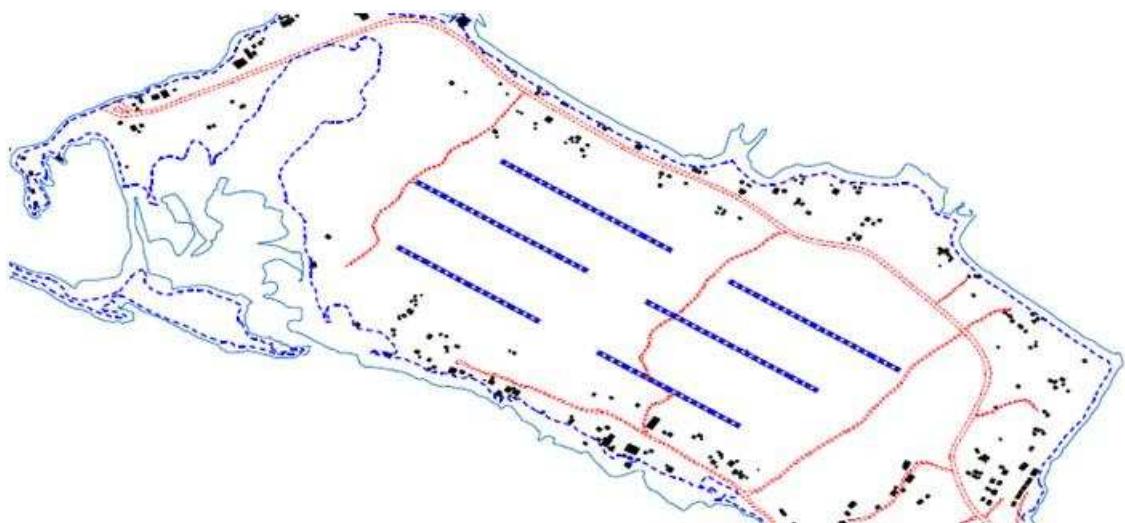


Figure 5-6: Spatial layout of infiltration galleries in Buota

Source: Metutera 2003

Notes: Figure 5-5 and Figure 5-6 show the layouts of infiltration galleries on the islands of Bonriki and Buota. Thick blue lines indicate infiltration galleries and red lines indicate roads. Black dots indicate houses. The blue outlines indicate the edges of the islands. Figure 5-5 also shows an outline of the airport runway.

5.2.1.2 Droughts

Being an island, the only inflow of water into Tarawa is via rainfall, with the exception of smaller volumes of bottled water. Rainfall in the central Pacific, where Kiribati is located, is dependent on variations in sea surface temperatures in the central and eastern Pacific regions, and therefore dependent on El-Nino Southern Oscillation (ENSO) events (White *et al.* 1999b). Rainfall in Tarawa is strongly correlated with the Southern Oscillation Index (SOI) which is used to indicate ENSO events (White *et al.* 1999c). This in turn leads to high variability in rainfall, and high coefficients of variation (Falkland 1999). Drought is a relative term and simply indicates below average soil moisture and rainfall to which society and ecosystems have adapted (White *et al.* 1999b). With high variability of rainfall in the central Pacific, this indicates relatively frequent occurrences of drought. Falkland indeed states for the Gilbert Group that:

[...] very high rainfall is associated with El Niño episodes and long droughts can be associated with La Niña episodes. (Falkland 2003: 4)

A major drought event occurred in 1998-1999 in South Tarawa (Falkland 2003; White *et al.* 1999b) and this led to definite increases in shallow groundwater salinity in the freshwater lenses on the reserves (White *et al.* 2008) as shown in Figure 5-7.

It has been shown that droughts in combination with over-extraction of water from groundwater resources significantly impacts on the thickness (i.e. size) of the freshwater lens (White *et al.* 1999c). For the case of South Tarawa, it is however difficult to assess what this means in terms of impacts on the community, as little is currently known about the volumes of alternative sources that are used, nor the losses that occur throughout the system (White *et al.* 1999c).

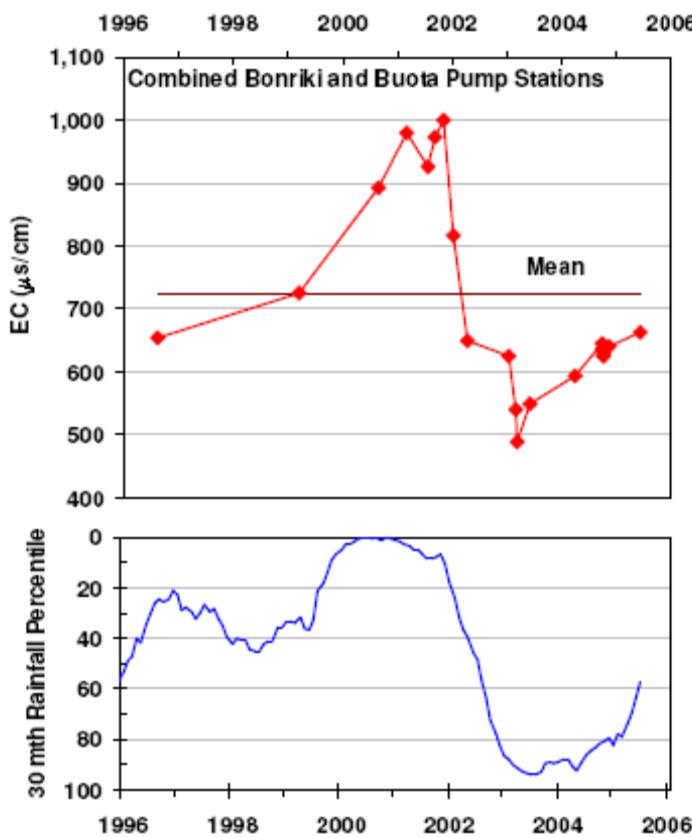


Figure 5-7: Impact of the 1998-2001 droughts on groundwater salinity

Notes: In this figure salinity is indicated by Electrical Conductivity (EC) and measured in $\mu\text{S}/\text{cm}$ and the graphs show the salinity for the combined freshwater lenses in Bonriki and Buota. The source of the figure is White *et al.* 2005.

5.2.1.3 Agricultural use of water

In Kiribati, where industrial activity is negligible, water use is mainly for household use, and for agricultural purposes. The main crops grown in Kiribati are coconut, breadfruit, pawpaw, taro (referred to as babai in I-Kiribati language), cabbages, banana and pandanus leaves which are used for mat (Kiribati National Statistics Office 2006). However, agriculture is limited due to unfavourable conditions:

Agricultural development schemes are unfortunately encountering prevailing unfavourable environmental and climatic conditions not to mention the restricted land area and limited plant species. (Government of Kiribati 2002: 2)

The factors that hinder agricultural development related to the common calcareous soils are:

- Low fertility of soil due to absence of growth elements;
- High pH of soil (alkaline);
- Low rainfall;
- Prolonged droughts; and
- Intrusion of salt water resulting from rising [and variable] sea level (Government of Kiribati 2002: 3)

Not surprisingly, only a small amount of commercial agriculture exists and even this is mainly for local consumption (Government of Kiribati 2002). The exception is that there is a small amount of copra production for export purposes with a copra mill in South Tarawa.

5.2.1.4 Water reserves

Extracting groundwater at the Bonriki and Buota reserves for distribution to South Tarawa communities is a complex and sensitive social, cultural and economic issue (White *et al.* 1999b). A key issue of contention is that when the water reserves were established, through the Laws of the Gilbert Island in 1977 (White *et al.* 1999b), the traditional landowners were displaced by the government (Crennan 1998; Dray *et al.* 2006a; White *et al.* 1999b). Given circumstances, this is a major sacrifice for the public good by the affected families, and in terms of obligations to a centralised administration for the purposes of a common good:

- Centralised control of land for public purposes is a superimposed notion inherited from a period of foreign rule;
- There is an historic distrust of outsiders or government bodies ‘carving up’ the land for whatever purpose, private or public;
- The historic personal relationship to the land and the pressures of extended family obligation are far more compelling than the expectation of co-operation or sacrifice for the common good;
- Monetary compensation does not always compensate for the loss of relationship to the land, the dignity and identity that it provides; and

- A lesson that could be learnt from the Bonriki story, which was set in a land/subsistence based culture, is not to overburden one community with too much demand for public sacrifice (Crennan 1998: 5-7).

This level of contention is perhaps not surprising given that land in Kiribati is crucial for both social and economic reasons, and most families rely substantially on land for subsistence living, even in urbanised South Tarawa (White *et al.* 1999b). Additionally, the norm in I-Kiribati culture is that landowners can do whatever they wish on their land; and as such these norms are obviously in conflict with the declaration of reserves (White *et al.* 1999b). Traditional land tenure also tends to imply ownership over water (White *et al.* 2007) which in combination with the fact that seeing water as a commodity is a foreign concept to in most Island countries; and this has been claimed to be the reason why many small island countries have been reluctant to introduce national water policies, as is often imposed by international aid agencies and development banks (White *et al.* 2007; 2008). To balance for the sacrifice made by these families, the Government of Kiribati provide financial compensation to landowners in Buota and Bonriki, but this has also become an issue of contention primarily in terms of how much should be paid (White *et al.* 1999a).

Further complicating the issue on the reserves is that, by 1999, no lease had been established between the government and the landowners in order to formalise the arrangement for extraction water for public good purposes (White *et al.* 1999a). The reason for this is that landowners have refused to sign the leases, because of a combination of reasons such as inadequate compensation, the lure of potential resettlement in the Line Group (i.e. Kiritimati Island), and reluctance to give away any rights over the reserves that they still have (White *et al.* 1999a).

Another reason for dissent is that in the lead up to the establishment of the water reserves, there appears to have been no community involvement or consultation by the colonial government (White *et al.* 1999b). There was however meetings with Bonriki and Buota families during the extensions of reserves in the 1980s but no objections were raised at that point because it was

perceived that the project would generate employment opportunities during its construction phase (White *et al.* 1999b). It is also worth noting that

There is a traditional process of consensus within the village structure in the maneaba context but this was based on allegiance to, and respect for the senior citizens particularly the old men of the village, the unimane. Staff from any government organisation are often perceived by the wider community as an assembly of individuals whose primary motivation is the promotion and support of their family's interests. That self-interest may be seen as being furthered under the guise of the activities of the Ministry concerned (Crennan 1998: 5).

Unfortunately, the wider community seems to regard the water reserves as common property which can be exploited, and activities such as squatting, market gardening and pig-raising occur (White *et al.* 2007). As a consequence there is wide-spread occurrence of e-coli in the Bonriki lens; and probably Buota albeit no data exists for this reserve (White *et al.* 2008). Perhaps more disturbing is the practice of gravel mining causing erosion of land and increasing evapo-transpiration (South Pacific Applied Geoscience Commission 2007b). In fact, in a survey of 280 South Tarawa households, 206 (approximately 72 %) engage in gravel mining (South Pacific Applied Geoscience Commission 2007b), and the most commonly mined island is Bonriki where approximately 20% of the volume of all mined gravel in Tarawa is from. Gravel was found to be used for private use or for sale, for landscaping, and for home construction and brick making (South Pacific Applied Geoscience Commission 2007b).

5.2.3 Institutions and Legal arrangements

Institutionally a number of agencies have some responsibility for the provision of water supply in Tarawa as shown in Figure 4-5. Some of the abbreviations, i.e. those relating to the South Tarawa water supply, are as follows (adapted from White 2006b):

- MPWU: Ministry of Public Works and Utilities:

- PUB: Public Utility Board with responsibility for water supply provision in South Tarawa
 - WEU: Water Engineering Unit with responsibility for water supply provision in North Tarawa (including Bonriki and Buota)
- Ministry of Environment Lands and Agricultural Development (MELAD) with the responsibility for water and land conservation and protection (including against pollution). MELAD are also responsible for lease agreement and agriculture.
- Ministry of Health and Medical Services (MHMS) with the responsibility for water quality monitoring and guidelines, as well as for health monitoring;
- Ministry of Finance and Economic Development responsible for funding sources, economic sustainability and economic efficiency; and
- Office of the President (OB) which have a coordinating role.

There is no specific legislation in Kiribati covering all the major water issues in the country, but there are a number of pieces of relevant legislation (Asian Development Bank 2003b):

- The Public Utilities Ordinance 1977 which applies only to the activities of the Public Utilities Board (PUB). This ordinance gives the PUB the right to declare a part of any island to be a water or sewerage area and has the exclusive rights to supply water for this area. It also gives the PUB the rights to declare water reserves, as well as the necessary power to undertake all works relating to the provision of water and sewerage services. This ordinance also provides the relevant minister the power to make regulations in the area.

Critical omissions in the ordinance concerns issues such as:

- The level and standards of service to community that needs to be provided;
- Adopted water quality standards;
- Monitoring of system performance;
- Reporting to government or the community;
- Control of extraction rates from reserves;

- Details about how NGOs may operate in the water sector;
 - Standards of plumbing;
 - Regulations about how and when and if to cut off services to customers.
- Local Government Act 1994 which provides the Outer Island Councils the authority to operate water and sanitation systems, and in particular:
 - To regulate most activities that can affect freshwater resources such as cropping, vegetation clearing, construction, pits, fencing, building works, burial grounds, wells, rubbish etc;
 - To ensure financial compensation for services;
 - To safeguard and promote public health;
- Environment Act 1999 which covers two areas:
 - Environmental Impact Assessment describing which areas that require impact assessment, such as water projects and water developments;
 - Discharge licenses relating to pollution
- Public Health Ordinance which says very little, but describes areas in which regulation may be issued. It covers all areas where health issues may be encountered such as water supply and sanitation systems as well as rainwater tanks. This ordinance is perceived to be relatively weak.

There seems to be a potential conflict between the Public Utilities Ordinance 1977 and the Local Government Act 1994 in some locations, in terms of whether it should be the local councils or the PUB which is responsible for water services. This is particularly applicable at the edges of South Tarawa, in islands which can be classified both as being outer islands, but at the same time potentially within the legal responsibility of the PUB. The exact effect of such unclear roles is difficult to gauge.

Another major concern about the legislative system concerns regulation, i.e. who regulates the PUB and the Local councils, to make sure that they deliver an adequate service. There is also no clear mandate about what constitutes an acceptable level of service.

At a regional level, it is worth noting that there is a regional agency based in Fiji, SOPAC, which has acted to coordinate development efforts in the Pacific Island Countries. They also undertake some basic analytic and exploratory research to support water management; and have for example coordinated the Sustainable Integrated Water Resources Management Project for Pacific Island Countries (South Pacific Applied Geoscience Commission 2009) which has specific outputs for Tarawa and Kiribati.

5.2.4 Key events

Considerable amounts of funds have been spent on the water and sanitation sectors in Kiribati.

For example, White and colleagues argue:

Over the past 30 years, aid projects worth tens of millions of dollars have attempted to address the major water supply and sanitation issues in Kiribati. With a few exceptions, these have been short term and narrowly focused and have had limited impact. Indeed, some have been driven by international agendas rather than local priorities and needs (White *et al.* 2008: 285).

In this section, a number of the key projects and developments will be described which have all been useful contributions in one way or another but which have had varying degrees of success and return on investment.

5.2.4.1 Sanitation Public Health and Environment Improvement Program

The Sanitation, Public Health and Environment Improvement (SAPHE) program was approved by the Asian Development Bank in 1998 and the appropriate loans approved by the Government of Kiribati in 2002 (Asian Development Bank 2008a, 2008b). The overall objective was to improve the overall health and well-being of the population in Kiribati, with a particular focus on water supply, sanitation, solid waste disposal, and environment conservation (Asian Development Bank 2008b). The geographical focus was on the islands of South Tarawa; and relating to the water supply area the relevant components were (Asian Development Bank 2008a, 2008b):

- Restructuring and commercialisation of the Public Utility Board;
- Public education on water conservation;
- Trials of constant-flow meters at household level;
- Rehabilitation and improvement of water supply infrastructure;
- Solid waste collection program;
- Promotion of increased rainwater harvesting via micro-financing scheme; and
- Further declaration of water reserves to increase supply.

The overall assessment of the agents involved, including itself, in this project by the Asian Development Bank is merely “satisfactory”, which if one reads between the lines would indicate that more could have been achieved given the considerable investment. According to the Completion Report of this project, the major outstanding issues after completion relate to the declaration of reserves, and the restructuring and commercialisation of the Public Utility Board (Asian Development Bank 2008a). The main barrier for the strengthening of the PUB is considered to be the lack of human resources, and the inability to recover costs from households and other water users (Asian Development Bank 2008a). The report also indicates that lack of progress is to a major part due to inability to take into account local customs, context and culture (Asian Development Bank 2008a). It also acknowledges the very sensitive situation on the water reserves which are strongly inter-linked with land tenure issues. The constant-flow were found to be very expensive due to the context, and were poorly implemented and have added complexity, cost, operation and maintenance needs, and are therefore no longer operated (Asian Development Bank 2008). On the positive side, the introduced solid waste collection and disposal processes have been relatively successful, albeit the landfill arrangements have been inadequate (Asian Development Bank 2008a).

5.2.4.2 Establishment of a national water and sanitation committee

Because of overlap in responsibilities and regulatory duties between government departments, and with the high stakes involved in the water and sanitation issues in Kiribati, there is a need for a whole-of-government approach, and it has been suggested that this be achieved through a national water and sanitation committee (White 2006a) who would have as its task to oversee, implement and monitor the outcomes of government policy (White *et al.* 2008). Jones even suggests that coordination is in fact needed not only for the water and sanitation sectors, but for the entire urban sector (Jones 1997). It has also been argued that NGOs and community also need to be represented in this committee (White 2006c; White *et al.* 2008).

A water and sanitation committee was indeed established in 1990 involving relevant ministries (White *et al.* 1999b). What has happened to this important committee in between 1990 and now is not clear from the literature, but there is an obvious need to explore this further. Such efforts are currently underway in the EU funded Pacific Water Governance Project which is coordinated via the South Pacific Applied Geoscience Commission (White, 2006b).

5.2.4.3 The AtollGame and AtollScape experiences

Based on assessments of sustainable extraction rates in North Tarawa and an increasingly marginal supply in South Tarawa due to increasing demands, there are plans to set up new water reserves in Abatao and Tabiteuea which would add a supply of approximately 700 m³ per day (Falkland 2003). This was set to occur as part of the SAPHE project, but warning bells rang due to the problematic situation on reserves in Bonriki and Buota. To find a resolution or understanding of these issues, a project was funded by the Australian Centre for International Agricultural Research (ACIAR) and undertaken by researchers at the Australian National University. The aim of the project was said to be:

Our project aims at providing the relevant information to the local actors, including institutional and local community representatives, to facilitate dialogue and devise together sustainable and equitable water management practices (Dray *et al.* 2006b: 1-2).

The methodology that was employed is the Companion Modelling approach which has been described in chapter 3. As previously mentioned, this is an iterative framework based on a combination of participation and model building; where the models are used in engagement with stakeholders. Two major iterations were undertaken:

1. AtollScape where an Agent Based Model was developed based on knowledge elicitation and knowledge engineering (Perez *et al.* 2003)
2. AtollGame where a role-playing game was devised and applied, in conjunction with the AtollScape model (Dray *et al.* 2006a, 2006b, 2007).

Through in particular the AtollGame, a process was facilitated in which stakeholders shared viewpoints, and made apparent a number of intricacies in the interaction between migratory pressures, monetised land value, and access to water which had so far been dismissed in the official discourse about the reserves issues (Dray *et al.* 2007). A flowchart of financial, technical and social solutions was also generated (see Figure 5-8), which essentially showed that the current situation is unsustainable

- The government relies on the land leases [] to secure social acceptance of the water reserves. The land market has already pushed land prices to levels that cannot be matched by current government leases. In addition, other possible technical solutions (desalination plants, improved distribution) are not yet directly linked with the water exploitation issues on the islands (Dray *et al.* 2007: 13).
- Some local residents claim that the perceived environmental risks, such as the decreased yield of coconuts, created by the pumping in the water reserves should be compensated for as well. These damages [] should be paid to all the permanent residents of the island, aside from the land leases granted to the water reserve landowners. However, fewer claims were made for the negotiated and regulated use of the water reserves, weakening somewhat the environmental risk claim (Dray *et al.* 2007: 13).

However, a number of solutions were also suggested:

- The financial solutions could be aided with technical solutions, including regulated access to the water reserves or the participatory management of pumping (Dray *et al.* 2007: 13).
- The water exploitation issues could be more strongly linked with the water distribution issues and eventually with sanitation issues (however, sanitation issues are generally disconnected from the others by most people) (Dray *et al.* 2007).
- Exploring [] more ‘consensual’ stakeholders to participate in negotiations that are presently dominated by more extremist views (Dray *et al.* 2007).
- Management issues on the existing water reserves (on Bonriki and Buota) and implementation issues on the potential ones (on Abatao and Tabiteuea) are inherently interrelated (Dray *et al.* 2007).
- On one side, creating new water reserves without addressing the actual problems on the existing ones will perpetuate problems. On the other side, the introduction of new actors in the debate may help reduce the actual bipolar confrontation between landowners and the government on the existing water reserves (Dray *et al.* 2007).

Based on this, a number of recommendations were made in regards to how this process could be continued at a different level, reaching real decision and policy makers, but at the same time keeping the direct interaction with communities, families and island representatives. Unfortunately, this did not happen due to events in the ongoing SAPHE project described above (Dray *et al.* 2007). The SAPHE steering committee rejected the AtollGame outcomes, primarily on the basis that important decision makers were not part of the process, and because it was in opposition to the agenda of the project. Since then, parliament have delayed until further notice the extensions of water reserves to two more islands, and have increased the lease payments to better match the land prices.

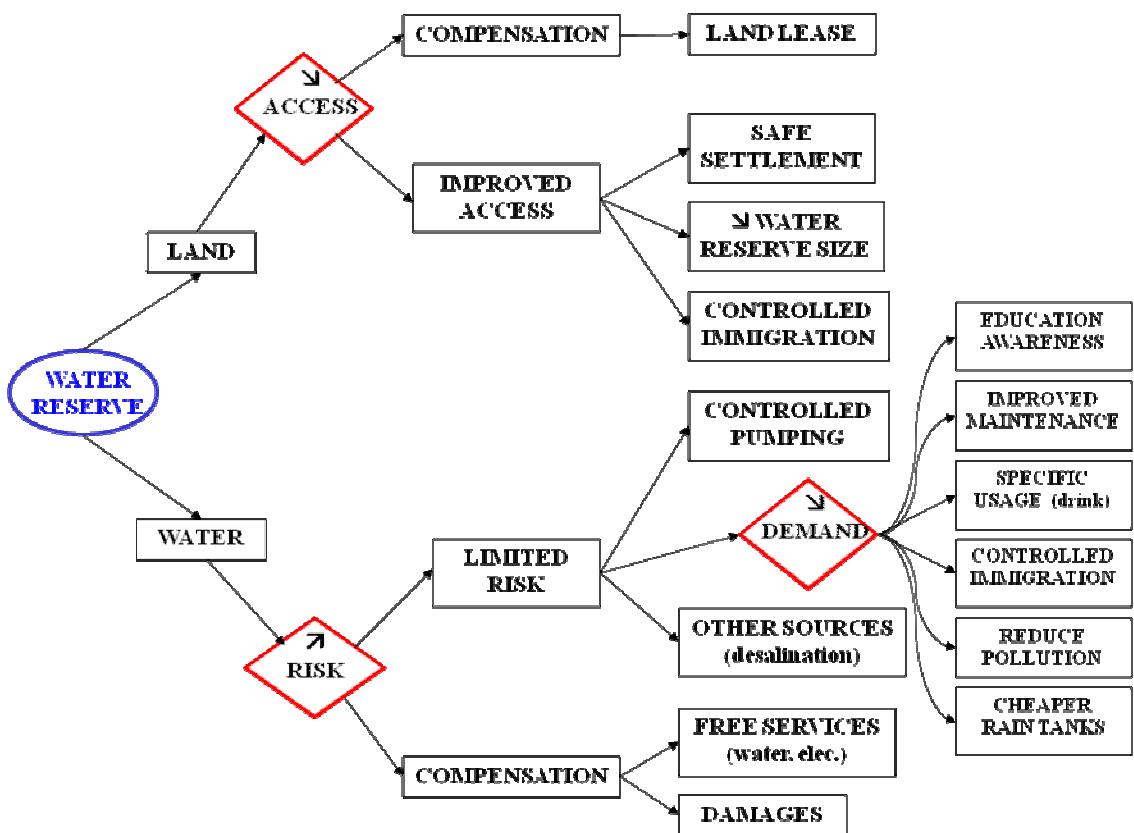


Figure 5-8: Framework for co-management of water reserves

The leader of the AtollScape and AtollGame projects has subsequently made the following statement:

Despite preliminary successes in terms of social learning and co-designing stages, the final outcomes were negatively affected by the fact that:

- (i) Key stakeholders (i.e. the water utility) did not take ownership of the negotiated outcomes; and
- (ii) That political conflicts and rivalries caused a stalemate situation.

The AtollGame experiment showed that despite a series of sustainable solutions being collectively proposed during the companion modelling sessions, most participants representing government agencies did not have any mandate beyond the experiment. Furthermore, the experiment demonstrated the schizophrenic position of these individuals, trapped between their cultural sensitivity and their professional rationality. Despised by

their communities while endorsing their administrative role, they often end up enforcing hard line strategies while managing water infrastructures. Unfortunately, this behaviour is encouraged by the project-funded nature of water infrastructure maintenance and rehabilitation in the Pacific region. As it was the case in Tarawa, contracting arrangements, financial settlements and project milestones seldom provide opportunities to re-assess project objectives, and even less chances to genuinely engage with local communities. It is only through an early and unconditional political support to participatory solutions that government officers might step out from their rigid roles and exchange with community leaders. Scarce human resources, erratic funding opportunities and high transaction costs in the Pacific plead for participatory and adaptive governance of water facilities. The AtollGame experiment provided a basis for co-management of water infrastructures between local communities and the Government. Only a strong political determination would have: (i) sidelined extremists from both sides and (ii) provided incentives for Government agencies to endorse the process.

As a matter of fact, the situation in Tarawa is representative of a majority of countries in the Pacific where under-resourced administrations struggle to negotiate with traditionally-ruled communities. Across the Pacific, western world-born legislations have failed, so far, to subdue custodian rules. Hence, political realms play a key-role in arbitrating between administrative duties and ancestral rights. Such processes are, by nature, obscure, subjective and prone to defiance (Moglia *et al.* 2008b: 53-54).

This is the point where the process was entered, and as such the current study can be seen as a continuation of the AtollScape and AtollGame experiences, in the spirit of the Companion Modelling framework. In other words, the challenges of this project are to:

1. Increase the ability of international and local agencies to consider local customs, culture and context by embedding more participatory practices into management frameworks;
2. Improve the ability of local agencies to manage the water supply and sanitation despite considerable resource deficiencies;

3. Improve the adaptive and coordination capacity, and embed abilities for negotiation within existing institutional structures.

5.2 Case study summary

The review of the case study provides some background and grounding for this study, with a review of the literature, expert knowledge, predetermined practice, field guides and manuals. It provides a description of the socio-cultural and bio-physical nature of the system and identifies its components, and some of the key dynamics. The case study review has also identified a number of troubling concerns relating to the provision of water and sanitation services, identifying some of the barriers to achieving adequate, if not universal, water and sanitation access.

In terms of the water flows in the system, it has been identified that the key water source is groundwater underneath protected reserves, but that this supply source is both under threat, and that extensions necessary for urban growth are highly problematic. Alternative water supplies, such as from rainwater tanks or desalination have also been shown to be difficult, with a poor track record so far.

For the purpose of modelling activities, key reports and data sources have been identified that ought to adequately support integrated systems assessment.

Chapter 6: Information collection

This chapter describes the efforts within this study to generate data and information from which to draw conclusions to provide a deeper context understanding and to support subsequent analytical methods. In other words, this chapter describes the processes of data collection through interviews and an email-based Delphi survey. Much of these results have previously already been published in two journal articles, but it is here laid out as a unified whole, providing complementary perspectives.

The methodology of this study requires data to support modelling approaches, and for generating a deeper understanding of the small town water governance problem. This will provide a basis for further modelling exercises as well as a foundation of learning that will allow for the formulation of a management framework for small town water governance. The case study in the previous chapter has also provided a basis for how to go about knowledge elicitation.

The results of the information collection refer both to the Delphi survey as well as the Interviews. The historical review of the case study water sector has provided the setting and has allowed for continuity in the on-going learning experience. The interviews will provide a more integrated, holistic and rich understanding of issues and factors. For this component, there is a preference for richness of information ahead of reliability of information; and there are constraints on the extent to which individuals can be identified as sources. This means that observations can be challenged, and that interpretations are those of the researcher.

The Delphi survey allows for formally collecting perspectives and narratives from various stakeholders and experts in the wider South Pacific at large, and thereby allowing for generalisation. The understanding based on the Delphi survey is the outcome of a structured process where the focus emerges, and where validation by participants is integral. This is a

facilitated and interactive social process from which outcomes reflect the views and perceptions of the participants.

6.1 Interviews and field observations

The field study and interviews have been undertaken in order to provide an understanding of the issues relating to the provision of water and sanitation in the urban areas of South Tarawa. It has been undertaken in a qualitative research mode as described in chapter 4. The material included: emails, books, notes, diagrams and transcripts of interviews. This diverse material has been synthesized into a single narrative by the researcher. While acknowledging the bias created by this individual filter, we need to emphasize the fact that our primary objective is to get a ‘rich picture’ in order to feed an inductive theory building (see chapter 4) rather than using it to test a theory.

An effort was made to work closely with the Public Utility Board as well as the Water Engineering Unit, as representatives of local agencies. Coming cold into a complicated situation, there was a need to quickly get up to speed with issues before going into the field, and therefore the first step was to undertake discussions with a number of key experts, and this was partly done in a workshop set up in Canberra with the aim to identify key themes, concepts, and questions.

6.1.1 Expert consultation

The initial discussions in the form of expert consultation were primarily undertaken at a small workshop in November 2005 with a number of invited high profile participants to identify key concepts, themes and questions. At this workshop, there were seven individuals with considerable experience in Tarawa, and with solid track records of reports and/or academic publications written on the complex issues of water management in Tarawa. The participants of the workshop were chosen on the basis that they were or would be involved in past, current and future water related projects in Tarawa, such as the IHP Humid Tropics Programme, the SAPHE project, the AtollGame and AtollScape projects and the Kiribati Adaptation Programme II.

The workshops occurred at a point in time when the AtollGame project had been completed and while the SAPHE project was still in its final stages (see chapter 5). On the cards was also a new project, referred to as the Kiribati Adaptation Programme II (KAP 2) with the aim to assess, develop and manage freshwater resources (Government of Kiribati 2005) and by doing that to support the Kiribati Water Sector Road Map (Asian Development Bank 2004b).

A core theme of discussion was about available water supply alternatives; i.e. desalination, rainwater harvesting and groundwater extraction from water reserves. Unfortunately it was felt that all such options are inadequate, impractical or fraught with considerable difficulty. It was felt that so far, decisions about which water supply alternatives to develop had been made purely on the basis of financial comparisons of options. Making the situation worse is the fact that key local institutions, i.e. the Public Utility Board (PUB) and the Water Engineering Unit (WEU), are under-resourced and that they rely considerably on a small number of individuals.

Three water supply alternatives were identified, i.e. desalination, rainwater harvesting and groundwater extraction. The groundwater extraction occurs either locally by householders using domestic shallow wells, or remotely via pipes using water extracted by infiltration galleries under water reserves. Table 6-1 shows estimated relative benefits and disadvantages of each alternative, which was generally agreed upon by participants. In this table, the evaluations are on a scale from Poor (meaning inadequate or that it is simply a very difficult issue), to Average (meaning somehow adequate), to Good (meaning that the water supply option is good in respect to this issue).

What appears to be the only technically feasible option as a primary water source for South Tarawa, i.e. groundwater extraction from water reserves, is seen as increasingly difficult due to the failure to negotiate with families and traditional decision making systems. Whilst there are also issues with potential over-extraction, drought, and vegetation coverage increasing evapo-transpiration; at the core of the difficulty of utilizing groundwater resources from water reserves are issues relating to land ownership and complex relationships between traditional customs, financial compensation as well as the capacity to maintain a subsistence livelihood. Local

institutions and governance systems have largely failed to acknowledge this. As a consequence of this and other failures, it was felt that there is an urgent need to improve the capacity of the PUB and the WEU for evaluating/negotiating changes to the water extraction and distribution systems; and taking community sensitive issues and preferences into account in decision making.

Table 6-1: Water supply technology options and their issues

Issue	Desalination	Rainwater harvesting	Groundwater extraction
Investment cost	Average	Poor	Average
Operational cost	Poor	Good	Good
Maintenance	Poor	Good	Average
Reliance on rainfall	Good	Poor	Average
Extraction constraints	Good	Poor	Poor
Requiring skills	Poor	Average	Average
Modular development	Poor	Good	Average
Decentralised	Average	Good	Average
Water quality risk – health	Good	Average	Average
Water quality risk – salinity	Good	Good	Poor
Water quality – taste	Good	Average	Poor

It was also argued that institutionally there is a strong dichotomy between political will and technical implementation, which causes considerable frustration. There are also concerns about unclear legislation and regulation, and this is in particular in relation to land ownership issues, but also in terms of the responsibilities of institutions. For example, the PUB has the responsibility for water supply provision in the urban areas, i.e. South Tarawa, while the WEU

has the responsibility for water supply provision in the ‘outer islands’, which includes North Tarawa. However, this becomes particularly problematic with water reserves used for the South Tarawa water supply located in North Tarawa.

Another common theme during discussions was that of water safety, and this relates to the fact that Tarawa has a very high incidence of illness and death due to water borne diseases. There are concerns about a number of factors, and in particular the use of groundwater from shallow wells located in South Tarawa households, but also about the freshwater pumped from water reserves for which a number of land use activities threaten the water safety.

It was argued that Tarawa needed to be considered in terms of being a SIDS and a small town, and therefore being severely resource constrained. A number of strategies were also discussed that could be used to reduce the vulnerability of the water supply and to cope with resource constraints, such as:

- Modular development, i.e. incremental increase of supply to match demand, so as not to stretch resources further than necessary.
- Use of multiple water sources in order to improve the reliability of supply; and in order to have a backup in the case that groundwater sources become depleted or unusable due to pollution;
- Including Participatory design in intervention processes in order to better operationalise interventions, and reduce the risk of failure.

The concept of participatory designed was viewed particularly favorably in light of a number of failed interventions where local adoption had not been secured at an early stage and where technology effectiveness had not been evaluated neither before nor during implementation. It was argued that an efficient technology is only effective if proven appropriate and that in relation to this, early dialogue and priority setting are essential at all levels.

In terms of water use, it was argued that while little information is available but the general feeling is that there is considerable wastage at the household level. This echoes previous

conclusions that notions of public good are new in Kiribati which is a secondary consideration to the obligations to the extended family (White *et al.* 1999a). However it was also argued that there are unacceptable levels of leakage from pipes, and that this needs to be addressed for a number of reasons, not least to show that the water system is well managed.

The following key themes, concepts and questions emerged from the discussions as shown in Box 1, 2 and 3.

Box 1: Key Themes:

- Water supply alternatives
- Water reserves
- Local capacity
- Interventions
- Water safety
- Water use
- Institutions
- Culture and customs
- Resource constraints

Box 2: Key Concepts:

- Groundwater
- Land ownership
- Public good
- Subsistence
- Technology effectiveness
- Participation

Box 3: Key Questions:

- How can participatory design be embedded as part of an intervention, and as part of the capability at local institutions?
- What strategies could be used to better cope with resource constraints? For example, are modular development and the use of multiple water resources suitable strategies?

6.1.2 Field study explorations

The Tarawa water sector has been explored during field study trips⁴. The first trip was undertaken together with Ms Anne Dray and the second field trip was undertaken together with Professor Ian White. They have contributed significantly to the information base of this case study. Working with them has allowed for both more in-depth understanding of the experiences that these professionals have had in previous projects and studies; as well as to link into their existing social networks.

Selected individuals who have been interviewed during field trips are from the key departments and organisations such as the PUB, the WEU, MELAD and more. The following types of participants were interviewed:

- Technical aspects were discussed with technical and high level staff at the PUB and the WEU, and with international experts such as those from SOPAC;
- Water resource and Environmental management aspects, including relating to pollution, were discussed with high level staff at the WEU and the PUB, with representatives of the Environment & Conservation Division of the MELAD; and with international experts;
- Health aspects were discussed with World Health Organisation representatives, staff at PUB and WEU; the director of the Environmental Health Unit, Ministry of Health & Medical Services; and opportunistically with householders directly;
- Higher level risk aspects were discussed with representatives for the Office of the President and with WEU staff;
- Landowner and reserve issues were discussed with high level staff at the PUB and the WEU, and representatives of the Environment and Conservation Division of MELAD; international experts; and with landowners directly;

⁴ The first was partly funded by the regional coordination organisation SOPAC (South Pacific Applied Geoscience Commission) and others have been funded by the Australian National University.

- Social, cultural and community aspects were discussed with NGO representatives, with international experts, staff at the PUB and WEU, and representatives of the Ministry of Internal & Social Affairs (MISA);
- Organisational and capacity issues were discussed with PUB and WEU officers, including the Human Resource manager.

Because the themes listed in box 1 are inter-related in a fairly complex manner, a thematic summary of field study explorations is not suitable. Instead these themes are categorised into meta-themes, i.e. Water-supply alternatives, Socio-technical issues and Strategic concerns.

6.1.2.1 Water supply

As previously mentioned, the three main sources of water are groundwater extraction, rainwater harvesting and desalination. Groundwater is extracted both from infiltration galleries located on water reserves, as well as by households using shallow wells. Bottled water is occasionally mentioned but not a serious water supply alternative. These alternatives are further described below.

Groundwater extraction from shallow household wells

A key source of water for many households is the shallow domestic well (Asian Development Bank 2000b), shown in Figure 6-1, and these wells are located in highly populated areas where the shallow groundwater is usually polluted. Investigations have indicated a high frequency of *E-coli*, and while few tests have been done, it is likely that there is a larger variety of pollutants, such as nitrates, faecal coliforms, phosphates, protozoa, and viruses.

Unfortunately, laboratories are disorganised and equipment is missing which means that ongoing monitoring of wells is problematic. Even the campus of the University of the South Pacific does not have adequate facilities and it has been argued that it is not feasible to run efficient laboratories in Tarawa given the current educational and capacity situation. Such opinions have been raised by representatives of the University as well as experts such as Ian White, and Oxford University PhD student Natasha Kuruppu.



Figure 6-1: Shallow household well in South Tarawa

Groundwater extraction from water reserves

As described in chapter 5, freshwater is currently extracted via infiltration galleries in Buota and Bonriki, to be distributed via pipe network to customers in South Tarawa, as shown in Figure 6-4. Water is pumped to an aeration unit in Betio and then distributed to a number of tanks as intermediate storages before further supplied to customers via reticulation pipes. As a demand management measure, water supply is only intermittent with 1 hour supply per day as the norm. The amount of water available per capita varies widely between different parts of South Tarawa, ranging from a mere average of 12 litres per capita per day in Bonriki, to 55 litres per capita per day in Betio and 67 litres per capita per day in Antebuka. This inequity is perceived as unfair by at least some individuals in those areas that are less fortunate in terms of available water.

The leakage from the pipe system is a major concern, with estimates of leakage varying widely from 30 to over 70 percent. Indeed the monthly water consumption data provided by the PUB from January to May 2006 shows that the distribution leakages average 19 percent but this does not take into account reticulation leakages or illegal connections. Anecdotes indicate that illegal connections are a very considerable problem, especially in light of high levels of leakage that occur as a consequence of poor plumbing when households use rudimentary methods to connect to reticulation pipes.



Figure 6-2: Bonriki chlorination plant

The groundwater that is pumped through the reticulation system is chlorinated at two points before reaching household connections; with one of the chlorination points shown in Figure 6-2. Chlorination counteracts most pathogens, but at times when by mistake the chlorination has been disconnected, there have been incidents of diarrhoeal disease, including fatalities. This is not surprising because on inspection of the infiltration galleries, there are numerous activities that may cause severe pollution, as there:

- Are settlements and even burial grounds;
- Exist sand mining activities (as shown in Figure 6-3);
- Occurs coconut farming and other agricultural activity, including pig husbandry;
- Are open unprotected wells just next to, and on, the infiltration gallery; and
- Is a septic tank on top of one of the infiltration galleries.

Because of this, chlorination is insufficient on its own and has to be complemented with boiling of water before usage; in particular to remove potential Protozoa such as Cryptosporidium. It should be noted here that 96 percent of the community claim to boil the water before consumption (Asian Development Bank 2000). Another serious concern in terms of water

quality is the lack of 24-hour pressure in water pipes which leads to infiltration of polluted groundwater by backflow into the pipes and consequently a high level of chlorination is needed.



Figure 6-3: Sand mining on water reserves in Bonriki

Rainwater harvesting

Rainwater harvesting provides a key source of water for many households in Tarawa (Asian Development Bank 2000). The Government of Kiribati have regulated that those houses that have iron roofs are to be fitted with gutters and tanks for the collection and storage of rainwater (Government of Kiribati 2000). There is also a rain tank fund (which is a leftover from the SAPHE project) that allows any household to purchase a rain tank and then make monthly repayments of about \$10 until the tank is paid for. However, this fund is largely under-utilised and most people are not aware of it. Once the first tank is paid off a household can get another loan for another tank.

However despite regulation and funding, in 2000 only 28 percent of households with an iron roof are equipped with a rainwater tank and only about two thirds of these tanks are functional (Asian Development Bank 2000b). On visits in 2005, 2006, and 2007, based on observation, these numbers still appear to be fairly accurate (however no survey was carried out).

Hence while there are regulation and funding options in place regarding rainwater tanks, in reality it is up to the discretion of each household whether to invest, operate and maintain a rainwater tank. In a survey in South Tarawa done in 2000, the following was noted (Asian Development Bank 2000b): ‘Asked for the reason why so many households did not have a rainwater collection system, [most say that it], is that they were not in a position to afford such a system’. The fact that rainwater tanks are expensive to purchase, install and maintain is indeed a key factor contributing to the lack of uptake of rainwater harvesting, but according to the South Pacific Applied Geoscience Commission (2004) it is not the only reason. They also list lack of skills, motivation, confidence as well as fear of change and poor communication of roles and responsibilities as key reasons. One can speculate that this is the reason that despite both regulation and available funds, households are still reluctant to install rain tanks.

Perhaps more disturbing, as it sets a bad example, is that on inspection in 2006, even many government buildings lack rainwater tanks or have insufficiently sized rainwater tanks. The reason for this is perceived to be a combination of lack of coordination between government departments as well as a common view that rainwater collection from roofs is merely a supplementary source of water, because, as a consequence of the limited size of tanks, in times of prolonged drought there would be insufficient water volumes.

While rainwater harvesting is generally safe, it has been reported that tanks are rarely cleaned, roofs are un-protected from potential contamination (i.e. over-hanging trees), they are sometimes not covered, and there is poor consideration of the impact of storm events on water quality. For the functional tanks, about 20 percent are reported to have poor water quality (Asian Development Bank 2000), and several cases have been reported where drinking water from a rainwater tank has caused water-borne disease. This fact is most probably related to the fact that there is little regulation about the design of rain tanks, and no on-going monitoring or testing of tanks for their integrity and water quality.

Desalination

Desalination plants have been constructed at three locations in Tarawa, i.e. in Betio with a capacity of 100m³/day as well as two smaller plants, each with a capacity of 50m³/day, at the Otintaai hotel and at the hospital at Nawerewere. All three are based on Reverse Osmosis technology.

None of these plants are currently operational, but claims have been made that the desalination plant at the Otintaai hotel is being restored. The reasons that have been given for failure are mainly inability to source spare parts and inadequate maintenance. Another factor is that desalination plants are costly to operate and are hence used only when needed.

Desalination plants are complex feats of technology that require strict maintenance schedules to be followed; in particular in an environment with salt spray that creates rapid corrosion of metal components. This puts high demands on local capacity, as well as the supply of spare parts. Manufacturers and suppliers therefore need to be reliable and trustworthy into the future. Particularly problematic is that during times of inactivity, when extra volumes are not needed, maintenance is lacking. Subsequently, the effort required to get plants operational again when needed is onerous. The intake of sea water into desalination plants has been deemed to be unproblematic in Tarawa, and the risk of damage due to storms and big waves is also relatively small.

The main cost of operating a desalination plant is the fuel that is required for its operation. Currently, fuel is imported at a high and fluctuating price, and instead it may be possible to run a desalination plant on local coconut oil (Etherington *et al.* 1998). This would generate local employment, reduce the Kiribati trade deficit, and reduce the overall cost of water management in Tarawa.

Water storage in households

Most households store water in containers such as buckets (54%), small metal containers (14%), oil drums (11%) and concrete/plastic tanks (3%), while only eight percent of the population do not store water (Asian Development Bank 2000b). Storing water is a consequence of either not

being connected to the reticulation system or not having continuous 24-hour supply, and with intermittent supply in Tarawa of considerably less than this (1 hour per day is considered the norm) water storage is an important factor. Water storage is a considerable risk factor in terms of water contamination, especially given the common perception in Tarawa that what can't be seen, such as bugs in the water, can't hurt you.

Health impacts

Relatively little information is available about the health impacts related to the water supply. What is known is that Kiribati and Tarawa have some of the highest rates of infant mortality in the world, and much of this is related to water-borne diseases such as diarrhoeal disease. It is also known that there have been outbreaks of cholera (with a major outbreak in 1977). There are very serious concerns about what would happen in Tarawa if there is a cholera outbreak today; as individuals that experienced the last episode believe that a future outbreak would be catastrophic because of the increased population density and inadequate protection of water resources.

It is the Ministry of Health and Medical Services, who has responsibility for monitoring health impacts, but they are under-resourced and health records are sketchy.

6.1.2.2 Institutional issues

A number of social and socio-technical themes were raised in the initial expert consultation, such as the concerns about local capacity, institutional arrangements, and the importance of culture and customs. This was also framed around interventions and how such interventions often fail due to the lack of consideration of such factors.

Local capacity

The local capacity refers primarily to the key institutions, i.e. the PUB, the WEU and a handful of Government departments. However it also refers more widely also to that of local Non Government Organisations (NGOs), community members as well as the overall knowledge, skill and educational levels of society. It is hence a multi-layered issue, which cuts across many parts of society.

In terms of the public servants in higher engineering positions, the pool of potential staff is very small given it is essentially limited to a handful of individuals with university degrees from overseas countries, such as New Zealand and Australia. The only university in Kiribati, i.e. the University of the South Pacific has a small campus in Tarawa that has only very limited activities and no adequate training in terms of water management. When those key individuals move to a different country or simply to a better position in a different department, a huge gap is left. For example, both the PUB and the WEU each rely heavily on a single individual. Unfortunately, during the course of the field trips, the key individual at the WEU found a better paid job at a different department and because there was no adequate succession planning, the WEU was thrown into, at least temporary, disarray. Such events can be extremely disruptive as it delays interventions, diminishes adequate coordination between departments and it may even cause key projects and developments to fail.

Discussions with the human resources department at the PUB indicate that succession planning is poor and there are typically no obvious succession options for key roles. It was also argued that there is also a need for more clearly defined roles, better human resource management, and clear policies to reward good management behaviour.

At other levels, skills are also inadequate. For example, while there are approximately 30 plumbers on the payroll at the PUB, only 5 passed the recent certification tests. Providing training to these staff members is also problematic for a number of reasons:

- Only a few have sufficient English so are not eligible to undertake training overseas or training funded by donor agencies;
- Most people do not like to share information or training, and this is part of the culture in Kiribati. Skills are kept in the family as a kind of insurance policy. This not only applies to new trades and skills, such as plumbing or mechanical engineering, but more particularly about fishing, weather prediction, canoe making, rituals, dancing, martial arts etc. Sometimes individuals are ok with sharing information orally to a single person, but not in written form because that can be passed on.

The consequence of poor plumbing skills is of course poor plumbing practices and horror stories abound. For example, connecting two sewer pipes by tying a rag around them, with subsequent blockage as the pipes are filled with stones and rocks. One wonders to what extent such poor practices contribute to high levels of leakage (in particular from the reticulation system) and sewage polluting the groundwater.

At another level, the skills for using Geographical Information Systems (GIS) are also limited, with only a small number of sufficiently IT literate individuals. At the PUB, only one such individual was identified, but it is likely that other people exist in other departments such as within the Land Division at MELAD.

It is also worth noting that because the traditional decision making structures and new administrations work side by side, government officials and staff members from organisations such as the PUB and the WEU are sometimes perceived by some community members as partial in their decision making and representing their own family interests rather than public interests, which is obviously problematic.

In light of this, NGOs are critical for enabling local participation. This is reinforced because language is critical, as is the knowledge and understanding of local culture and sensitivities. It is also important to use facilitators or practitioners that are perceived as impartial. Therefore, the availability of strong NGOs is a critical factor for successful interventions. For example the AtollScape and AtollGame experiences were made successful by the use of a local NGO called FSP Kiribati. When re-visiting this NGO, it was expected but disappointing in the sense of loss of capacity to see that these key individuals had moved on to better positions and that FSP activities now are limited to little more than selling seeds for vegetable and flowers.

There are also other NGOs, such as KANGO (a national NGO umbrella organisation) and the Kiribati Women's Federation (AMAK), but due to lack of stability in terms of qualified staff and resources, it is questionable whether these NGOs have the capacity to take on considerable responsibility. There are also concerns in regards as to what role NGOs can play in a culture where family and church affiliations dominate social interactions.

SOUTH TARAWA WATER FACILITIES AND DISTRIBUTION SCHEMATIC DIAGRAM

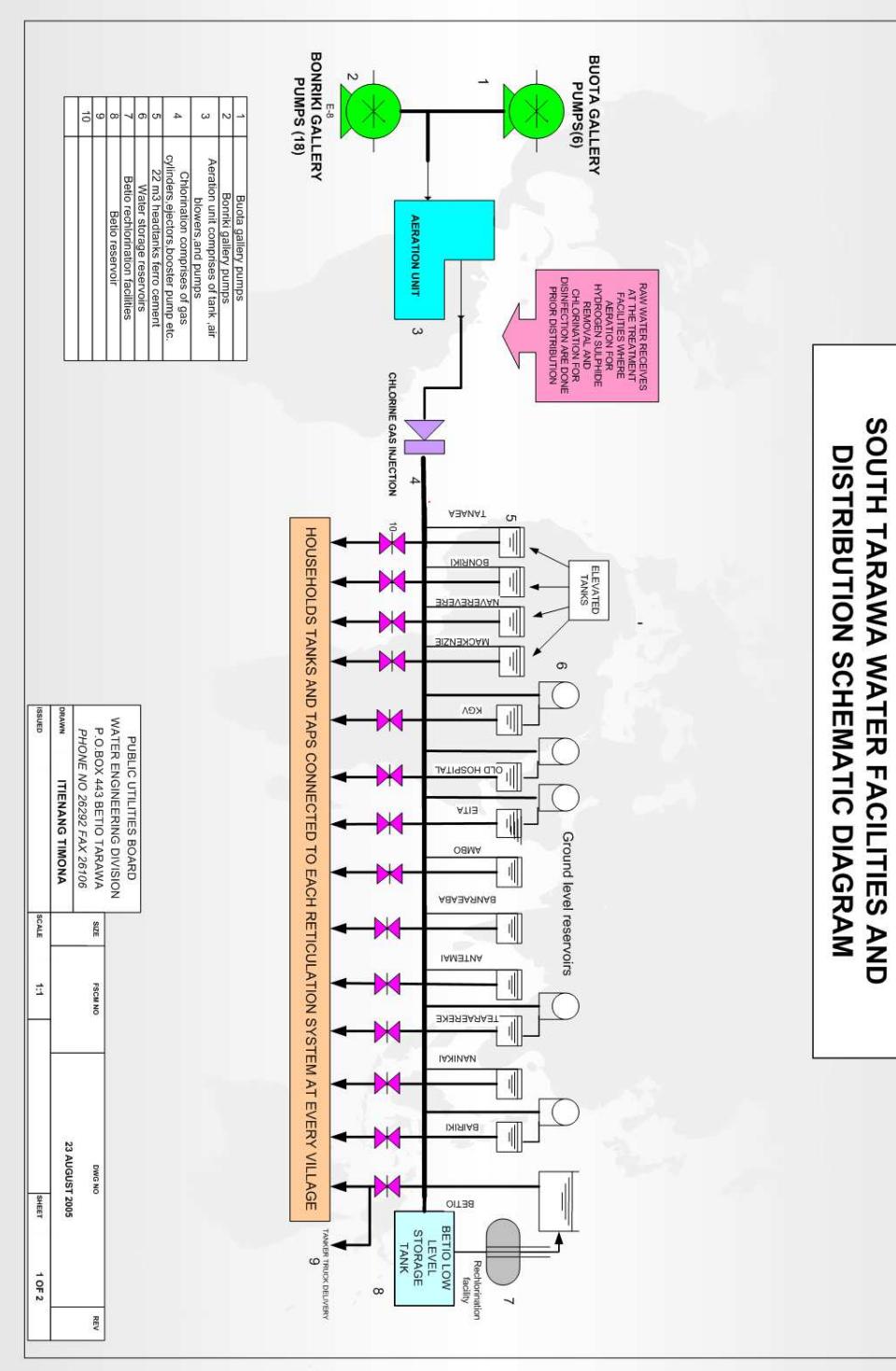


Figure 6-4: South Tarawa water facilities and distribution schematic diagram

Notes: Sourced from the local water utility in Tarawa, i.e. from a Public Utility Board staff member in 2007.

Another important local capacity issue is the capacity for upholding of the law. It has been argued by several interviewees that even when regulations and laws are in place, they are not followed and the Government of Kiribati seems powerless to enforce the rule of law. This is exemplified by the illegal activities on the water reserves, the lack of observance to the rain tank regulation, and the ad hoc payment of water bills.

Willingness and ability to pay

Many of those interviewed argued that for most Tarawa households, money is not an important motivating factor. The reason for this judgment appears to be that most I-Kiribati, even in Tarawa, lead a subsistence lifestyle with no abject poverty, as confirmed by Kuruppu (2009). On the topic of household expenditure and affordability of water supplies, Kuruppu (2009) has surveyed household expenditure in Tarawa. Kuruppu was also consulted during the case study visits.

Among other things, Kuruppu found that money not only symbolises independence but also the social commitments, to be spent on collective activities such as the church or village (2009). She also found that on average in urban Betio, 19% of a households funds goes to utility bills (mainly water and electricity, noting that electricity is significantly more expensive than water), and that this is on par with the amount paid to churches (18%). Noting the high level of discretionary spending towards churches, it could be argued that there is potential to at least double water prices, and still maintain within householders ability to pay. The willingness to let go of this discretionary payment, may be questioned, because as Kuruppu (2009) notes, giving less to the church is considered “shameful” at least by some I-Kiribati. In reality, this focus on donating money to churches means that fewer resources are available for water supply and sanitation. For example, in terms of the ability to pay for alternative supplies, Kuruppu (2009) notes that despite high demand for rainwater tanks, the cost of a suitably sized tank (\$750) is currently unaffordable for the average household. This should be seen in the perspective that Kuruppu’s survey respondents would donate \$80 per day to the church (Kuruppu 2009). As such, the cost of a rainwater tank would represent a mere 10 days of church donations.

In terms of paying for potable water reticulated water supplies, it is noted that water services are by no means regular. During case study visits, even the hotel which lies in a relatively well serviced area only had intermittent supplies (~4 hours per day). Comments from I-Kiribati indicated that the situation in some parts of Tarawa is even worse, and as an illustrative example one of Kuruppu's survey respondents notes that:

The water service isn't regular e.g., last month we didn't receive water for almost a week but this month it has been regular. We run out of [reticulated] water about twice a week and when this happens we use the rainwater or if we don't have enough rainwater then we use our brackish well water for cooking (Kuruppu 1990: 803).

In this situation, it may be argued on an ethical basis that services need to be improved before tariffs for water can be increased, an option explored by the PUB. When asking PUB staff about the collection of water bills, a number of issues were raised. Firstly, it was perceived that many households are faced with frequent shortages of cash and water utility staff thought that householders did not think payment of water bills is a priority; especially given that there is little consequence of non-payment. Furthermore, it was argued that customer databases are currently in such disorder that it makes collection of water bill payments somewhat arbitrary – an issue that was being fixed up during the last case study trip. At the time, it was thought that whilst some households regularly paid their bills, others simply do not; either because of database errors, or because of lack of motivation or shortage of cash.

In this situation, ability to pay appears to be adequate, but at the same time the willingness to pay is dependent on socio-cultural norms and values that prioritise donations to churches. It is also noted that payment of water bills was at the time of the last case study visit still relatively ad hoc and that payment for irregular, variable and intermittent reticulated services may raise fairness and other ethical concerns.

Policy

In terms of a coordinated water policy for Tarawa or Kiribati, the general consensus seems to be that it is simply not available. This is perhaps not strange given the apparent difficulties for the

various institutions to work together and the collapse of the national water committee on water and sanitation that was established in 1990. The reasons for the failure of this committee are obscure and no satisfactory explanation has been found other than that:

- There were inter-departmental and inter-personal conflicts for reasons which seem obscure;
- The issue of sitting fees (i.e. being paid to participate in meetings) was detrimental;
- It was not as inclusive as it should have been; and
- It seemed to lack a champion to drive it.

There are however currently attempts to revive the National Water and Sanitation Committee sitting directly under the Office of the President and with secretarial support from the Ministry of Public Works and Utilities. The views of a potential new National Water and Sanitation Committee (NWSC) seem positive and most claim to be happy to participate. In fact, the NWSC is perceived to be very good for sharing information and discuss issues, but there is also a concern about the difficulty to discuss the system when different members have very different levels of understanding, and that it would therefore be good to have tools, such as computerised tools, that support dialogue.

6.1.2.3 Strategic options

During interviews and discussions, different strategies and their relative benefits and disadvantages have been discussed. In this section a number of those strategies will be described.

Demand management

Various attempts have been made to reduce the water demand in South Tarawa and these have been largely unsuccessful:

1. In order to reduce demand, supply is often only provided for about an hour each day, and consequently households use various containers to store water for when it is needed. While

the strategy probably reduces demand, it is also fraught with a number of other concerns, such as relating to water safety of storing water and backflow of polluted water into pipes;

2. To minimise the consequences of this strategy, as part of the SAPHE project, 3200 households have been provided with a constant flow tank which will fill up during the intermittent supply and subsequently provide a trickle of water to households during the day. However, such attempts have been largely unsuccessful due to in part to technical difficulties, in part to the fact that there is poor ownership among households who have been reported to use the tanks for other purposes; and
3. In order to reduce water demand and improve the financial situation of the PUB, attempts have been made to introduce a tariff structure as a way to bill for water. However, given the fact that there is no adequate customer database, records are in disarray, and there is no adequate method for enforcing payments (especially given the vulnerability of many households), such efforts have also been largely unsuccessful and fraught with extreme difficulty. Such attempts would also be very difficult given the lack of metering at the household level.

It is also noted that while attempts can be made to reduce demand, most households only use a relatively small amount of water already, and it is difficult to gauge the amount of wastage that occurs. However anecdotally, it is reported that some households will leave taps running at all times and have extremely wasteful practices. This may again be related to what Crennan (1998) has pointed out, that the notion of public good is an introduced and foreign concept, and that the first and foremost commitment is to the family.

Increased utilisation of groundwater

A common theme in discussions about the Tarawa water supply is to increase the water supply by utilizing new freshwater lenses. The key options are of course either:

- To start utilizing new freshwater lenses in Abatao and Tabiteuea as suggested in the SAPHE project, and explored during the AtollGame and AtollScape experiences; or

- To utilise freshwater lenses in South Tarawa, and here Betio is the key alternative.

As has already been discussed, setting up reserves in Abatao and Tabiteuea is not realistic due to the high costs involved and due to the lack of community acceptance of such a solution. The AtollGame experience showed that community acceptance may be gained through co-management of reserves, but the financial burden is still going to be onerous given inadequate payment of water bills.

An alternative is the setting up of infiltration galleries in Betio. However, such infiltration galleries have already been abandoned due partly to the fact that groundwater sources are relatively small, but perhaps more importantly due to pollution. While there is only sketchy evidence to suggest anything about the water quality of the Betio groundwater, it is believed, due to extreme population densities and polluting land use practices, to be highly polluted. Especially high levels of Nitrogen are problematic given the difficulties and costs of removal.

Modular development

Modular development was discussed as another key strategy in order not to stretch financial and human resources. Modular development is the incremental increase of supply to match demand, so as not to stretch resources further than necessary. To allow this to happen, there is a need for technology that is extendible in small steps when the demand occurs and when financial resources are available. Examples are rainwater tanks which are however expensive in terms of price per cubic metre. Indeed, the main problem with this strategy seems to be the lack of technological options that will allow for modular development.

Compost toilets

Compost toilets refer to completing the nutrient and water cycle by composting waste from toilets. In this way, nutrients can be recycled and brought back into soils (which in the case of Tarawa are in dire need of such nutrients), and it also reduces the demand for sewer pipe networks. The key advantage would be less pollution of the groundwater and other freshwater sources. In particular it would mean that the lagoon would be better protected from pollution. However, this solution is perceived as not viable in Tarawa as there is a cultural preference

against it, which is also backed up by difficult experiences when compost toilets have been attempted in Kiritimati Island (personal communication, White 2006).

Participatory design

In the initial expert consultation, Participatory design was identified as a key strategy to attempt to implement in Tarawa. Participatory design is here perceived to be a method for incorporating each stakeholder (i.e. each person/organisation with an interest in or concern about water issues), or representatives for such stakeholders, preferences and needs into the design process.

This does not necessarily mean that each preference and need can be accommodated but there would be an open and transparent process for negotiating between conflicting needs and preferences. The advantages of Participatory design as they are perceived are shown in Figure 6-5.

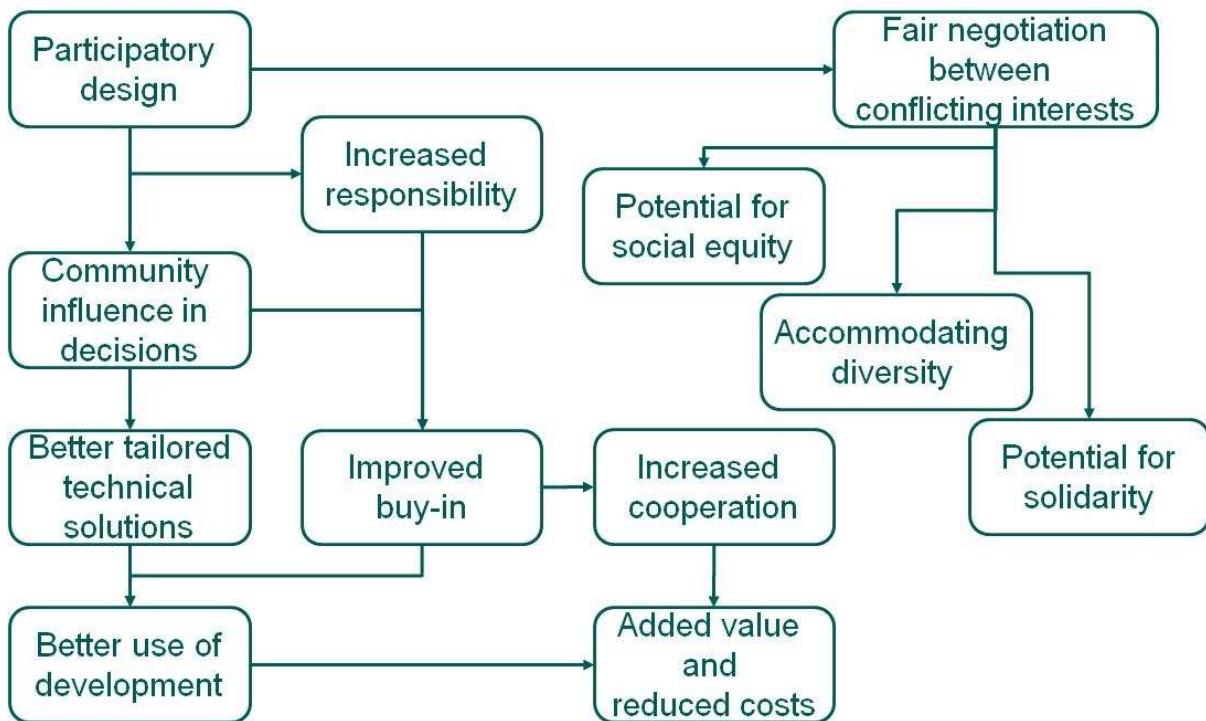


Figure 6-5: Benefits of participatory design

Participatory design means:

1. That community members and key stakeholders have greater influence in decision making;
 - a. Which also means that they are more likely to take an increased responsibility for solutions; and it ideally allows
 - b. Fairer and more transparent negotiations between conflicting interests;
2. Community influence in decisions tends to mean:
 - a. Better tailored technical solutions and a reduced risk of failure;
 - b. It also means a greater chance of improved buy-in from key stakeholders which means they are more likely to cooperate;
 - c. This in turn means better use of development, i.e. meeting more people's needs as well as reduced costs due to minimizing risk;
3. Fair negotiation between conflicting interests also tends to mean:
 - a. Potential for social equity; and
 - b. Potential for accommodating diverse needs as well as making transparent when certain community segments make sacrifices for the public good.

This model of participatory design was used in interaction with stakeholders at key institutions, i.e. the PUB and the WEU. Their responses were largely positive in terms of seeing the benefits. However, there is one key question left largely unanswered, which is '*how is it implemented?*'

Community of Practice

Another opportunity that has been discussed is to initiate a Community of Practice. A Community of Practice (CoP) could be an important resource for small town water management, if it is designed so that when:

- Motivation and dedication is low, it collects and channels motivated individuals to coordinate efforts;
- Information is limited and dispersed, it improves knowledge management, and directs information flows;

- Leadership is weak, it generates natural leaders;
- Skill levels are low, it provides opportunities for learning;
- Interests are varied, it provides a venue for discussion and conflict resolution;
- Issues are complex, it allows for discussion about assumptions and representations used for decision making;
- Trust in government and an outsider is low, it provides a venue for fair and transparent decision making.

It has been argued that for the CoP to work, rules need to be in place to ensure stable and efficient participation and contribution, and in the long term, the role of a CoP could be formalised via political processes so that it would work closely with relevant stakeholders.

The focus of the CoP could be either Water safety or Adaptive capacity, with purpose and tasks as shown in Table 6-2.

With a focus on water safety, community cooperation is important from the start of the chain in terms of protecting water sources, to the intermediate steps of maintaining infrastructure such as rain tanks, and all the way to the end of the chain of water storage and water utilisation (AusAID 2005). While extensive laboratory testing is deemed impractical, considerable information can be collected by simple observation of conditions surrounding water sources, such as infiltration galleries, domestic wells, or rain tanks, or by keeping health records (AusAID 2005).

With a focus on adaptive capacity in a resource constrained environment, it is critical to utilise local capacity for decision making and monitoring of the changing situation. A CoP can build adaptive capacity, which should be seen as an adaptive co-management approach where resource management is viewed as a continuous learning-by-doing process that recognises public participation and collaborative learning. For adaptive capacity a CoP provides the community and stakeholders a venue for identifying strategies to cope with diminishing

resources, understand the local and system wide changes occurring, and provides an opportunity for natural leaders to appear.

Table 6-2: Community of Practice design requirements

Focus	Purpose	Tasks
Water safety	Collection of information	Observation of conditions surrounding water sources, such as infiltration galleries, domestic wells, or rain tanks
		Health monitoring
	Coordination of efforts	Provide leadership and influence political decision making
		Understanding causes of water related health problems
		Provide a venue for concerned and motivated community members to improve the situation
	Increase awareness	Provide a venue for community discussion
		Discussion about assumptions and representations
Adaptive capacity	Adaptive decision making	Monitor and respond to changes in conditions
		Provide predictive capacity
	Coordination of efforts	Provide opportunities for learning
		Consider a holistic perspective of changing conditions
		Provide opportunities for conflict resolution around diminishing resources

6.2 Delphi survey

To complement the interview information, a Delphi survey has been conducted with experts, water managers and funding agencies with activities in the Pacific Islands region. The main reason is to provide multiple perspectives on the issues and to understand the diversity of mental models, viewpoints, situations and contexts. The theme of the Delphi survey was ‘Vulnerability of water services in Pacific Island Countries’; and the key process steps were:

- Brainstorming, i.e. identifying key factors relating to the theme;
- Selection, i.e. collectively selecting the most important factors;
- Ranking, i.e., collectively ranking the most important factors.

Within these steps, there are also opportunities for feedback, and the data generated is analysed for sense-making. The process for selection of participants, as well as issues about survey design, is described in chapter 4.

6.2.1 Brainstorming

In the brainstorming phase of the Delphi survey, participants were asked to respond to the following questions:

1. What do you think are the key local, national and "global-change" factors/situations that have an impact on the vulnerability of water services in the Pacific?
2. Please explain the reason for your answers in question 1.
3. In this question, please add any additional comments, thoughts or ideas relevant to the question above.

29 participants responded with a total of 177 responses; which are shown in Table A5-1 in Appendix 5. These responses were categorised into 35 factors, shown in Table A5-2. These are further categorised into four broad categories:

- Boundary conditions that can not be changed within the bounds of water management, and in other words, these are conditions which the water services provision system needs to be adjusted to;
- Policy issues, i.e. those issues that are put in place at a political, legislative or institutional level and which concern how the provision of water services is to be approached;
- Socio-technical issues, i.e. those issues which concern the interface between the social systems and the technical or environmental systems;

- Technical issues, i.e. those issues that concern physical infrastructure, or the environment.

The 35 factors are shown in the respective box below (box 4 includes boundary conditions, box 5, technical issues, box 6 socio-technical issues, and box 7 policy issues), where each box represents these four broad categories. It is particularly noted that gender issues have not been explicitly mentioned, but this issue has been raised in subsequent discussions.

Box 4: Boundary conditions

- Climate change
- Extreme events
- Sea level rise
- Physical conditions
- Economies
- Isolation, small scale and scattered nations
- Lifestyle changes
- Demographic changes

Box 5: Technical issues

- Appropriate technology
- Freshwater availability
- Pollution of water resources
- Water quality
- Maintenance and condition of infrastructure
- Adequacy of infrastructure
- Sanitation and waste management

Box 6: Socio-technical issues

- Groundwater and catchment protection
- Ability and willingness to pay for services
- Awareness and education
- Community participation
- Competing water demands
- Cultural constraints
- Demand management and over-extraction
- Human resources
- Community ownership

Box 7: Policy issues

- Adjusting services to local contexts
- Donor agency processes
- Information and analysis
- Institutional relevance
- Legislation
- Planning frameworks
- Politics
- Priorities
- Water policy
- Dialogue
- Funding

6.2.2 Selection

Following the identification of these factors and issues, participants received a document with the full responses, and after validating that they were happy with categorisations, they were then asked to select the ten most important factors. To identify the diversity of views depending on backgrounds, the responses were divided based on the background of participants. The Expert panel was further divided into two, with members of the Global Research Alliance entered into a separate panel. 28 participants responded at this stage, identifying a number of most important factors for each of the panels as in Table 6-3.

Table 6-3: Selection of most important factors by each panel

Local stakeholders	Experts	GRA Experts	Funding agencies
Ability and willingness to pay for services	Ability and willingness to pay for services	Appropriate technology	Ability and willingness to pay for services
Adjusting services to local contexts	Maintenance & condition of infrastructure	Information and analysis	Adjusting services to local contexts
Maintenance & condition of infrastructure	Appropriate technology	Climate change	Appropriate technology
Appropriate technology	Awareness and education	Groundwater and catchment protection	Awareness and education
Awareness and education	Community participation	Adjusting services to local contexts	Climate change
Cultural constraints	Demographic changes	Freshwater availability	Community participation
Community participation	Economies	Competing water demands	Competing water demands
Competing water demands	Human resources	Planning	Human resources
Demand management and over-extraction	Information and analysis	Community participation	Community ownership
Demographic changes	Isolation, small scale and scattered nations	Awareness and education	Planning
Donor agency processes	Planning	Human resources	Sanitation and waste management
Community ownership	Sanitation and waste management	Cultural constraints	Water quality

The issues in Table 6-3 can be further categorised into Boundary conditions, Policy issues, Socio-technical issues and Technical issues, as is shown in Table 6-4.

Table 6-4: Selection of most important factors by each panel, translated into meta-categories

Local stakeholders	Experts	GRA Experts	Funding agencies
Socio-technical issue	Socio-technical issue	Technical issue	Socio-technical issue
Policy issue	Technical issue	Policy issue	Policy issue
Technical issue	Technical issue	Boundary condition	Technical issue
Technical issue	Socio-technical issue	Socio-technical issue	Socio-technical issue
Socio-technical issue	Socio-technical issue	Policy issue	Boundary condition
Socio-technical issue	Boundary condition	Technical issue	Policy issue
Socio-technical issue	Boundary condition	Socio-technical issue	Socio-technical issue
Socio-technical issue	Socio-technical issue	Policy issue	Socio-technical issue
Socio-technical issue	Policy issue	Socio-technical issue	Socio-technical issue
Boundary condition	Boundary condition	Socio-technical issue	Policy issue
Policy issue	Policy issue	Socio-technical issue	Technical issue
Socio-technical issue	Technical issue	Socio-technical issue	Technical issue

It is noted that local stakeholders focus primarily on socio-technical issues (7/12), followed by Technical issues and Boundary conditions (both 2/12) and only a single Policy issue (1/12).

Experts have a more rounded focus but still the greatest focus on Socio-technical issues (4/12), followed by Technical issues (3/12), Boundary conditions (3/12) and Policy issues (2/12).

GRA Experts also have a focus on Socio-technical issues (6/12), followed by Policy issues (3/12), Technical issues (2/12) and Boundary conditions (1/12).

Funding agencies have the main focus on Socio-technical issues (5/12), Technical issues (3/12), Policy issues (3/12) and Boundary conditions (1/12).

The tentative conclusions would be that:

1. Socio-technical factors critically contribute (perhaps as much as half) to the vulnerability of water services in Pacific Island countries;
2. However, technical issues appear to have a much less dominant role, albeit still important;
3. Those with more knowledge and experience in the islands seem to have a greater respect of the Boundary conditions and how they affect vulnerability of water services;
4. Donor agencies focus considerably more than local stakeholders on Policy issues, and this may be a reflection of the different level that they operate on;
5. Experts who presumably have the greatest knowledge of the full range of scales have a more rounded view about what contributes to vulnerability of water services in PICs, but even they have a slight preference for socio-technical issues over policy issues.

6.2.3 Ranking

After the selection of factors, each panel was asked to rank the most important factors. This was repeated twice to allow participants to adjust their rankings based on others' responses. In this process, the participants were asked to rank the issues from 1 to 12, where 1 was the most influential and 12 the least influential. The ranking was conducted twice, the first time each participant was asked to rank the items individually and the second time they were shown the overall panel rank and asked to re-consider their original ranking. The original ranking was used in the case when participants have not responded within the second round of prioritisation. In a number of instances, participants voted using the same rank multiple times. For instance one GRA participant voted using the following ranks: 1 twice, 2 six times, 3 once, 4 twice and 6 once. In such cases, votes were transformed in order to maintain the internal order while keeping the sum to 78 (i.e. $1+2+3+\dots+12$). For instance, in the case described, 1 is translated to $(1+2) / 2 = 1.5$; 2 is translated to $(3+4+5+6+7+8) / 6 = 5.5$; 3 is translated to 9; 4 is translated to

10.5 and 6 is translated to 12. Also, by mistake, the ranking of 9 was not available as a voting option and this irregularity was ignored unless additional information was provided by the participant.

Using measures such as mean rank, median ranks, standard deviations, and correlation factors, the following were some key findings:

1. ‘Community participation’ was given a high priority by all panels;
2. ‘Adjusting services to local context’ was voted highly by three panels; and Ownership issues were ranked highly by two panels;
3. ‘Appropriate technology: selection, uptake and innovation’ was an issue ranked top priority by the Experts panel;
4. There is only a limited level of disagreement between panels, but considerable disagreement within some panels (i.e. Funding Agencies and Experts);
5. ‘Freshwater availability’ was highly ranked by some panels, but was not even considered by other panels;
6. Only Experts and Funding agencies have included ‘Sanitation and waste management’ on their lists, and this is also a contentious issue; with high variability in its individual ranks; and
7. ‘Cultural constraints’, ‘Climate change’, ‘Demographic changes’ and ‘Donor problems’ were consistently ranked as low in priorities (albeit still selected as key issues).

6.2.4 Feedback

At this point in the survey participants were explicitly asked to provide feedback on the results. Overall, there was a feeling that the disagreement observed was expected given:

1. The diverse perspectives, backgrounds and experiences of the people involved in the study;
2. That the identified issues were quite different; and
3. That there is unavoidable overlap between the identified issues.

However a strong message came that the priority of issues is strongly dependent on contexts. On the other hand it was felt by some that this study is a very good basis for discussion. It was also pointed out that sustainable water management requires consideration of a combination of all issues rather than just the top selection of issues.

Also, throughout this exercise, the following observations were made by participants:

1. Many factors are not mutually exclusive but are often inter-related;
2. It is difficult to make a selection that is valid for each context in the PICs as conditions vary considerably from country to country or even within a country;
3. The factors are different in nature, as some can be interpreted as goals while others impact on the viability of solutions.

6.2.5 Feedback on the particular issue of gender

A theme which was not originally included emerged throughout the process, i.e. gender issues, which were mentioned at a number of occasions:

- It was mentioned that gender issues need to be considered as an integral component of project development rather than an issue on its own;
- The approach to gender issues is dependent on the local context, relating to values and culture;
- Women's roles' were mentioned, and in particular their role in the daily functioning of the household and daily provision of family needs; but also as women as actors and decision-makers not only as those affected;
- It was mentioned that the way women are included often impacts strongly on the chances of success of a project: 'Evidently, many countries experience situations where projects only get off the ground and remain viable thanks to active support from, and input by, women. This goes far beyond western concepts of political correctness, and into practicalities of who, in a given community, actually gets things done, on one hand, and, on the other, who has the biggest stake in a successful outcome.'

- It was noted that: ‘The “gender issue” has been often misunderstood as to focus on inclusion of or attention to women only, without specifically recognising the different roles both MEN and WOMEN play in water resources management and how to address this.’

Additionally, from a contextual point of view it was mentioned that:

- ‘In Papua New Guinea, and in particular the rural areas and village communities, the women play a very significant role in the water and sanitation sector.’
- ‘In Kiribati involvement of woman in water management only happens at household level. Women in Kiribati are not involved in collecting water from distance sources as in the case of Asian and African countries. Women should be involved in their household role capacity.’

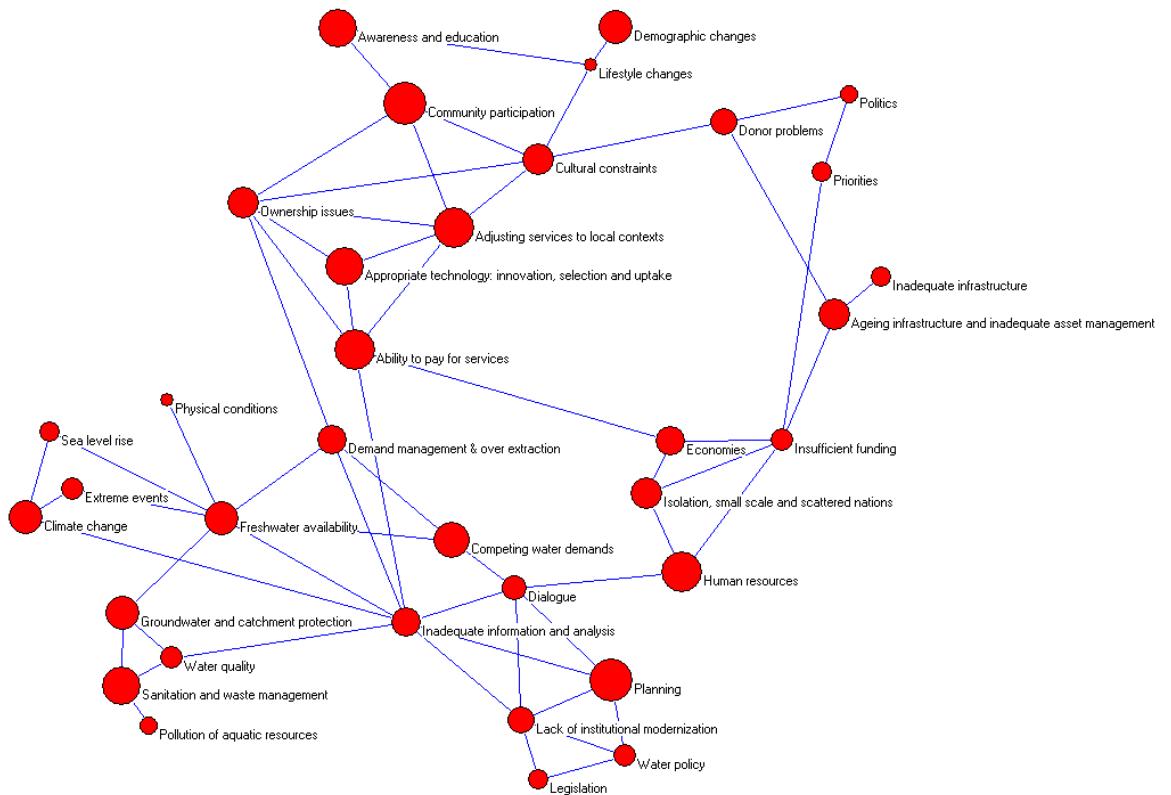


Figure 6-6: Network view of inter-related factors

6.2.6 Network view of factors

As it was noted that there is a considerable overlap between issues, the response to this fact was to acknowledge the inter-related nature of the issues at hand, and therefore links between factors were identified. This was done simply by evaluating whether the original responses indicated some kind of causal link between two factors. For instance the responses:

- ‘Water market is not favourable due to low buying power, especially the poor’ which was classified into the ‘Ability to pay’ category, indicates a causal link to the ‘Economies’ factor. Hence a link between ‘Ability to pay’ and ‘Economies’ is made.
- ‘Cultural issues are a key factor that impact on the vulnerability of services. Water provision does not generally take the cultural needs of the communities into account; this should be addressed at an early stage in determining how future water and sewerage services are developed’ was classified into the factor ‘Adjusting services to local contexts’ but is also linked to the factor ‘Cultural constraints’. Hence a link between ‘Adjusting services to local contexts’ and ‘Cultural constraints’ is made.

Based on such linkages, a network representation of the factors could be generated and visualised using the Pajek network analysis software (Batagelj and Mrvar 2008), where edges are identified using the process above, and where nodes represent factors. The size of the nodes in the diagram represents the number of times that a node was selected by a participant in the Selection stage of the process. This network is displayed in Figure 6-6.

This type of network representation is not only good for visualisation of the interactions of the various factors but may also help in identifying critical weaknesses at a particular location; and help in identifying which factors in a given system need strengthening. Such analysis however would have to be quantitative, and further research is required in order to achieve this. This analysis would help address both points 1 and 2 above.

6.2.7 Challenges, enablers and constraints

The third point in the feedback above made comments concerning the fact that: ‘The factors are different in nature, as some can be interpreted as goals while others impact on viability of different solutions’ thus led to a re-evaluation of the factors in terms of Challenges, Constraints, and Enablers. There has therefore been an attempt at characterizing all issues into these categories, and the result of this is the classification in Table 6-5.

Table 6-5: Factors classified as Challenges, Constraints and Enablers

Challenges	Constraints	Enablers
Adjusting services to local contexts	Ability and willingness to pay for services	Community participation
Competing water demands	Cultural constraints	Technology: innovation, selection and uptake
Community ownership	Climate change	Awareness and education
Sanitation and waste management	Demographic changes	Planning
Freshwater availability	Isolation, small scale and scattered nations	Maintenance and condition of infrastructure
Groundwater and catchment protection	Economies	Information and analysis
Demand management and over-extraction	Donor agency processes	Human resources
Water quality	Priorities	Legislation
Sea level rise	Politics	Dialogue
Extreme events	Physical conditions	Institutional relevance
Pollution of water resources	Lifestyle changes	Funding

6.3 Information collection chapter summary

By reporting on interviews, this chapter has provided rich contextual description of the issues relating to water and sanitation supply in Tarawa. By reporting on the Delphi survey, this rich contextual information on issues in Tarawa has been put into the context of a wider cross-cutting comparison of urban water issues in PICs. Largely, issues in PICs are similar to those in Tarawa, although it appears the relative importance is somewhat variable; especially as Tarawa appears to be more resource constrained than most other locations in the PICs. This was of course expected as Tarawa was chosen on the basis of a kind of “worst case scenario”.

Furthermore, this chapter has provided additional information to support modelling activities, and some of the empirical basis for the synthesis and framework proposed in chapter 8. In particular, this chapter has: 1) via the Delphi survey provided the generic themes of the synthesis in chapter 8; 2) provided the empirical evidence used for the synthesis in chapter 8; 3) provided the identification of options explored in integrated analysis in chapter 7; and finally 4) provided the qualitative information to support model development (ABMs and BNs) in chapter 7.

Chapter 7: Modelling

This chapter reports on the modelling efforts that have been part of this study and that are linked to the case study. This comprises Agent Based Modelling and the development of Bayesian Network models. These models can be seen as output of this study. However it is noted that in the spirit of participatory modelling, models primarily serve the purpose to provide a basis for the discussion that will help formulate tools and frameworks to support local water managers in small towns in developing countries in the generic case, and in Tarawa in the specific case.

Modelling forms a key part of the methodology for this study, in that it allows for exploring cause and effect relationships, complex dynamics and system properties in a context that is very difficult to observe. This is partly because many of the key processes are based on social dynamics, behaviours and decision making for which the underlying mechanisms can merely be guessed. In this uncertain environment, guidance is sought using methods within the Complex Systems Science toolbox, and in particular Agent Based Modelling and Bayesian Networks.

In the development of the methodology for this thesis (chapter 4) the Cynefin framework was adopted to guide the choice of investigation and exploration tools; with the explicit assumption that the water system in Tarawa can be described as complex and adaptive. So far the historical review, the interviews and the Delphi survey have provided a rich but fragmented and often static view of the local reality. The two modelling approaches of this study, Agent-Based Modelling (ABM) and Bayesian Networks (BN) aim to provide a more dynamic view of the interactions and feedback loops that characterize complex and adaptive systems.

Following Searle (1995), it is acknowledged that modelling efforts are inherently subjective and that the resulting representation of the urban water management system in Tarawa is not,

therefore, unique and perfectly accurate. It is, however, assumed that these efforts contribute towards a better understanding of constraints and opportunities attached to the studied system.

Agent-based models have been used to allow for systems analysis whereby probes can be designed to explore scenarios analysis in order to assess a given situation according to different perspectives. Hence it is expected that the model will improve the understanding of how to promote desirable patterns of behaviour in the simulated system.

Bayesian networks have been used to allow for describing causality relationships characterizing water policy interventions in Tarawa, in a highly uncertain context. Hence, it is expected that the model will support a better understanding of how social and technical uncertainties propagate across different components of specific policy interventions.

7.1 Agent Based Model

The ABM that has been developed for the Tarawa water system is from hereon referred to as the Waterscape model. The agent based model and associated simulation is described in three ways:

1. The high level system representation, illustrated via the UML class diagram,
2. Description of individual components, including UML sequence diagrams,
3. Simulation results from ABS, as the application of the ABM using ‘What if scenarios’.

A UML class diagram describes the structure and components of the Agent Based Model; or in other words the class types, their methods and attributes, as well as any connections, linkages or inheritance between classes.

Similarly, a UML sequence diagram describes a sequence of activities, events and actions within the model; or in other words the time steps. For the Waterscape model, multiple time scales are relevant and there are therefore multiple sequence diagrams.

In the description of the ABM, the following terms are used, from the programming paradigm called Object-Oriented Programming (adapted from Gilbert and Troitzsch, 1999: 166):

- Objects: program structures which hold both data and procedures for operating on those data
- Classes: the software template from which objects are created and all objects created from a particular class are similar in terms of methods and attributes
- Methods: the procedures that an object possesses for operating on data
- Attributes: data slots for data used by objects within their methods.

The classes, attributes and methods of Waterscape are shown in Figure 7-1.

Table 7-1, provides a brief description of each *class*, while individual behavioural models help agents to perform (when required) water use, land use or vegetation clearing activities. Dynamics of the freshwater lenses are described by a very simple hydrological model derived from Perez and colleagues (2003). Infrastructure operations and maintenance are also described in the model.

The classes in the *Waterscape* model are classified into three categories, as shown in Table 7-2. These are the *social classes*, representing those objects that interact with each other; *spatial classes*, representing the spatial environment; and *passive classes* representing non-interacting types.

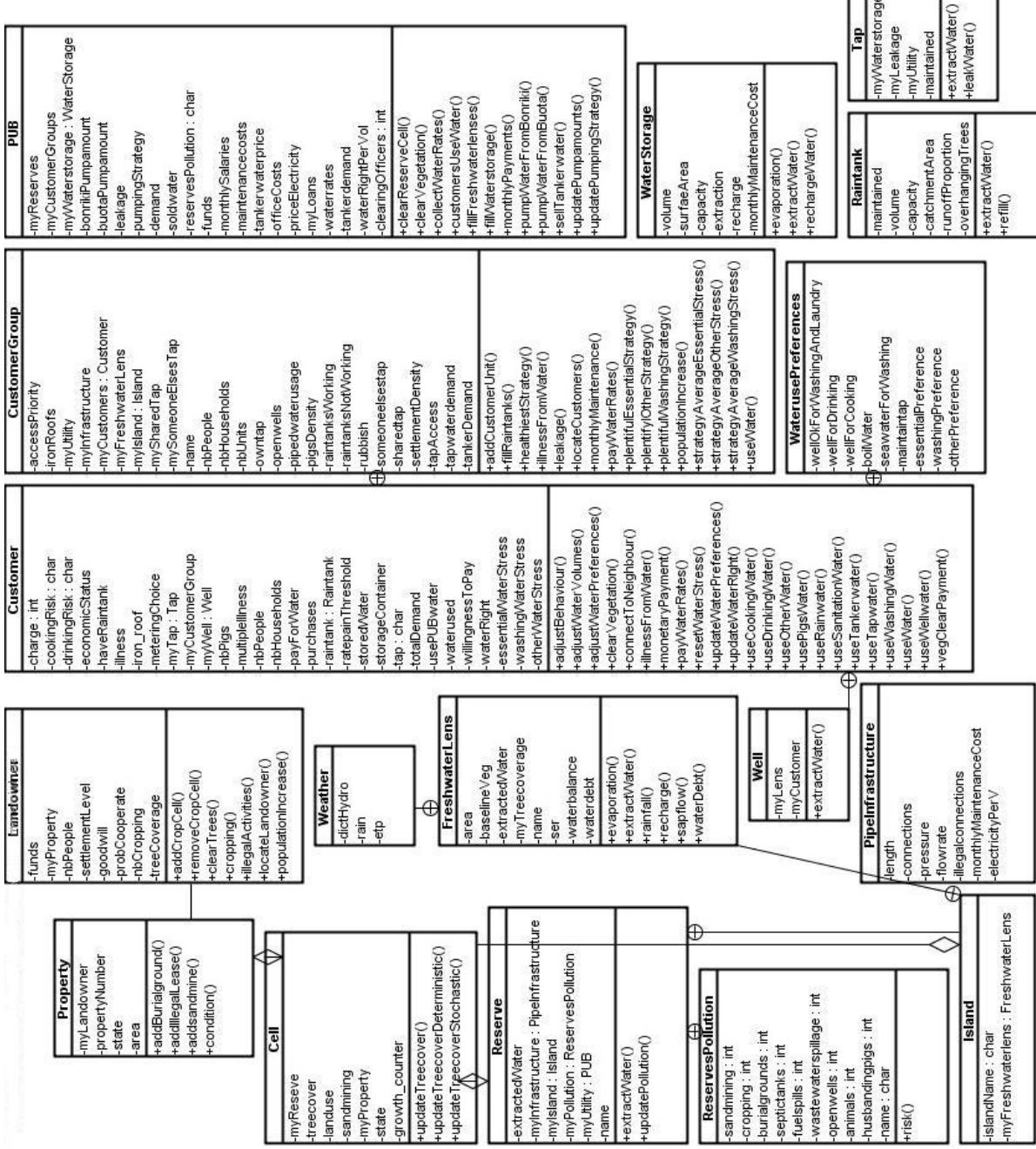


Figure 7-1: Waterscape UML class diagram

Notes: This figure shows the UML Class Diagram with key classes in the Waterscape Model and most methods and attributes. There are classes related to customers, the operation of the water system (within the PUB class), as well as classes related to the reserves; and some classes representing infrastructure and the spatial environment.

Table 7-1: Descriptions of classes in Tarawa Waterscape

Classes	Representing	Key activities / attributes
Customer	A typical water use unit; or in other words a household	Water use Illness from water Pay for water Update water use strategy
PUB	The public water utility responsible for the provision of urban water services	Pump water Collect water rates Sell tanker water Adjust pumping amounts Clear vegetation Maintain infrastructure
Landowner	A land owner on the reserves (the water catchment areas)	Settlement patterns Land use Clear vegetation Protect land
CustomerGroup (aggregate)	A group of customers with similar access to water; typically representing an urban village or an island	Same as customer
Cell	An area of land, ocean or lagoon	Tree cover Land use
Property (aggregate)	An aggregate of cells representing the property of a land owner	Land use activities
Reserve (aggregate)	An aggregate of cells representing the catchment area of a freshwater lens	Land use activities Pollution of the lens Vegetation cover
Island (aggregate)	An aggregate of land cells joined into an island	For display purposes
WaterStorage	The reservoir or dam used by the PUB for storing water	Extraction and recharge Evaporation
Well	A well that a customer can use to access the freshwater lens corresponding to its island	Extraction of water from a freshwater lens
Raintank	A tank connected to the roof of a household's house	Extraction of water Recharge of water from rain.
Tap	A connection point to the pipe network providing access to water	Maintenance Extraction of water Leakage of water Access by customers
ChlorinationPlant	A Plant operated by the PUB for chlorinating the piped water	Chlorination Maintenance
Weather	The weather changing on a 10-daily time step	Rainfall Evapo-transpiration
FreshwaterLens	A freshwater bubble sitting in sand and located under islands	Evaporation Extraction of water Recharge of water Sap flow
ReservesPollution	The level of pollution on a water reserve	Sand/gravel mining, Cropping, Settlements, Burial grounds, Septic tanks, fuel spills, etc.
PipeInfrastructure	Transmission or distribution pipes transporting water	Leakage Electricity use Illegal connections

Table 7-2: Categorisation of classes in the Waterscape Model

Social classes	Passive classes
Customer PUB Landowner CustomerGroup (aggregate)	Infrastructure WaterStorage Well Raintank Tap ChlorinationPlant Weather
Spatial elements	
Cell Property (aggregate) Reserve (aggregate) Island (aggregate)	FreshwaterLens ReservesPollution CustomerBehaviour PipeInfrastructure ToiletSystem

WaterScape is a time step-driven model. One simulation time step, described by t , corresponds to a 1 day period, but has different activities at different frequencies. For example, population increases occur at a yearly time step; weather changes on a 10 day time step as described by T , with subsequent recharge of freshwater lenses and rain tanks; customers' water use occurs daily, as do reserve activities.

The main functions within the Waterscape model are:

- Weather providing the recharge of water;
- Water flows; such as for example recharge, evapo-transpiration, sap flow and leakage;
- Water use; or in other words different uses of water by various customers;
- Land use activities and vegetation coverage on the water reserves;
- Infrastructure operation and maintenance by the water utility (PUB).

7.1.1 Weather

The weather is a key driver in the model as it provides a recharge to the freshwater lenses. The two key attributes/variables in the weather are the rainfall, and the potential evapo-transpiration (PET). 10-day period values for each variable are read by a Weather class from an external data

file (comma separated format, .csv). The file that has been used as a default is the same that was used for the AtollScape and AtollGame models (Dray *et al.* 2006a; 2006b; 2007).

7.1.2 Water flows

Figure 7-2 shows the water flows in the model. The Weather class of Table 7-1 controls the inflow of water into freshwater lenses and rainwater tanks via rainfall and evaporation. A historical file of weather is used that allows for the exploration of scenarios, including scenarios relating to drought or rainy conditions. In Tarawa, such conditions are generally governed by El Nino or La Nina events.

As described by Alam and Falkland (1997), in small atolls such as Tarawa, the freshwater lens is essentially a lens-shaped layer of freshwater that floating on saline (hence, more dense) water intruding from the surrounding ocean. There is no sharp interface between both liquids but a very dynamical transition zone where fresh, brackish and saline waters mix due to vertical (infiltration, pumping) and horizontal (tidal cycle) movements (see Figure 7-2). In WaterScape, these hydro-geological processes have been simplified by using a mass balance equation that is solved every 10 days (Eq. 1).

$$V(T + 1) = V(T) + A \cdot [R - ETP - S] \quad (1)$$

Where, $V(T)$ is the available freshwater volume (in litres) at time T ; A is the catchment area in m^2 ; R is the rainfall in millimetres; ETP is the provided evapo-transpiration potential (in mm); and S is the sap flow, which is the loss of water through vegetation. On the basis of estimated sustainable extraction rates, the area of each lens is calibrated using Equation 2, based on historical time series of rainfall and evapo-transpiration (using the file described in the section 7.1.1):

$$A = 1000 \cdot SER / \left(\sum_{T=1}^N [R(T) - E(T)] / 10 \cdot N \right) \quad (2)$$

Where, SER is the sustainable extraction rate of the lens (in cubic metres per day); N is the number of data points in the weather file; $R(T)$ is the rainfall at data point t , and $E(T)$ is the evapo-transpiration. There is also a scaling factor of 10 because there are 10 days per weather data point, and a scaling factor of 1000 in order to convert millimetres to metres. Sustainable extraction rates of the various islands in the atoll are shown in Table 7-3; or entered in the user interface as shown in Figure 7-3.

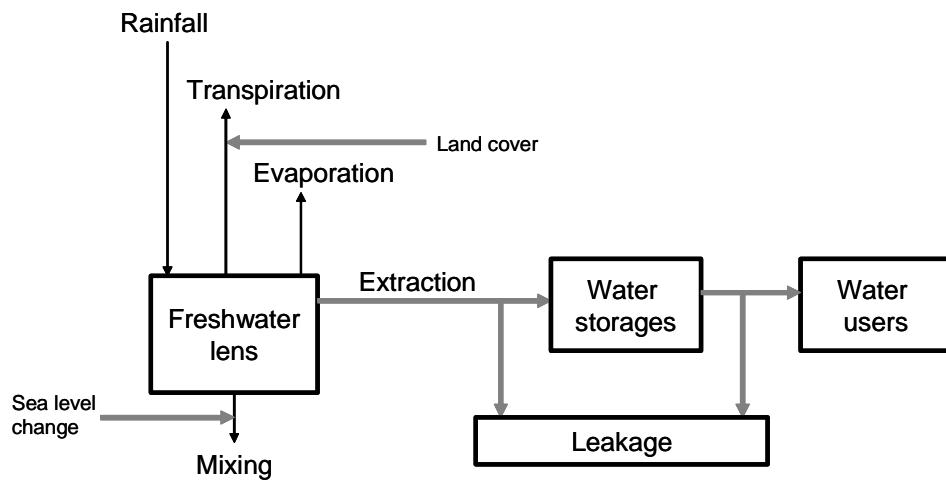


Figure 7-2: Water balances of the freshwater lenses under water reserves

Freshwater lenses	
Sapflow vol [mm/day]	4
Desired reserve tree coverage (%)	10
Bonriki ser [m ³ / day]	1350
Buota ser [m ³ / day]	350
Betio ser [m ³ / day]	500
Bairiki ser [m ³ / day]	200
Bikenibeu ser [m ³ / day]	200
Rural Tarawa ser [m ³ / day]	500
North Tarawa ser [m ³ / day]	1500

Figure 7-3: Part of the user interface used to initiate the specifics of the freshwater lenses

Notes: The values in Figure 7-3 are used to initialise the freshwater lenses. Specifically, the user can adjust the sustainable extraction rates for each of the lenses in the model; but also adjust the sap flow, which is the loss of water through vegetation. The tree coverage levels are currently initiated at 20 percent for most freshwater lenses.

Table 7-3: Values on sustainable extraction rates for each freshwater lens

Island	Sustainable extraction rate (m^3 per day)
Bonriki	1350
Buota	350
Betio	500
Bairiki	200
Bikenibeu	200
Rural Tarawa	500
North Tarawa	1500

Notes: The values in Table 7-3 are as much as possible based on Falkland (2003); and when estimates have been missing, they have been made on the basis of guesses by the chief engineer and the CEO at the Public Utility Board. It is also noted that the North Tarawa and the Rural Tarawa Lenses objects are in fact representations of a collection of lenses. With the ABM implementation, these numbers can also be adjusted via the user interface.

After water is extracted from the freshwater lenses, it is pumped via water pipes to water storages, and subsequently to households who only have water supply for about one hour each day. During the transport of water through pipes, there is leakage, which is modelled on the basis of leakage per kilometre of pipe, and the number of customer connections. Leakage from a pipe is modelled using a model developed by Lambert (2001, 2002) where leakage is calculated based on the number of legal and illegal connections; the length of the pipe; and the pressure of the water in the pipe (in metres head above sea level). The leakage from a connection is calculated as per Equation 3, and leakage from a kilometre of pipe is calculated as per Equation 4:

$$\text{Leakage} = \varpi \cdot C \cdot d \cdot p \quad (3)$$

$$\text{Leakage} = \frac{\varpi_p \cdot l \cdot d \cdot p}{1000} \quad (4)$$

Where ϖ_p and ϖ are model parameter, empirically fitted by Lambert (2001), but which can be adjusted to suit local conditions. For connections, the parameter varies depending on whether the connection is legal or illegal, l is the length of the pipe in kilometres, d is the number of days, p is the operating pressure, and C is the number of connections. Default values of leakage model parameters in the leakage equations are based on Lambert (2001, 2002), but these numbers can be adjusted using the user interface in order to represent local conditions, as per Figure 7-4. When water services are only available for part of the day, this is represented in the d variable.

Leakage	
Illegal connections	80
Legal connections	40
Pipe leakage per km	220

Figure 7-4: User interface section to initiate the specifics of the leakage calculations

Notes: The values in Figure 7-4 are used to initialise the leakage calculations. Specifically, the user can adjust the leakage from illegal connections, legal connections and from a km of pipelines. For connections, values represent leakage in liters per day per meter head of pipe pressure. For pipes, the values represent liters per day per meter head per kilometer of pipe.

Another common source of water is rainwater tanks that collect rainwater from roofs. Not all households have rainwater tanks, and many existing rainwater tanks are in fact either non-operational or unsafe. From a water safety perspective, lack of maintenance and over-hanging trees impact on the quality of the water, and hence water safety. Rain tank flows are modelled so that if the rain tank is functional (that are well maintained), at the time of rainfall, water is recharged into the rain tanks based on the rainfall, roof catchment area, and estimated run-off proportion. The values for this are set in the part of the user interface shown in Figure 7-5.

For the households that do not have sufficient amounts of freshwater, water can be purchased from the water utility at a cost of \$2 per m^3 , which is considered rather expensive. The water utility provides $20 - 30 m^3$ per day but this is limited by having only a single truck for deliveries. In times of drought there is often a long queue for receiving water this way. In the model, water users have the option to purchase truck water, which is delivered to their private water container. It is also assumed that 10 percent of the water is lost in each delivery.

Raintanks			
Capacity [m3]	2.0	Maintained [%]	80
Catchment area [m2]	10	Overhanging trees [%]	40
Runoff proportion [%]	80		

Figure 7-5: User interface section to initiate the specifics of the rain tank population

Notes: The values in Figure 7-5 are used to initiate the Raintank population, where each tank has the capacity, catchment area and a run-off proportion as described. In the initialisation process, a certain percentage, randomly assigned, have their attributes set to 'not maintained', and the same process is applied for initialising a proportion of rain tanks with over-hanging trees.

An important factor that influences the dynamic of household water use is the various households' access to water which is dependent on the allocation by the water utility to various villages (also referred to in the model as customer groups).

Under the current regime, there is a considerable difference in the water per capita provided. The amounts of water pumped to different areas vary greatly, ranging from 55 litres per person per day to the most populated island down to a much smaller allowance of 22 litres per person in the village with smallest volume of supply. It is possible to explore other allocation strategies in the model, such as having the allocation to villages proportionally based on their population sizes. Not surprisingly considering the limited tap water access, local wells and rain tanks are critical complements for households, and some hospitals and hotels have alternative water supplies, such as from small desalination units.

7.1.3 Water use

Behaviour of agents is the main source of complexity in *Waterscape*, and from the urban water system point of view (in other words, when ignoring the reserves), in particular because of the way that customers respond to events and conditions in their choice of water source.

Customers, which in the case of Tarawa are mainly households, can access freshwater from four different sources, via 1) a household tap, 2) domestic wells, 3) water tank trucks, or 4) rainwater tanks. However, the set of options for an individual customer will vary depending on what level

of service and water that is accessible, and this was initiated on the basis of a household survey (Asian Development Bank 2000b). However, all customers can purchase water from water trucks, but the amount of water available in this way is limited by the number of water trucks operated by the water utility.

Three categories of water use are taken into account, as shown in Figure 7-6: (1) drinking water such as for drinking and cooking, (2) domestic water use such as for bathing, sanitation and washing of clothes, and (3) other use such as for feeding animals and watering gardens.

Each time step, the customer will decide on what source type to use for each use category, as per Figure 7-6 and Figure 7-7. This means that the water use preferences can be described using a three-dimensional vector for which each value can take four discrete values: 'Tap', 'Rain tank', 'Truck water', or 'Domestic well'. In other words, specifying if the customer uses tap water for drinking and cooking, rain tank water for domestic uses, and domestic well for other uses.

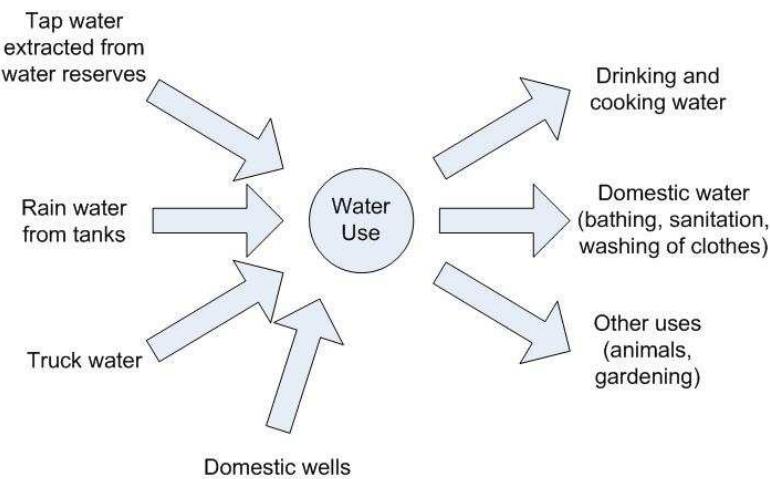


Figure 7-6: Water sources and water uses

The way that this decision is modelled is on the basis of the principles applied in the *Consumat* model (Jager et al 1999; Janssen and Jager 1999) where the decision is based on two dimensions for cognitive processing; or in other words 1) the cognitive effort required in the decision, and

2) the social or individual orientation of the process, which depends on the level of certainty or uncertainty involved in the decision situation. This means that there are four situations:

- Deliberation: Low level of needs satisfaction, and low uncertainty of the decision situation, in which case the customer will essentially maximise its utility of the decision based on its representation of the system;
- Social comparison: Low level of needs satisfaction, but high level of uncertainty; in which case the consumer will apply social comparison, which means to update mental map and subsequently find customers with similar abilities, calculate the potential benefit of their strategy, and change strategy in case the other customer's strategy is found to provide more benefit;
- Repetition: High level of needs satisfaction, but low level of uncertainty; in which case the customer will repeat previous decision;
- Imitation: High level of needs satisfaction, but high level of uncertainty; in which case the customer will imitate the behaviour the customer which he/she last compared herself with (in social deliberation)

In the case of water use in Tarawa, the level of uncertainty is always high, which means that the customers will base their decisions on either *social comparison* or *imitation* depending on the level of needs satisfaction. The level of needs satisfaction depends on three types of occurrences, 1) water scarcity, or in other words not being able to get enough water to cover needs, 2) health concerns; or in other words incidents of water related health problems, and 3) payment difficulties; or in other words having to pay more than what the customer is willing to pay for the water service. To switch the decision from imitation to social comparison, there are trigger levels for each of the types of needs. In other words, if there are too many health incidents in a given period of time or the customer has to pay more than he is happy to pay, or he does not receive enough water; the customer will switch from *imitation* to *social comparison* as a mode for decision making. In the *social comparison* mode, the customer will find another customer in the same village (a customer group) is perceived as the equivalent of finding a

customer with similar abilities. Figure 7-7 shows the sequence of methods corresponding to household water use in *Waterscape* (UML sequence diagram).

7.1.4 Landowner activities

Landowner activities on the water reserves happen on different time scales 1) Cropping: daily; 2) Illegal activities: monthly; and 3) Clearing of vegetation: monthly. These activities are further described below. The decision by landowners is made on the basis of a utility function, based on income from cropping, benefit from illegal activities, such as sand mining, and illegal settlements, and any benefits generated from clearing, or not clearing, vegetation. These activities are described below.

7.1.4.1 Cropping

Cropping by landowners is sometimes an essential component of a landowner's subsistence activities, but more importantly it also provides some income by selling crops such as coconuts, taro or vegetables at markets in South Tarawa. The number of cropping plots on each property depends on the landowner's behavioural variable: nbCropping. The number of cropping plots is updated on a daily time step in a simple manner shown in Box 1 in Appendix 6. In the model, a landowner receives a cropping income proportional to the number of cropped plots. The amount earned per plot is accessible through the user interface. The decision variable, nbCropping, is adjusted on a monthly basis.

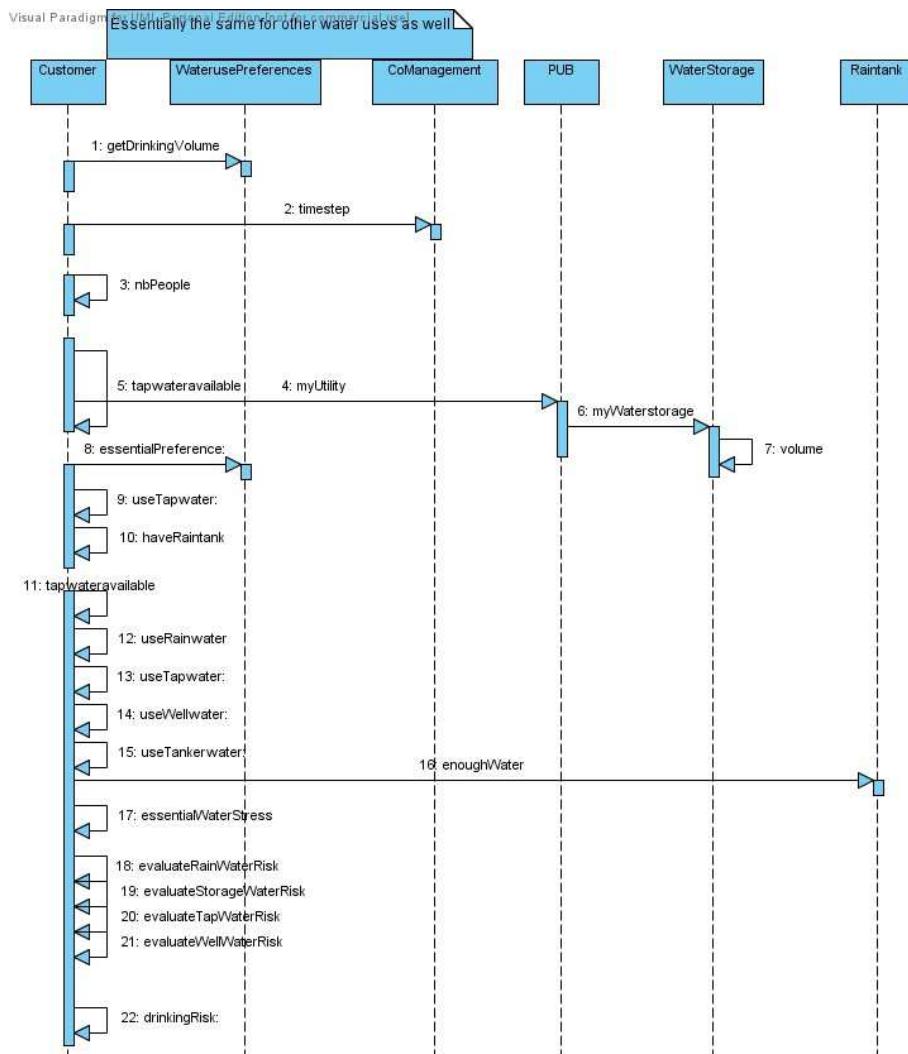


Figure 7-7: UML sequence diagram for a customer's use of drinking water

Notes: This figure shows the UML Sequence diagram for a customer's use of drinking water. As can be seen the key steps are 1) finding out how much water is required, 2) finding out the level of service that is available to the customer at the particular point in time, 3) decision to use water from a particular source based on decision as described above, and 4) updating the level of needs satisfaction depending on whether illness, payment problems, or water scarcity occurred.

7.1.4.2 Illegal activities

In addition to cropping on the water reserves, there is a range of illegal activities that occur on the reserves such as:

- Sand / gravel mining, where large pits are dug out to extract gravel. The gravel is then sold in South Tarawa for building materials. Asked what is the reason for sand mining, 98 percent say they use it for landscaping, 55 percent sell it to generate household income, 44 percent use it for home construction and 41 percent use it for brick making (South Pacific Applied Geoscience Commission 2007b);
- Burial grounds. As public land is extremely scarce in South Tarawa, the water reserves present something of an opportunity for establishing informal public places like burial grounds. Unfortunately, burial grounds on the water reserves that protect small and shallow groundwater resources will have an extremely negative impact on the water supply;
- Illegal settlements: squatters are illegally settling on the water reserves, which of course increases the risk of groundwater pollution. It is difficult to see that these semi-permanent settlements would be allowed without the permission of the landowners.

These issues are particularly problematic as reserves have become some kind of in-between public lands and private lands, with no clear enforcement power by the Government of Kiribati (GoK), the Land Division or the PUB. Numerous attempts have been made by the GoK to fence the area but these fences are quickly removed or destroyed.

Illegal settlements have been traditionally dealt with by sporadic removal of settlers. In late 2007, 53 households were surveyed on the two reserves. While there is some lack of clarity about the reasons for the squatter settlements, in late 2007 the main reasons for settlements appeared to be:

- An expectation that squatters on the reserves will have priority in the Kiritimati resettlement pilot project which is about to start and in which a 150 selected South Tarawa household will be given land for re-settlement on Kiritimati island;

- The increasing real estate prices which gives the land owners and incentive to undermine the GoK in its operation of the water reserves. This is based on previous experiences where water reserves have been abandoned in the face of expanding urbanisation and land related conflicts;
- Land owners are renting out land in the buffer zones (according to the head of the Land Division, 50 percent of the people living in the buffer zone are not land owners), and consequently landowners are themselves forced to settle on the water reserves.

The way that illegal activities on the water reserves are modelled in the Waterscape model, is inherently linked to the Landowners. Each Landowner has a decision variable, cooperate, and if this variable takes the value #false, he may allow the types of illegal activities above. Such activities however occur randomly as a stochastic process, but have lasting effects whenever they are approved by the land owner. Landowners also receive payments for illegal leases which is income and this is of critical importance when updating and adjusting the landowner's decision variables. The way that a landowner updates the decision variables is further described below.

7.1.4.3 Vegetation clearing

Clearing vegetation on the water reserves has the potential to increase the sustainable extraction yields by up to 50 percent, based on estimates of sap flow (4 mm per day), and current estimated levels of vegetation cover (20 percent) on the reserves.

Currently vegetation is not being cleared because of landowners' requirements for crops combined with unclear responsibility of who is supposed to carry out the task. In terms of future management strategies, it appears that the responsibility could be distributed in three distinct ways; via:

- The PUB, who will have to employ staff members to clear vegetation;
- Landowners on reserves, who will be rewarded for their land lease on the basis of monitored vegetation cover. This may also work to increase the feeling of ownership for the

water reserves, so that they will be increasingly protected against illegal activities such as sand mining;

- Households or water service customers, who would be offered the opportunity to undertake vegetation clearance as a way to avoid paying their water and/or electricity bills.

In the user interface, there is consequently the option of allocating this responsibility to Landowners, PUB, Households or No-one. When the responsibility is with the PUB, a certain level of tree coverage is maintained. When the responsibility of clearing trees is with the landowner, the method shown in Box 2 in Appendix 6 which describes how land clearing is achieved in the model.

7.1.4.4 Adaptive strategies

In the Waterscape model, Landowners adjust their behaviour based on their utility function, but due to dynamic and self-referential properties of the system, it is not a straightforward issue of optimisation in order to model land owner behaviour, as is the case when using the rational actor assumption commonly applied in economics.

In fact Landowners are faced with a situation of bounded rationality, where insufficient information and insufficient computational capacity is available when deciding on an appropriate strategy. Therefore, in accordance with the Consumat model, which has previously been described, there is a decision situation in which the landowners change from imitation to social comparison depending on their needs satisfaction. Based on a definition of high and low levels of returns, calculated based on the utility function, each landowner changes their decision making approach as follows:

- High return => Imitation, which means repeating behaviour (or in fact copying the behaviour of the one last compared with, but this is pretty much repetition);
- Low return => Social comparison, which means copying the behaviour of an individual that is perceived as successful.

The decision variables that Landowners adjust are (as per Appendix 6):

- treeCoverage, relating to the level of tree coverage that the land owner keeps on his property,
- cooperate, relating to whether or not the land owner accepts illegal activities on the property,
- nbCropPlots, relating to how many crop plots the land owner has on his property.

The utility function of the landowners has three components:

1. Income from legal activities, such as any legal cropping;
2. Income from illegal activities, such as illegal leases;
3. An undermining incentive, depending on the discrepancy between the real estate price and the lease payment; as well as on the perceived chance of succeeding.

The methods shown in Box 3-8 in Appendix 6, describes the utility function. As can be seen in the scripts, the Land Division can set a number of different parameters:

- How much that they pay the land owners for leasing their land (\$1807 per annum in 2007);
- How much cropping that they allow each landowner to have; described by the variable croppingAllowed;
- How much rental money that a landowner may earn legally through leases; described by the variable rentalAllowed.

However, there are also a number of critical factors that the *Land Division* does not directly control, such as the crop price; the real estate price; the reserve condition; the amount of goodwill that exists with the land owners (even if it can be argued that they have some control over the level of goodwill).

7.1.5 Impacts on water resources

Landowner activities on the water reserves primarily impact on the freshwater lenses through:

- Intrusion of pollutants into the freshwater lenses; and
- Vegetation extracting water for transpiration.

The impact of vegetation changes is described above but the impact of reserves activities on pollution are more difficult to define. A risk function has been defined taking into account (with weights in brackets): number of fuel spills (5); number of septic tanks (5); waste water spillage (3); husbanding of pigs (4); open wells (5); and animals (5); number of households living on the reserve (3); extent of cropping activity (1); number of burial grounds (5); and sand mining activity (3). The numbers of such occurrences are set for each reserve at initialisation, and subsequently some others appear dynamically.

For a particular freshwater lens, each of these areas of concern is ranked between 1 and 5, and then a weighted sum is created and scaled so that the final risk also falls in the range 1 to 5. This risk score is used in the evaluation of the risk of water related health problems for those water users that use tap water for cooking or drinking. If the water from any of the reserves' (i.e. Buota and Bonriki) lenses gets a risk score of 4 or above; the level of reserves pollution is considered to be #high. If the water from any of the reserves gets a risk score of 2 or below; the level of reserves pollution is considered to be #low. If neither of these conditions is fulfilled; the level of reserves pollution is considered to be #medium.

Similar calculations are carried out also for other water sources such as wells, rain tanks and water storages. For the rain tanks, the two risk factors that are considered are whether the tank is maintained and whether it has overhanging trees. Wells are connected to the freshwater lenses where the household is located, and the risk is calculated in a similar manner as that from the water reserves; but does not dynamically change due to landowner behaviour. These risks are set during initialisation of the model.

7.1.6 Financial aspects

There are also a number of financial features of the *Waterscape* model, such as PUB finances and the Tariff structure, charging for water and non-payment.

7.1.6.1 PUB finances

Finances are a critical aspect in the provision of urban water services; in particular for small towns with limited resources. The main categories of expenditure for the PUB are:

1. Electricity costs; or in fact fuel costs for electricity generation. Diesel is currently used as fuel but perhaps other options should be sought as fuel import costs soar. Using coconuts for producing fuel has been thought to be a viable fuel alternative;
2. Salary costs; for a relatively large pool of staff of which only a few have the appropriate accreditation or education (mainly due to the lack of educational opportunities in Kiribati);
3. Material costs for spare parts and other components;
4. Payment of lease for land in Betio.

Worth noting is that two key cost sources for the urban water systems are currently not carried by the PUB:

1. Infrastructure investments, which is carried by the Department of Finance, typically on the basis of an international loan (from the World Bank or the ADB) or donations from aid organisations and friendly governments
2. Payment for land leases for the reserves, which is carried by the Land Division (representing the GoK) which is a part of the MELAD.

Currently, Waterscape includes a very simple financial model that only takes into account operational costs recorded by the PUB, based on real budgets and accounts provided by the relevant officers.

7.1.6.2 Tariff structure, charging for water and non-payment

Currently water is charged at a flat rate of \$9 per household per month, and in theory if not paying, the water is turned off, but this procedure is not straightforward and there may be delays; especially considering the lack of accredited plumbers. However, there are also difficulties in charging for water due to the lack of an accurate customer database, making

charging for water unfair and somewhat random. Another difficulty is the extent of illegal connections to distribution pipes. Illegal connections are damaging both in terms of the ability to charge for water as well as in terms of the leakage that it causes. There are also anecdotes also that seem to indicate that households may damage their own tap and use someone else's tap in order to avoid having to pay for water. This in turn is an indicator that the piped water has increasingly become a common pool resource from which it is difficult to exclude users, and where individual utility maximisation is causing damage to the availability of the resource as a whole. The conclusion based on this is that the PUB as the centralised enforcer is currently lacking power in protecting the piped water resource.

To allow the *PUB* to explore alternatives in the way that they charge for water, and hence increasingly protect their piped water resource, some alternative options for charging for water are available:

- Having a volumetrically increasing charge;
 - Based on the individually metered water usage;
 - Based on the per household metered water usage for the customer group;
 - Allowing users to choose between the two alternatives above;
- Having a way of dynamically allocating the pumping amounts to each customer group and order in which they receive water based on the per person water usage.

The sequence of events and class method calls is shown in the Water usage UML sequence diagram in Figure 7-8.

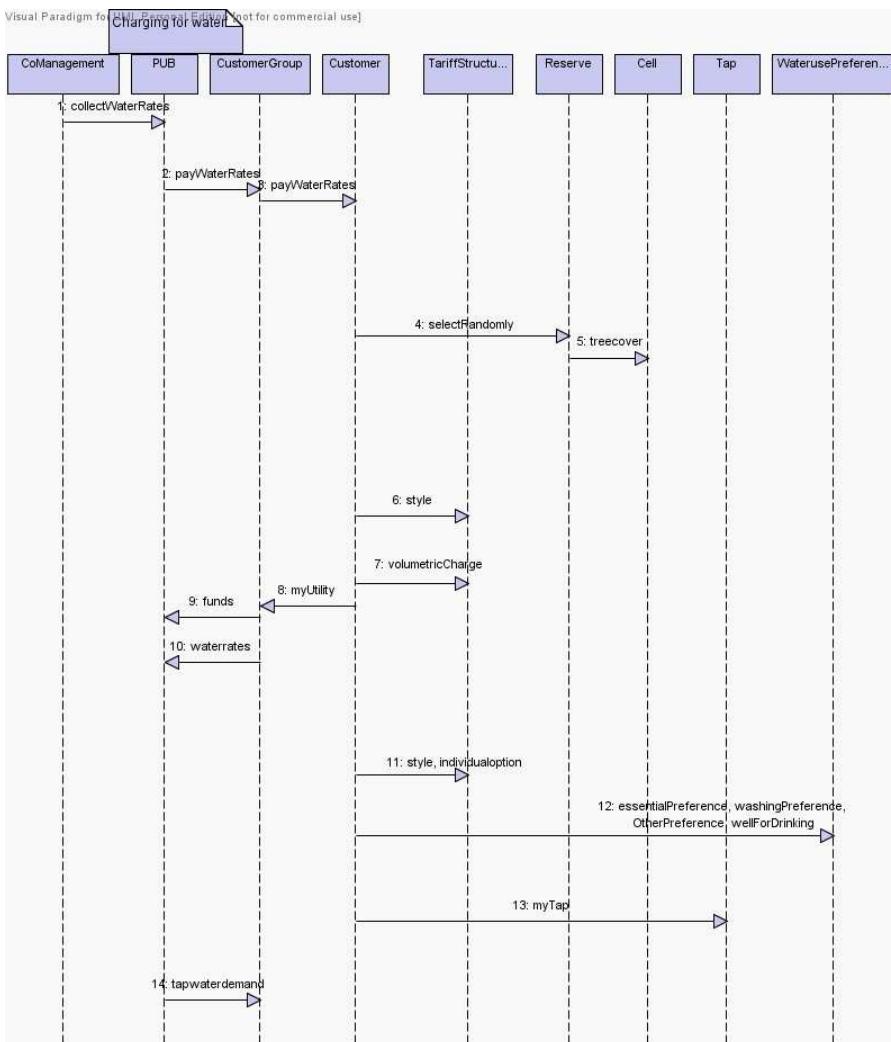


Figure 7-8: UML sequence diagram for calls related to charging for water

7.1.7 Spatial representation

The space is represented by cells which have attributes representing the state of each cell (#island, #lagoon, or #ocean); land uses (#burialground, #illegallease, #cropping, #sandmining, etc, etc); tree cover (#trees, #bushes or #none); landownership (indicating which property, if any, a cell belongs to); and water reserve (indicating which reserve, if any, a cell belongs to).

Based on these attributes we have created spatial aggregates:

- Islands: #Bonriki, #Buota, #Betio, #Bairiki, #Bikenibeu, #RuralTarawa and #NorthTarawa
- Reserve: #Buota and #Bonriki
- Properties: 1 to 10 on each Reserve

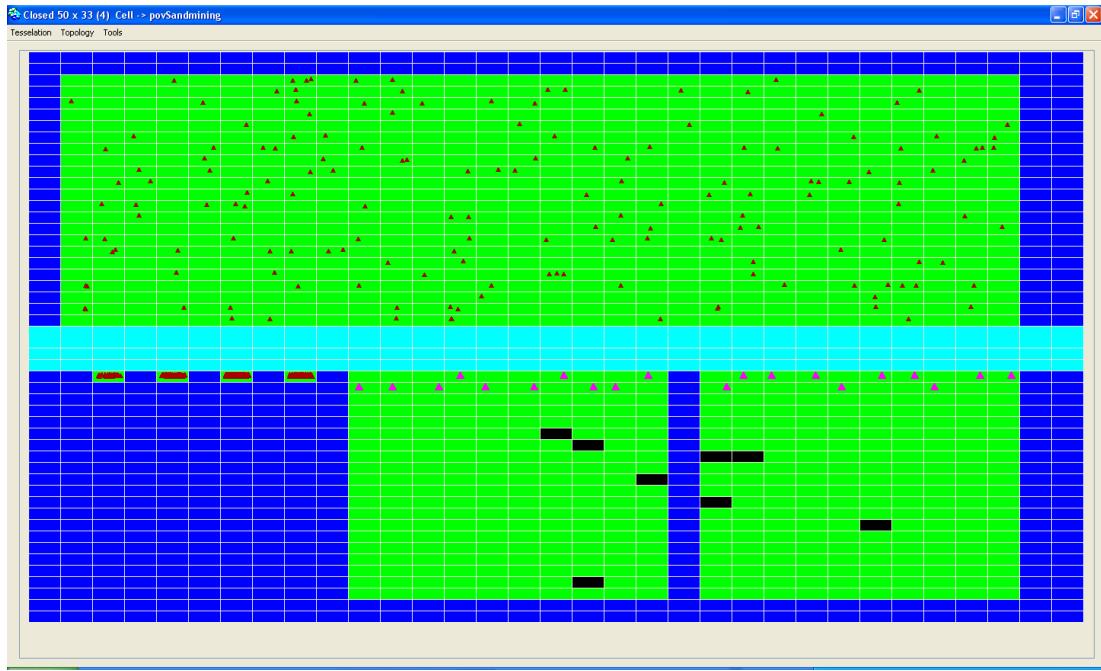


Figure 7-9: Map of the spatial representation, showing islands, ocean and the lagoon

Notes: The spatial configuration of Waterscape is represented by a grid of 50 by 33 cells. In Figure 7-9, cells are rectangular and where the dark blue cells represent the ocean, the green cells represent islands, the turquoise represents the lagoon. Black cells represent locations of sand mining on the water reserves. The triangles represent agents, and in this case customers and land-owners. Brown triangles are customers and pink triangles represent land owners.

Customers inhabit the islands of #Betio, #Bairiki, #Bikenibeu, #RuralTarawa and #NorthTarawa, but only the island of #Betio has multiple cells allowing for exploration of the heterogeneity of the customer agents. The Figure 7-9 shows a view of the map, displaying the state of the cells, where the green areas represent islands, the deep blue represents the ocean, and the turquoise areas represent the lagoon. The agents, or in other words customers, landowners, and others, are represented using small triangles. The large island is Betio, while the two mid sized islands are Buota and Bonriki. Buota and Bonriki contain the water reserves, represented by pink and green colour in Figure 7-10. As can be seen there is a buffer zone, in yellow, left for settlement for the landowners of these islands. Figure 7-11 shows the level of vegetation on each cell.

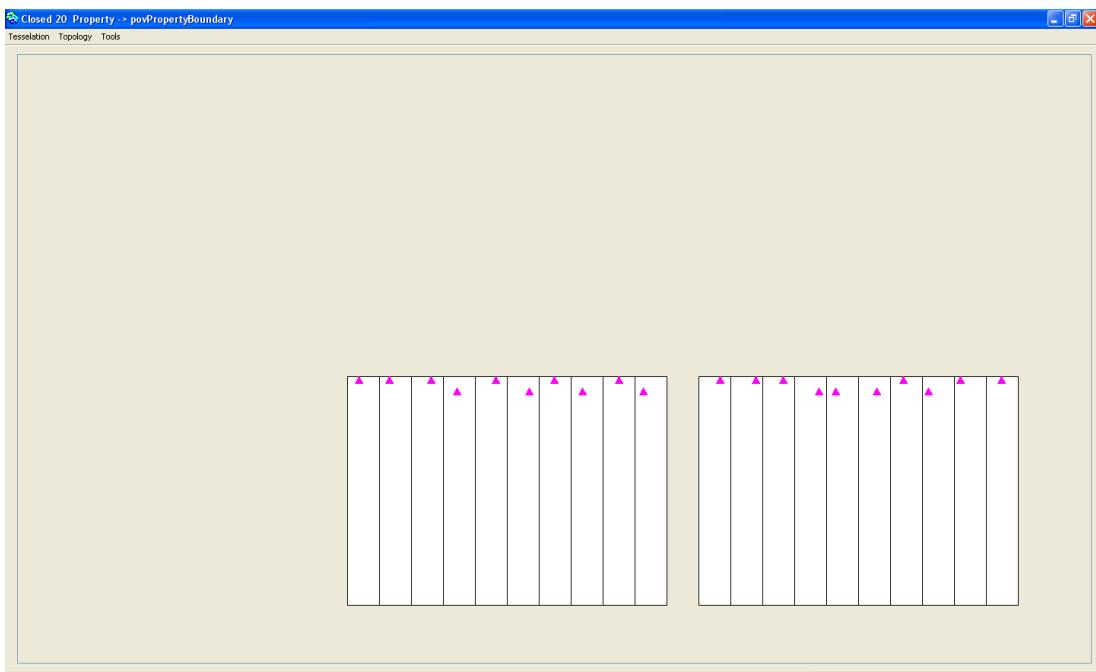


Figure 7-10: Map of location of the properties on reserves stretching across the islands

Notes: The white strips represent the properties on the islands of Bonriki and Buota that stretch from one side of the island to the other, in the same fashion as is customary in Kiribati. The landowners (pink triangles) are located on the edge of the island, where there is no water reserve.

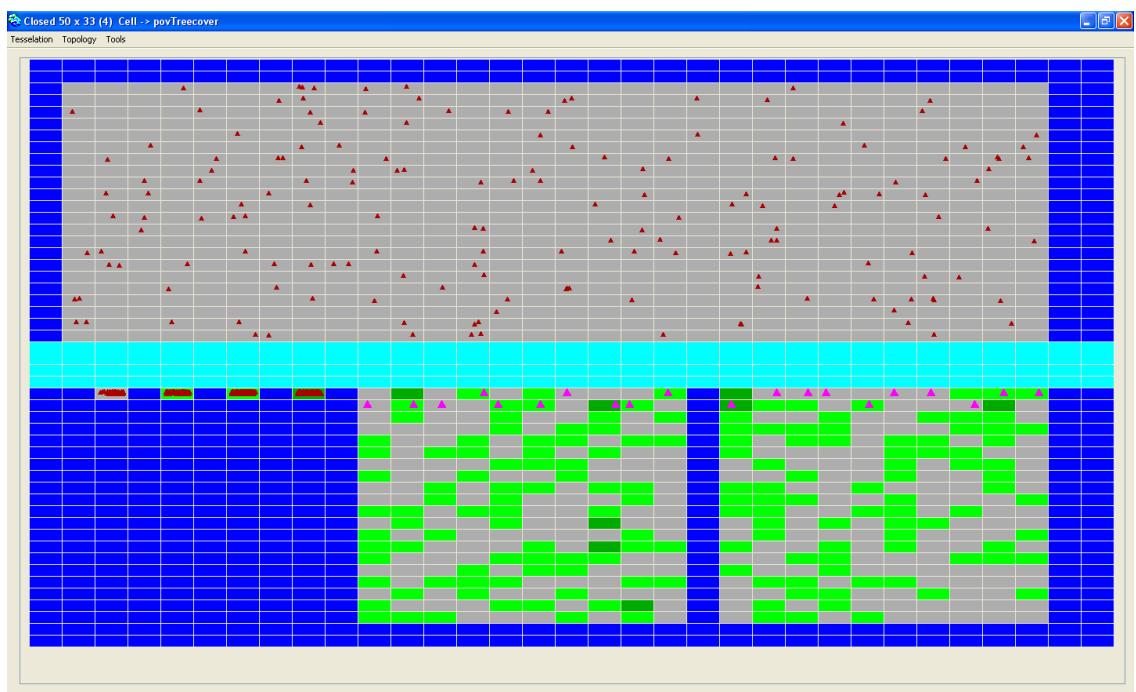


Figure 7-11: Map of the spatial representation; vegetation on islands

Notes: This figure shows the spatial representation, but this time focusing on vegetation on the reserves. Dark green cells represent "Trees", whilst the light green cells represent "Bushes" and grey cells represent "No vegetation". The transitions from one state to another can be either deterministic or stochastic based on input in the user interface.

7.1.8 Model parameters

There is a range of model parameters which are described in the tables in this section. Furthermore the user can enter a number of model parameters via the user interface. This is done via the user interface that pops up as a window before running the model (see Figure 7-12). These model parameters and their default values are shown in Tables 7-4 to 7-14.

The figure shows a complex user interface window for model parameters, organized into several sections:

- Filenames**: Environment file (TarawaXc3), Weather file (dicHydro360).
- Raintanks**: Capacity [m3] (2.0), Maintained [%] (80), Catchment area [m2] (10), Overhanging trees [%] (40), Runoff proportion [%] (80).
- Tariff structure**: Style (volumetric), Increasing (steps), Individual option (#true), Frequency (31).
- Rate pain thresholds (\$)**: Wealthy (12), Normal (8), Struggler (2).
- Population increase**: Style (deterministic), Frequency [days] (365), Yearly increase [%] (3).
- Freshwater lenses**: Sapflow vol [mm/day] (4), Desired reserve tree coverage (%) (10), Bonriki ser [m3 / day] (1350), Buota ser [m3 / day] (350), Betio ser [m3 / day] (500), Bairiki ser [m3 / day] (200), Bikenebeu ser [m3 / day] (200), Rural Tarawa ser [m3 / day] (500), North Tarawa ser [m3 / day] (1500).
- Rainfalls**: Vegetation clearance (None), Growth type (deterministic), Growth frequency (270), Growth probability (0.5), Clearance officers (PUB) (5).
- Leakage**: Illegal connections (75), Legal connections (40), Pipe leakage per km (800).
- Water use**: Amounts [liters]: Drinking (8), Sanitation (2), Washing (10), Cooking (15), Other (5), Pigs (5), Bathing (15). Water stress adjustment trigger [days] (7), Health adjustment trigger [events] (3), Stop drinking well water (false).
- Water reserve landowners**: Relocation program (false), Tree clearing (false), Selling firewood (false), Sandmine reward (500), Illegal activity acceptance (true), Crop price per month (\$) (100), Firewood price (\$) (30).
- Land division**: Conditional payment (true), Inspection cost (50), Real estate property lease (8000), Landlease amount (700), Cropping allowed (3), Rental lease allowed (5000), Fine for reserves condition (true).
- PUB strategies**: Pumping strategy (current), Allocation strategy (proportional).

Figure 7-12: User interface as a pop-up window before the model runs

Table 7-4: Tariff structure parameters

Name of parameter	Description	Default value & Source
Style	Whether water is being charged on a fixed or a volumetric basis.	Flat rate of \$9 per month per household; which is what it was in Tarawa during field visit
Increasing	Steps or linear	The default is that this variable is not activated
Individual option	Whether households can choose to be charged on an individual basis; which requires metering of households	No individual option
Frequency	How often water is being charged; i.e. Monthly weekly, monthly or yearly	
Rate pain threshold – wealthy	How much is considered by a wealthier household consider to be too much to pay for water services?	\$12
Rate pain threshold – normal	How much is considered by an average household consider to be too much to pay for water services?	\$8
Rate pain threshold – struggler	How much is considered by a poorer household consider to be too much to pay for water services?	\$2

Table 7-5: Vegetation parameters

Name of input	Description	Default value
Vegetation clearance	Who is responsible for clearing vegetation; no-one, landowners or households	No-one
Growth type	Whether the vegetation grows in a probabilistic or deterministic manner	Deterministic
Growth frequency	How often vegetation grows	Every 270 days
Growth probability	The probability of growth; if probabilistic	50%
Clearance officers (PUB)	The number of PUB officers hired to clear vegetation	5

Notes: The growth of the vegetation is set up on the basis of replicating rough re-growth behaviour. As no data was available in regards to this, I relied on sense-checking by those that have observed the system, and have calibrated the model to maximize their perceived accuracy of the model in this respect. The calibration has involved changing the growth frequency and the growth probability. The number of PUB officers to clear vegetation is relating to a currently un-utilised management option that can be explored. The responsibility for clearing vegetation impacts on the individual utility functions of the involved agents (landowners or households).

Table 7-6: Population increase parameters

Name of input	Description	Default value
Style	Does the population increase in a probabilistic or deterministic manner?	Deterministic
Frequency	How often does the population increase in the model?	Yearly
Yearly increase	How much does the population increase each year (on average if probabilistic)	3%

Notes: the probabilistic style of population growth is based on a Poisson distribution based random arrival process.

The yearly increase of 3% is in line with census data and population projections.

Table 7-7: Water use behavioural change parameters

Name of input	Description	Default value
Water stress adjustment	How many days of water stress are acceptable before changing behaviour? (days)	7
Health adjustment trigger (event)	How many water borne health incidents need to occur before changing water use pattern?	3
Stop drinking well water	Is there a policy that people should stop drinking the well water? Slightly unrealistically, this parameter stops all well water use for drinking purposes.	No

Notes: there is not data to back up the default values of these triggers; but they are set purely on the basis of what seems acceptable; with some limited insights into the reasoning of local I-Kiribati people gained during the field study.

Table 7-8: Leakage parameters

Name of input	Description	Default value
Illegal connections	Leakage from illegal connections; per connection; in litres per day per metre head of pipe pressure	80
Legal connections	Leakage from legal connections; per connection; in litres per day per metre head of pipe pressure	40
Pipe leakage per km	Leakage from pipelines in litres per day per metre head of pipe pressure; and per kilometre of pipe	220

Notes: The estimates of leakages come from Lambert (2001) and Lambert and McKenzie (2002) on the basis of leakage estimation methodologies used in developed countries which have served as a benchmark and a rough guide about relative proportions between the different types of leakages. Furthermore, local estimates by PUB staff have been used to allow for calibration of the default parameters. It has also been assumed that illegal connections leak double the volume in comparison to what legal connections do. Actual leakage rates are unknown except indications of leakage at a systems scale for certain parts of the distribution network.

Table 7-9: Raintanks parameters

Name of input	Description	Default value
Capacity	The size of a household rain tank; assuming they are all the same size	2.0 ^a
Catchment area (m ²)	The size of the roof catchment area; ; assuming they are all the same size	10 ^b
Runoff proportion	The proportion of water falling on roof catchments that ends up in rain tanks; i.e. minus overflows etc	80%
Maintained (%)	The proportion of rain tanks that are adequately maintained	80% ^c
Overhanging trees (%)	The number of rain tanks for which there are over-hanging trees	40% ^c

Notes:

^a The default value for the Capacity (rain tank size) was chosen on the basis of observation of the perceived typical size of household rain tanks in Tarawa.

^b The catchment area is similarly a rough estimate of a perceived typical roof size; on the basis of personal observation.

^c The proportion of tanks that are maintained, and that have over-hanging trees, has been taken from the SAPHE household survey (Asian Development Bank 2000b).

Table 7-10: Freshwater lens parameters

Name of input	Description	Default value
Sap flow (mm/day)	The sap flow from vegetation leading to losses from groundwater	4 mm/day
Desired reserve tree coverage	The ideal tree coverage for the water reserve through management	10%
Bonriki ser (m ³ /day)	Sustainable extraction rate from the island of Bonriki	1350
Buota ser (m ³ /day)	Sustainable extraction rate from the island of Buota	350
Betio ser (m ³ /day)	Sustainable extraction rate from the island of Betio	500
Bairiki ser (m ³ /day)	Sustainable extraction rate from the island of Bairiki	200
Bikenibeu ser (m ³ /day)	Sustainable extraction rate from the island of Bikenibeu	200
Rural Tarawa ser (m ³ /day)	Sustainable extraction rate from the island of Rural Tarawa	500
North Tarawa ser (m ³ /day)	Sustainable extraction rate from the island of North Tarawa	1500

Notes: These sustainable extraction rates are based on the assessments by Falkland (2003), and when accurate

data is not available, based on less detailed statements in other reports (Asian Development Bank 2003b; 2004b).

Numbers have subsequently been sense-checked with technical staff members at the PUB.

Table 7-11: Land division parameters

Name of input	Description	Default value
Conditional payment	Land lease payments to landowners depends on the state of the land?	Yes
Inspection cost	The cost for the land division of inspecting the land	\$50
Real estate property lease	How much a land-owner can lease out the property for on the real estate market	\$8000
Land lease amount	Land lease payments	\$700
Cropping allowed	Whether land owners are allowed to grow crops on the reserves (number of plots)	3
Rental lease allowed	The amount of rental lease payments that are legally allowed for people living on the reserve	\$5000
Fine for reserves condition	Fine being paid in case the reserve is in an inadequate state	Yes
Clearing of reserves	Whether landowners clear reserves	No

Notes: The default value for the real estate property value has come out of anecdotal evidence in interviews; whilst the actual land lease amount was the current land lease paid by the government to land owners at the time. Other default parameters values are set according to current practice.

Table 7-12: Water use volume parameters

Name of input	Description	Default value
Drinking	The amount of water in litres used for drinking purposes; per person per day	6
Cooking	The amount of water in litres used for cooking purposes; per person per day	15
Sanitation	The amount of water in litres used for sanitation purposes; per person per day	20
Other	The amount of water in litres used for other purposes; per person per day	20
Washing	The amount of water in litres used for washing purposes; per person per day	30
Pigs	The amount of water in litres used for pigs purposes; per person per day	10
Bathing	The amount of water in litres used for bathing purposes; per person per day	20

Notes: The estimates of water use volumes have been set with a total of a conservative total water use of 121 litres per capita per day; in comparison to for example White (1999a) which states a range of total water use per capita of between 150 and 600 litres per capita per day. The total has been set so low in response to interviews which indicate that actual water use in Tarawa is very low and dropping, and in fact below 150 litres per capita per day. The proportions separated into various components were checked against sources on the internet, that don't need to be mentioned, but with a lack of real data are only rough estimates.

Table 7-13: Landowner activities parameters

Name of input	Description	Default value
Relocation program	Are land-owners to be relocated to Kiritimati island?	No
Selling firewood	Do landowners sell firewood?	No
Illegal activity acceptance	Do landowners accept illegal activities?	Yes
Crop price per month	How much money can be made from selling crops from a patch of land?	\$100
Firewood price (\$)	How much money can be made by selling firewood from a patch of land?	\$30
Tree clearing	Do land-owners clear trees?	No
Sand-mine reward (\$)	Do land-owners receive a reward for sand-mines on their property? I.e. are they paid?	\$500

Table 7-14: Water inflow and outflow parameters

Name of input	Description	Default value & Source
Pumping strategy	How does the PUB decide to pump water from the water reserves? What volumes are pumped? There are 5 relatively self-explanatory strategies: #current, #sustainable, #supply-focus, #recovery and #mixed	#current
Allocation strategy	How does the PUB allocate water to the villages? There are a number of strategies: #current, 20 40 60 or 80 litres for each person (as far as it lasts); and #proportional (to the population); and #preferential (some villages get significantly more)	#current
Weather file name	Which weather file is used?	TarawaXc3

7.1.9 Simulation results

As discussed previously there are severe problems in Tarawa water management, such as: endemic water borne diseases contributing to one of the highest infant mortality rates in the world; over-extraction of freshwater from groundwater sources, especially at times of drought; social disruption and conflict due to displacement of traditional landowners from water reserves; and inability to finance water services by charging customers for water.

There are trade-offs to be made when attempting to mitigate or minimise such problems; for example there is likely to be serious water contamination and health consequences if all households have to pay for water services. Similarly, there would be serious health problems if landowners were allowed back on water reserves. Other strategies, such as minimising leakage, or increasing the utilisation of rainwater tanks may be more beneficial, but are difficult to implement without adequate funding.

Waterscape has been used to explore the trade-offs that can be made between such multiple goals. To illustrate the type of scenarios that can be run, and the reasoning that this can support, two weather-based scenarios have been explored. The ‘normal’ climate scenario uses a historical weather file corresponding to average rainfall and evaporation condition. This scenario is described by an average monthly rainfall of 195mm, which is roughly the 60%-percentile of rainfall in Tarawa (White *et al.* 1999c). The drought scenario uses a historical weather file corresponding to the 10%-percentile of 30-month averages of approximately 100mm per month (White *et al.* 1999c). The management options as shown in Table 7-15 have also been explored. The first five options were first explored separately, and then a combined strategy is explored which involves strategy 2, 3, 5 and 6. Scenarios and management options have been evaluated on the basis of two criteria, which are the extent of over-extraction of the main freshwater lens, the water debt, as well as the percentage of the community at severe health risk due to the source of water used for cooking and drinking, as shown in Table 7-16.

The two output variables in Table 7-16 are evaluated for the various scenarios, and their mean values and standard deviations are calculated in each case. This allows for statistically confirming effects of management strategies, whilst acknowledging that there is a random component in the effect on output variables. It is concluded that in terms of health impacts, the most outstanding strategy is relocation of landowners on reserves and clean-up of the reserves. In terms of resilience to drought, no strategy is as dominant, but clearing of vegetation and recovery pumping shows the greatest promise. This means that it is clear that the key focus needs to be on the protection and management of the freshwater lenses that are being utilised as a freshwater source for water distribution.

Table 7-15. Water management options on Tarawa explored in the Waterscape model

Name of scheme	Description
1. Current management approach	This involves a groundwater pumping and water allocation scheme, current population and state of rain tanks in the community, current levels of leakage as well a situation of stalemate and considerable pollution on water reserves.
2. Relocation and clean-up	Relocating landowners on the water reserves to Kiritimati island, and clean up all sources of pollution on water reserves. This involves taking out all the landowners from the model, and to change the status of cells in order to remove sources of pollution from the reserves.
3. Reduce leakage	Reducing the current leakage rates from pipes and connections. In the model, it involves reducing the leakage from illegal connections from 80 to 10 litres per day per metre pressure, and leakage from legal connections from 40 litres per day per metre pressure to 5 litres per day per metre pressure; and leakage from distribution pipes from 220 litres per kilometre per day per metre pressure, to 40 litres per day per kilometre per metre pressure. The pipe pressure is assumed to be at 20 m head. The calculation also takes into account that there is water supply for approximately 1 hour per day.
4. Proportional allocation	This involves providing the same amount of water per capita to each village, or in other words choosing the pumping volumes to each area/island's water storage as proportional to their populations. Currently this is not the case, and instead the allocation varies between 25 litres per person per day in the less dense areas, and up to 55 litres per person per day in the most densely populated area (Public Utility Board 2008)
5. Recovery pumping	Reduce pumping rates from water reserves to 80 percent of sustainable extraction rates at times of drought in order to preserve water. Sustainable extraction during normal times.
6. Clearing of vegetation	This involves the land division, which is a government department, clearing all the vegetation on the reserves, on a monthly time step.
7. Repair and double the size of all rain tanks	This involves increasing the capacity of all existing tanks from 2m ³ to 5m ³ as well as to increase the percentage of tanks that are maintained to 100 percent, and reducing the amount of tanks that have over-hanging trees to 0 percent.

Table 7-16. Description of variables used for exploring outcomes of scenarios

Name	Description
Water debt (WD)	This is calculated on the basis of water flow calculations, where 1 day is equivalent of the daily sustainable extraction rate, which in the case of the largest freshwater lens in Tarawa (Bonriki) is 1,350m ³ /day. For illustration purposes, the Bonriki lens is used to calculate the water debt.
Percent of population at high health risk (HHR)	The water related health risk is calculated on the basis of a broad brush risk assessment, in line with guidelines by the Australian aid agency AusAID (2005), on the basis of the path of the water from rainfall to household water use. For example, the tap water is exposed to a number of pollution sources on its way to households; or in other words on the basis of the following risk factors: fuel spills, septic tanks, waste water spillage, pigs husbandry on reserves, open wells, animals, settlements, burial grounds and sand mining; Back flow of groundwater into pipes that have only intermittent supply; as well as water storage and the possible contamination that can occur because of this.

The model results in Table 7-17 show that there are statistically significant differences between the outcomes of key management strategies. Each strategy has been evaluated against two performance criteria: 1) water debt: the level of over-extraction of water from the freshwater lens in Bonriki; and 2) health hazard risk: the proportion of households that are exposed to a high level of water quality risk. For each of the evaluated strategies, the empirical mean of these performance variables have been calculated, as well as the standard deviations (shown in brackets).

The 95% confidence interval for the theoretical mean values, based on the assumption that the output varies randomly according to a Normal distribution, is the empirical mean $\pm (1.96/2.24)$ multiplied by the empirical standard deviation. Because of the relatively small values on the standard deviations, 5 replicates were considered appropriate in most cases, but because of the relatively higher standard deviation the number of replicates was increased to 10 for the “Reduce leakage” and “Proportional allocation” strategies.

Table 7-17. Outcomes of each scenario and management option in the Waterscape model

Management option	Climate scenario	Water Debt	Health Hazard Risk (%)
Current management	Normal	0 (± 0)	52 (± 1)
Relocation and clean-up	Normal	0 (± 0)	20 (± 2)
Reduce leakage	Normal	0 (± 0)	68 (± 8)
Proportional allocation	Normal	0 (± 0)	69 (± 10)
Recovery pumping	Normal	0 (± 0)	51 (± 1)
Clearing vegetation	Normal	0 (± 0)	51 (± 0.4)
Combined strategy	Normal	0 (± 0)	24 (± 2)
Current management	Drought	1639 (± 13)	53 (± 1)
Relocation and clean-up	Drought	1663 (± 15)	20 (± 2)
Reduce leakage	Drought	1616 (± 14)	71 (± 10)
Proportional allocation	Drought	1435 (± 7)	68 (± 8)
Recovery pumping	Drought	1073 (± 2)	51 (± 1)
Clearing vegetation	Drought	1091 (± 1)	53 (± 1)
Combined strategy	Drought	767 (± 2)	23 (± 2)

Notes: To collect the results shown in this table, the Waterscape model has been simulated for 1000 time steps, and then the empirical means and standard deviations of two key performance variables have been calculated based on 5 or 10 replicates. The empirical means are in columns 3 and 4; whilst the empirical standard deviations are shown in brackets.

Whilst the hypothesis that strategies are equivalent can not be disproven when evaluating the water debt in Normal conditions; all strategies can be shown to be statistically different in terms of the water debt performance in Drought conditions, using a traditional t-test for testing hypotheses. For the health hazard, most strategies can be shown to be statistically different

using the same t-test. The general trend is also that drought increases the health hazards, but this is in most cases not a statistically significant effect.

7.1.10 Sensitivity analysis

To explore the sensitivity of the Waterscape model to uncertainty in parameter values, the two key output variables, *Water debt* and *Health hazard risk*; have been evaluated for the parameters shown in Table 7-18 which shows their default values. This set of parameters was chosen on the basis of their perceived potential to significantly influence output variables. The sensitivity analysis has been carried out by replicating the model runs 8 times for each parameter value in the parameter range. This has been done with the “*Current management*” scenario and utilising the “*Normal*” climate conditions data series. The parameter range has a number of discrete steps, with between three and five plausible parameter values.

Table 7-18: Parameters explored in sensitivity analysis

Class	Name of parameter	Default values
Customer	healthTrigger	3
PUB	TankerDeliveryVolume	2
	tankerSpillage	0.1
WaterusePreferences	drinkingRequirement	6
	cookingRequirement	15
Raintank	capacityPerTank	2.0
	proportionMaintained	0.8
	propOverhangingTrees	0.4
PopulationIncreaseDynamics	increaseRate	3
FreshwaterLens	bonriki_ser	1350
	sapflowVol	4
PipeInfrastructure	illegalConnectionLeakage	80
	legalConnectionLeakage	40
	PipeLeakagePerKm	220
LandDivision	realEstatePrice	8000
	landleaseAmount	700
TariffStructure	chargeAmount	10
Cell	growthFrequency	270
CustomerGroup	illegalConnectionsProportion	0.25

The results of these simulations are shown in Figures 7-13 to 7-31. Based on these results it is found that there are only modest changes to the health hazard risk in response to plausible changes in parameter values, but for most parameters, there is a trend with changes in parameter values. The sensitivity analysis also consistently shows a water debt of zero for all simulations, but this is hardly surprising because this is expected in ‘Normal’ climate conditions.

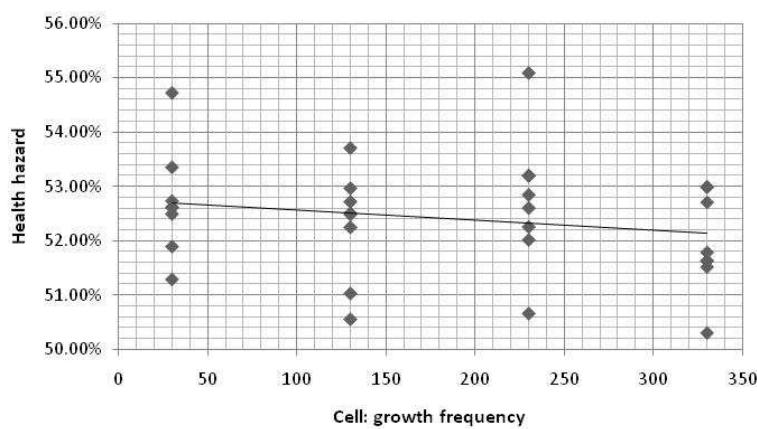


Figure 7-13: Cell growth frequency versus Health Hazard

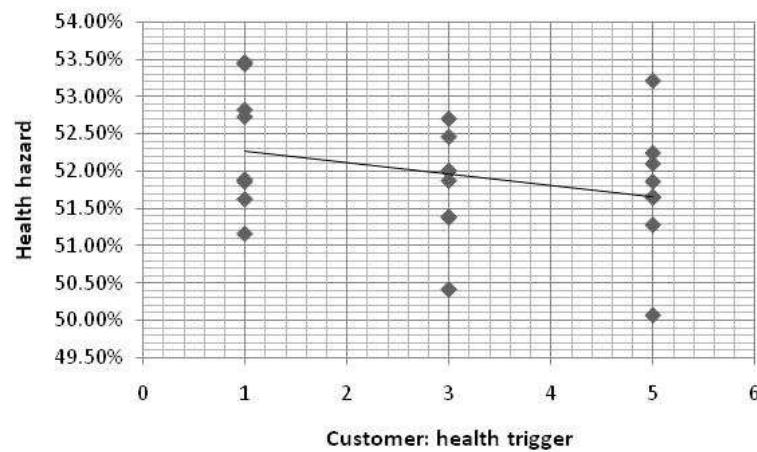


Figure 7-14: Customer health trigger versus Health Hazard

As shown in Figure 7-13, slower growth of vegetation (330 days re-growth time instead of 30 days) tends to lead to a slightly reduced health hazard (by approximately 0.5%), presumably because it reduces sap flow losses and increases the availability of a relatively safer water source.

As shown in Figure 7-14, a higher health trigger, means a reduced frequency of changing water use behaviour (5 events before changing behaviour instead of 1), leads to a slight reduction in the health hazard (approximately 0.5%). This is very small effect but still unexpected and may have to do with not over-reacting to temporary water safety problems; and that changing supply source may often lead to even worse outcomes.

As shown in Figure 7-15, more illegal connections (30% of households instead of 15%) tend to lead to slightly higher health hazards (approximately 1% higher) and the reasons are not known but this may relate to inequities in allocation that this may lead to.

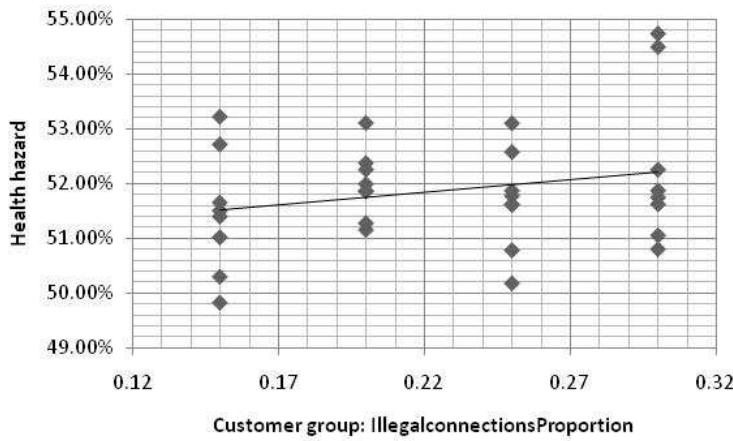


Figure 7-15: Customer group illegal connections proportion versus Health Hazard

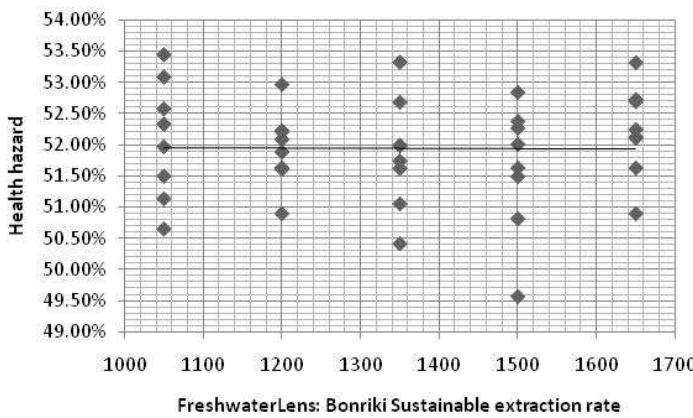


Figure 7-16: Bonriki sustainable extraction rate versus Health Hazard

Not surprisingly, a higher sustainable extraction rate of the Bonriki freshwater (1650 m^3 per day instead of 1050 m^3) lens does not significantly impact on the health hazard. The effect of a higher salt content in the water is not modelled as it is considered to be marginal.

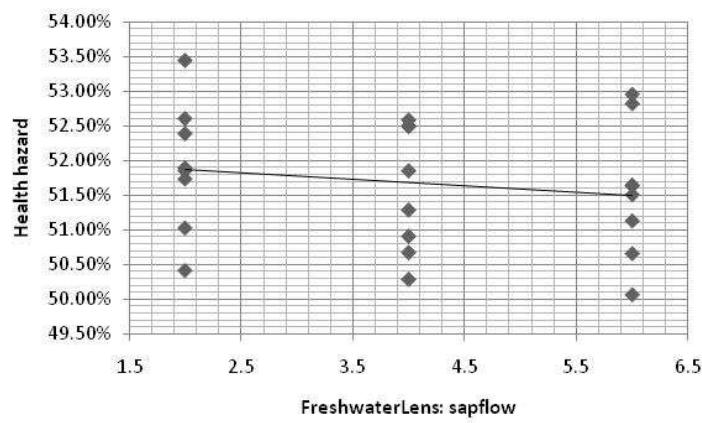


Figure 7-17: Sap flow versus Health Hazard

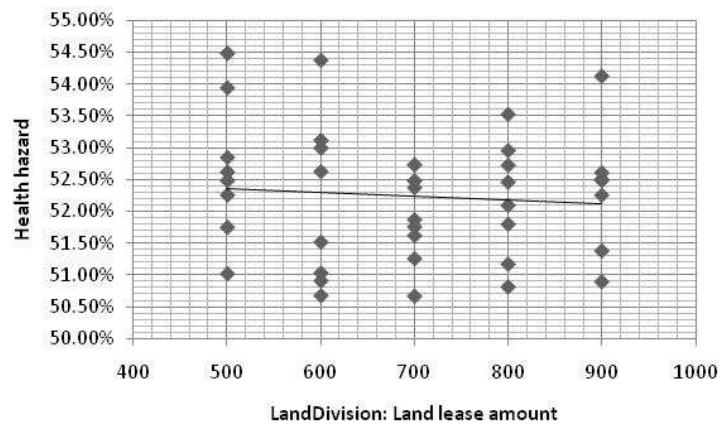


Figure 7-18: Land lease amount versus Health Hazard

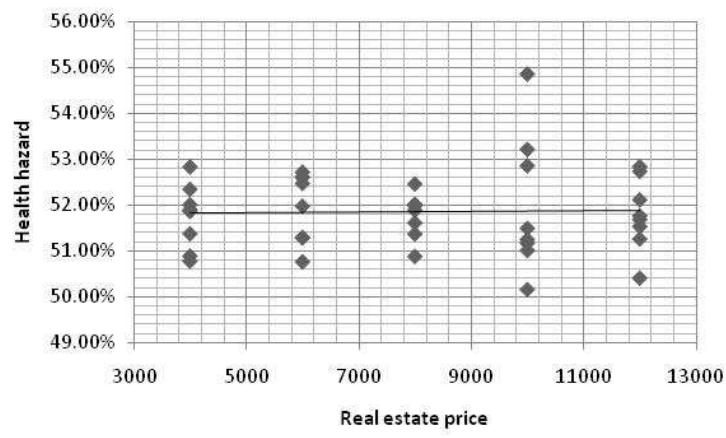


Figure 7-19: Real estate price versus Health Hazard

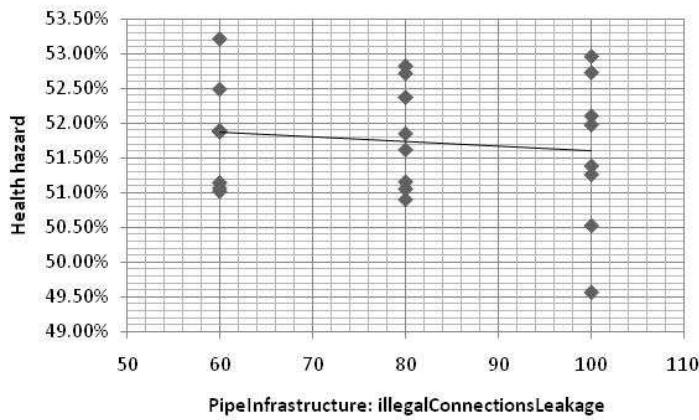


Figure 7-20: Illegal connections leakage versus Health Hazard

As shown in Figure 7-17, somehow surprisingly, increased sap flow (6mms instead of 2 mms) tends to lead to a slight reduction in health hazard (<0.5% difference). As shown in Figure 7-18, there is only a very small weak relationship between land lease amount paid to land owners for the land, and the health hazard; presumably because there are other dominant forces to their incentives. As shown in Figure 7-19, similarly there is only a very small trend between the real estate price of properties on the reserve and the health hazard; presumably because there are other dominant factors that influence their incentives, or because the plausible values in the range do not change the direction of incentives. Figure 70-20 shows that higher leakages from illegal connections reduce the amount of water available from the distribution system, and this surprisingly slightly reduces the health hazard (<0.5%). This reason is presumably because it would make fewer households reliant on the distributed water system for cooking and drinking.

As per Figure 7-21, a similar argument would be made for leakages from legal connections as for illegal connections in order to explain the reduced health hazard (2.5% reduction) as a consequence of increased leakage levels from almost half of current estimates to about double of current estimates. The reason why explanations for the leakage from connections do not extend to pipe leakages is tenuous, but the explanation is probably related to the fact that pipe leakage would affect the water available to all community segments, whilst leakage from connections would primarily affect those community segments that are to a greater extent

serviced by via the distribution system. More leakage in pipes would make less available for those households that are in more marginal segments which would only receive water on an intermittent basis.

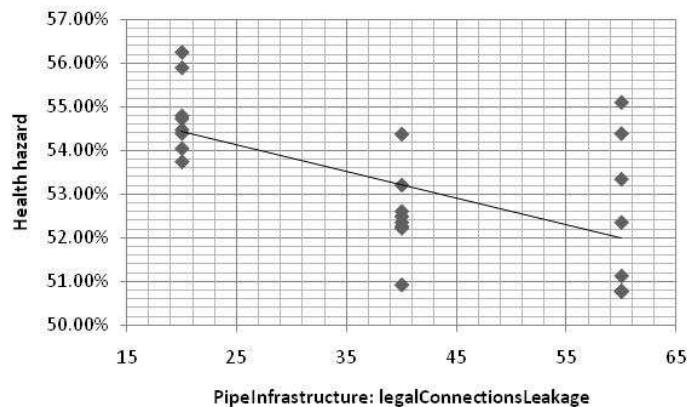


Figure 7-21: Legal connections leakage versus Health Hazard

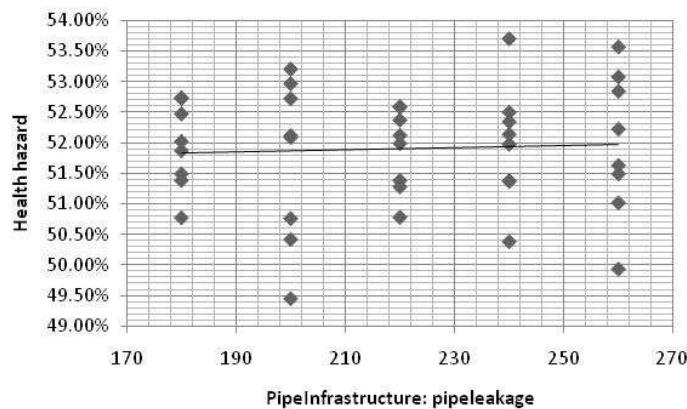


Figure 7-22: Pipe leakage versus Health Hazard

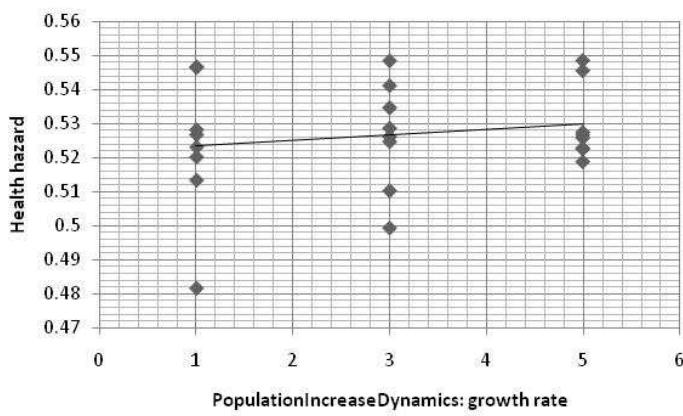


Figure 7-23: Population growth rate versus Health Hazard

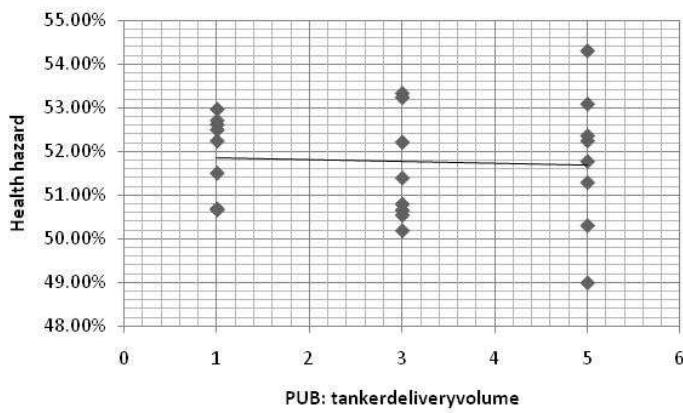


Figure 7-24: PUB tanker delivery volumes versus Health Hazard

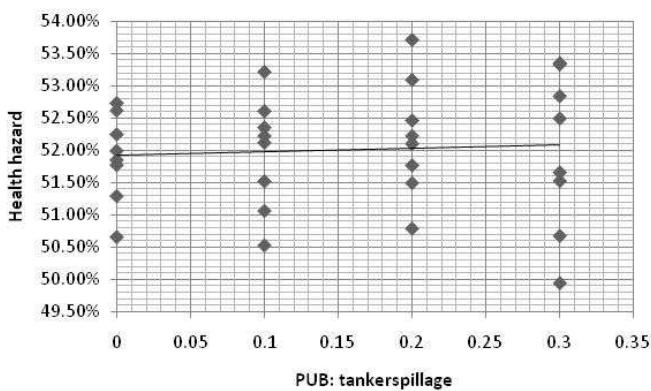


Figure 7-25: PUB tanker spillage versus Health Hazard

As shown in Figure 7-23, a higher population growth (5% instead of 1%) would slightly increase the health hazard (1% increase). The reason is presumably because there would be less safe water per capita. As shown in Figure 7-24, the amount of water delivered by the PUB for emergencies via tanker only marginally has an impact on the health hazard, but instead it changes the spread of health hazard outcomes. With a capacity to deliver 5 m^3 per day instead of 1 m^3 , the health hazard varies between 49% and 54.5% instead of the narrow range of outcomes between 50.5% and 53%. As shown in Figure 7-25, the amount of water lost in tanker spillages, only has a minor impact on the health hazard and even that it is tenuous because the average health hazard with 30% spillage is slightly lower than that for 20% spillage.

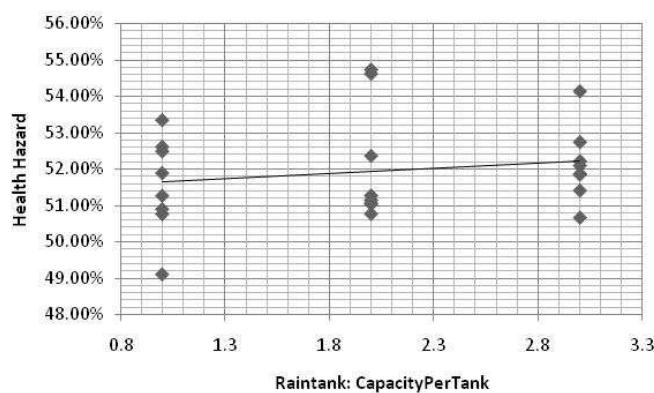


Figure 7-26: Capacity per tank versus Health Hazard

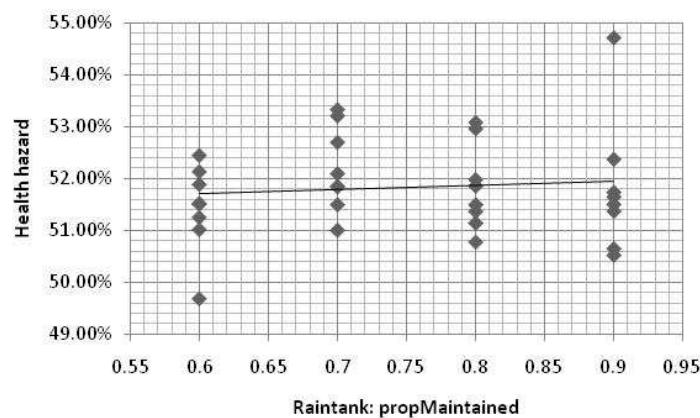


Figure 7-27: Proportion maintained versus Health Hazard

Figure 7-26 shows that increasing the capacity of rain tanks from 1 m^3 to 3 m^3 increases the health hazard from 51.5% to 52%; presumably because this would mean a slightly higher reliance on rain tanks which may sometimes be a more unsafe water source for cooking and drinking purposes.

Surprisingly, Figure 7-27 shows that increasing the rate of maintenance of rain tanks that are maintained (from 60% to 90%) does not significantly change the health hazard. This shows that what seems like an obvious approach to improve the health outcomes does not necessarily lead to the desired outcomes.

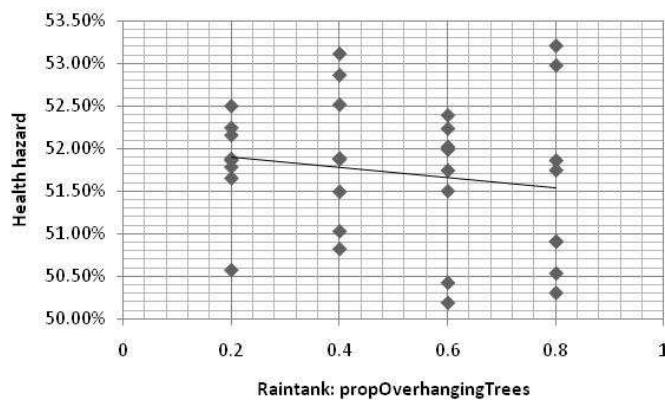


Figure 7-28: Proportion overhanging trees versus Health Hazard

Figure 7-28 shows that reducing the occurrence of overhanging trees (from 80% to 20%) over rain tanks does not significantly change the overall health hazard. Hence reducing the number of over-hanging trees does not necessarily lead to desired health outcomes.

Figure 7-29 shows that the health outcomes do not significantly depend on the amount charged by the PUB for water usage, as is shown in Figure 7-29, but there is a slight trend that shows that higher prices lead to reduced health hazards.

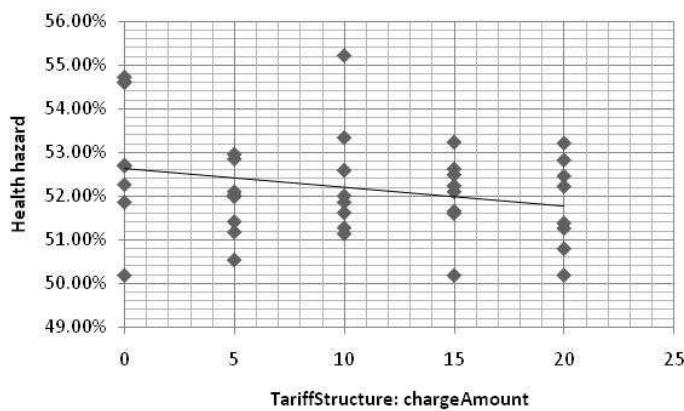


Figure 7-29: Tariff structure charge versus Health Hazard

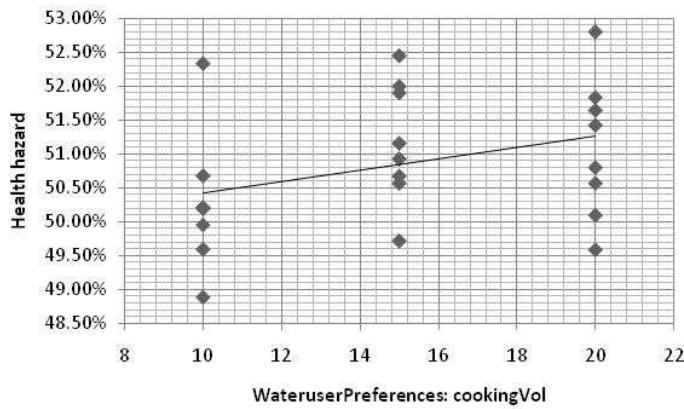


Figure 7-30: Water preference cooking volume versus Health Hazard

Figure 7-30 shows that a reduction in the volumes of water required by households for cooking (from 20 litres to 10 litres) means that there is a smaller likelihood of running out of water, and hence to use another source which is generally more unsafe. A more modest requirement hence reduces the health hazard (with approximately 1%).

Similarly, Figure 7-31 shows that a reduction in the volumes of water required by households for drinking (from 9 litres to 3 litres) means that there is a smaller likelihood of running out of water, and hence a reduced likelihood of having to use another source which is generally more unsafe. This reduced health hazard is however not present in the sensitivity analysis (see Figure 7-31).

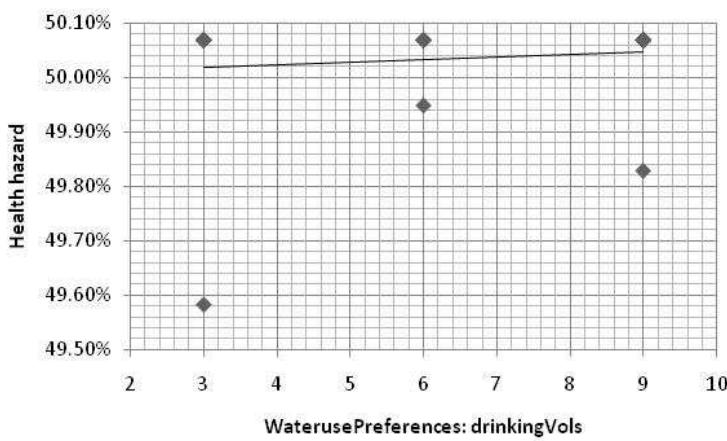


Figure 7-31: Water preference drinking volume versus Health Hazard

7.1.11 Discussion of simulation results

The outcomes of the combination of scenarios (normal weather vs. drought) and management variables (those described in Table 7-15) are shown in Table 7-17. This table shows the empirical means and standard deviations of the two selected outcome variables of the model. The results have been calculated on the basis of the output of simulations that have been let to run for 1,000 time steps.

Standard deviations are in most cases relatively small (<5% of the empirical mean), indicating some level of predictability of the model. Five iterations were used when the empirical standard deviation indicated a variability of less than 5% of the output variable mean, and in other cases the number of repetitions was increased to ten, but this did not significantly change estimates. A number of insights are gained from these simulations and these are described below.

Freshwater over-extraction

Drought inevitably leads to over-extraction of freshwater resources in Tarawa. None of the strategies generated a water debt in normal conditions but in drought conditions the water debt varied between 767 days for the combined strategy, to 1663 days for the strategy involving relocation and clean-up.

It is noted that this strategy creates a somewhat greater water debt than the current management strategy at 1639. This is presumably due to a higher reliance on this water resource when the water quality has been improved. It is also noted that reduction of leakage on its own does not reduce over-extraction much (with an average water debt of 1616 in drought only slightly lower than the current management strategy at 1639), and this is because pumping volumes remain the same.

There are essentially only two efficient methods for reducing the risk of over-extraction in the case of droughts; the first being to reduce the pumping volumes, bringing the water debt down to 1073 in the recovery pumping strategy; but perhaps more importantly via clearing vegetation from reserves which reduces sap flow and hence increases sustainable extraction rates. With a water debt of only 1091, clearing of vegetation on the water reserves provides almost as much benefit as recovery pumping in terms of resilience to drought and with less over-extraction.

Water quality improvements via reserves management

Focussing on the management of the water reserves provides the most significant outcomes – both in terms of better health as well as in terms of resilience to drought. The relocation and clean-up strategy brings the health hazard down from 52% to 20% (for both normal and drought conditions), due to significantly improved water quality for the main freshwater resource. No other strategy can achieve anything near this impact on the health hazard.

Other management options that have been explored are to clean up reserves and relocate landowners, or more controlled pumping regimes (i.e. recovery pumping). It is also noted that the strategy of relocation of landowners to Kiritimati Island has almost no beneficial impact on water safety unless combined with an environmental clean up of all the existing sources of pollution of the water reserves.

Leakage management

Surprisingly and in isolation, there is a net negative effect of leakage reduction on health hazards, from 52% to 68% in normal conditions and from 53% to 71% in drought conditions.

The reasons are that this means a relatively higher reliance by households on water from household taps, and a reduced reliance on rainwater for basic needs. This is logical because rainwater is considered safer and of better quality in most instances.

Allocation of water

In contrast to initial suspicions, proportional allocation of water to all segments of the community is not conducive to good health outcomes; and in fact the health hazard increases from 52% to 69% in normal conditions, and from 53% to 68% in drought conditions. Instead, allocations to community segments need to be done in a way that is mindful of considering the particular water resource options that are available.

On the basis of this, it is recommended that water safety assessments to undertaken for each community segment to understand their particular water availability and water safety profile. This should then inform the allocation decisions that are made, and such decisions also should be linked adaptively with the monitoring of water quality and health outcomes.

Strategy portfolios

The combined strategy includes a portfolio of strategies and hence represents a more likely management strategy designed to reach desired outcomes. This is also the strategy that provides the best performance, reducing health hazards from 52% to 24% in normal conditions and from 53% to 23% in drought conditions. It also reduces the water debt from 1639 to 767 in drought conditions, and hence outperforms all other strategies in both aspects.

This shows that it is important to have a portfolio of strategies and interventions. Furthermore, it is seen that it is important to analyse portfolios of strategies conjunctively rather than separately, because effects are not additive.

This is indicated when reviewing the performance of the combined strategy of Table 7-17, which shows that in terms of drought resilience, the combined strategy does not generate the total added individual effects of vegetation clearing (-548) and recovery pumping (-566) but the total impact (-872) is less than what would be expected if effects were simply added. It is also

noted that even the combined strategy remains susceptible to over-extraction in times of drought. This reflects the fact that the water supply in Tarawa is at its limit and there are no other options other than to add new water supply sources in order to sustain a growing population.

7.2 Bayesian Networks

BN analysis has been applied in order to allow for, at least temporarily, understanding the cause and effect relationships in water development interventions which are often both complex and uncertain. In this chapter, three strategies are explored which have, in the historical review (chapter 6) and Interviews (chapter 7), been identified as very important:

- Reserves extensions to the islands of Abatao and Tabiteua has been suggested in order to significantly increase the potable water supply volumes by allowing extraction from an additional two freshwater lenses;
- Desalination of sea water to freshwater has been applied in Tarawa in response to the drought of 1998-2002;
- Rainwater harvesting has been increasingly utilised in Tarawa, with building regulations stating that each new house must have an adequately sized rain tank.

All these strategies have been problematic for one reason or another; and those reasons have often been difficult to predict in advance. Therefore, to better understand the network of factors that impact on the chances of interventions, these have been mapped in influence diagrams as an output of the interviews, and these are shown in Figure 7-32 and Figure 7-33 for two of the strategies.

Subsequent to the mapping of these factors based on the interviews, statements and information from the literature have also been included in order to improve these mappings. This output is shown in Figure 7-34 to Figure 7-36 that have more detailed BN diagrams representing the

factors impacting on the chance of successful implementation and operation for the three strategies.

These diagrams ought to be read in the following manner: each circle represents a factor or a strategy; and an arrow represents a causal relationship between two circles. These causal relationships cannot always be easily described using logical formalism (such as by using AND, OR, and other logical operators).

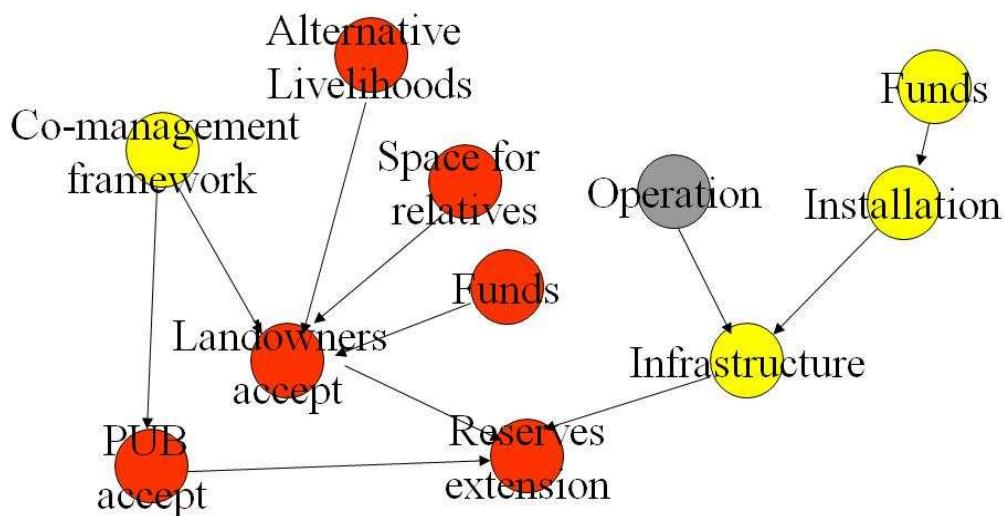


Figure 7-32: Factors considered to impact on the risk of the Reserves extension strategy

Notes: In this figure the red circles represent conditions that failed, whilst the yellow circles represent conditions that were in place; and the grey circle indicates where it is not clear if the condition was met.

It is also worth to again note that there can be no cycles in the diagrams for the BNs and that this to a small extent has limited our expression of the influences. The links of the influences are described probabilistically, using Bayesian reasoning, which means by describing the probability of something happening assuming that a given condition is true. An example of such a value is the probability of successful desalination under the assumption that adequate skills and staff are available. Judgments of such probabilities are not always straightforward, and not easy to decouple from other factors such as the availability of finances and good access to spare parts. The following types of data have been used to define and quantify models: reports and scientific articles, as well as statements by individuals with different levels of expertise.

Naturally, it has been found that there are inconsistencies between different statements and different judgments. Fortunately, with the chosen software system (*Sheba*) such inconsistencies can be taken into account by individually putting a different reliability on each statement that is being used.

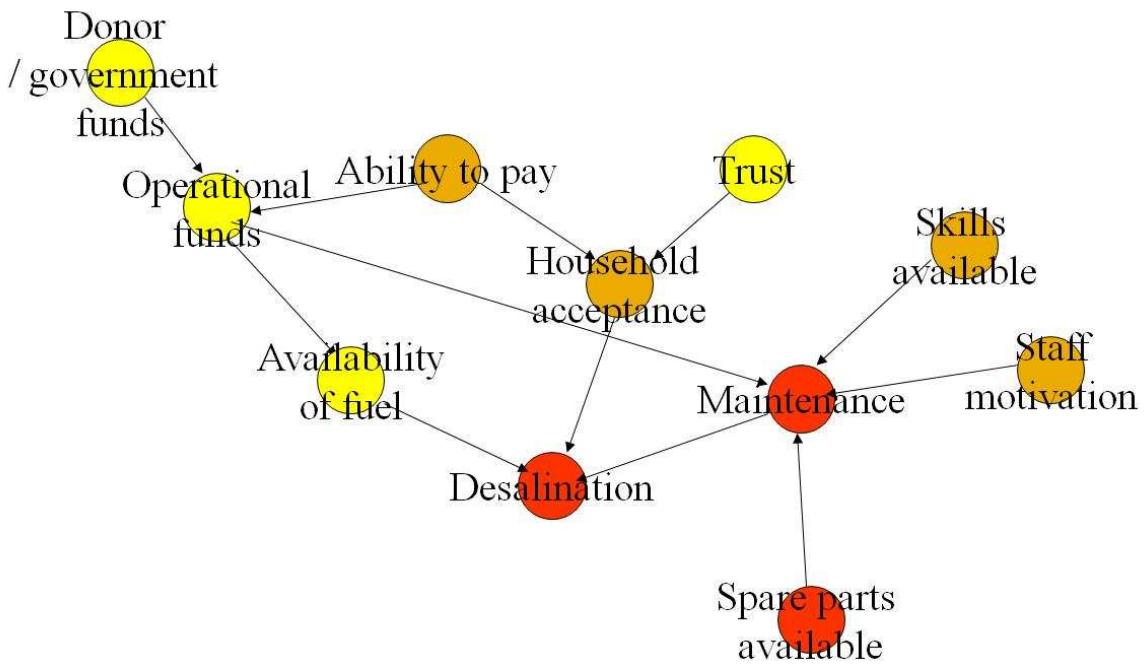


Figure 7-33: Factors considered to impact on the risk of the Desalination strategy

Notes: In this figure the red circles represent conditions that failed, whilst the yellow circles represent conditions that were in place; and the brown circle indicates where it is not clear if the condition was met.

7.2.1 Reserves extension

The primary freshwater source for Tarawa is the groundwater pumped from the urban periphery where water reserves have been established. It has been suggested to continue the expansion of water reserves to another two islands (Abatao and Tabiteuea), but this is a controversial and contentious issue, as has been previously discussed in chapters 6 and 7. This section describes a BN for analysing the risk of failure, or chance of success of such attempts, given underlying conditions and the choice of strategy.

7.2.1.1 Topic domains

The factors, or in other words the topic domains, in Table 7-19 have been identified as those influencing the chances of successful reserves extension, according to the diagram shown in Figure 7-34. This diagram has been identified on the basis of the interview results described in chapter 7, as well as a number of key documents that mention potential reserves extensions in Tarawa, e.g. the Kiribati water resources assessment report by Falkland (2003), the articles describing the AtollScape and AtollGame experiences (Dray *et al.* 2006a; Dray *et al.* 2006b; Dray *et al.* 2007; Perez *et al.* 2003; Perez *et al.* 2004), the SAPHE project completion report (Asian Development Bank 2008a), the Kiribati water master plan (Government of Kiribati 2000), documents and articles by Professor Ian White and others (White *et al.* 1999a; White *et al.* 2005; White 2006a, 2006b, 2006c; White *et al.* 2007; White *et al.* 2008) as well as one UNICEF and one UNESCO report (Crennan 1998; Crennan 2001).

7.2.1.2 Influence diagram

As per Figure 7-34, the three factors that are direct requirements for successful reserves extension are ‘Reserves management’, ‘Declaration of reserves’, and ‘Sustainable extraction’.

In turn the chances of successful:

- Declaration of reserves are improved by Community agreement and Adequate Legal arrangements; while the chances of successful
- Reserves management are improved by Institutional commitment and strength, Clearing of vegetation, and a Traditional sense of ownership over land; and the chances of successful
- Sustainable extraction is improved by Groundwater investigations, Monitoring, Sustainable pumping and the Clearing of Vegetation.

Similarly the chances of:

- Community agreement are influenced by the implementation of a Co-management framework, an appropriate and culturally sensitive Engagement processes, and Clearing of vegetation; which in turn

- Impacts on the chances of a Traditional sense of ownership which will allow for better Enforcement of protection of the land.

Table 7-19: Descriptions of topic domains impacting on successful water reserves extension

Topic domain / Node	Description
DR: Declaration of reserves	Formal declaration of reserves, including a strategy for dealing with landowners, and legal arrangements to support this
CA: Community agreement	Overall agreement from landowners with a stake in the reserves
RM: Reserves management	Management of the reserves, in terms of ensuring no unsuitable land use or pollution occurs, and ideally that vegetation is cleared
SE: Sustainable extraction	Extraction of less or equal to the sustainable extraction rate, which depends on the rainfall conditions, such as for example droughts, and knowing the sustainable extraction rates, and the changing salinity levels
LA: Legal arrangements	The legal arrangements that will allow the declaration of the reserves, and which ought to define the status and rights of landowners
EP: Engagement process	The process by which relevant stakeholders, such as landowners, are engaged. In particular whether it has allowed for the traditional pattern of Maneaba decision making
TO: Traditional sense of ownership	Referring to whether the landowners feel ownership and pride over their land, and whether they feel an obligation to protect it from harm and intrusion
IC: Institutional commitment and strength	The extent by which the key institutions are committed and strong enough to manage the water reserves; and whether they support or undermine the process.
CV: Clearing of vegetation	Whether vegetation is being cleared on the reserves in order to increase sustainable extraction rates, and to make transparent inappropriate land use
GI: Groundwater investigations	Investigations of the thickness and width of the freshwater lens in order to establish a sustainable extraction rate
M: Monitoring	Monitoring the salinity of the freshwater lens, to evaluate whether over-extraction is occurring. This also may involve monitoring of water quality, by measuring e-coli/faecal coliforms.
SP: Sustainable pumping	Ensuring that pumping supports sustainable extraction
CM: Co-management of reserve	Co-management of water reserves including landowners and the relevant Government departments and the PUB, as suggested in the AtollGame project

7.2.1.3 Conditional probabilities

In quantifying the links, a number of assumptions/estimates of probabilities have had to be made, which are shown in Appendix 7. These probabilities all refer to equations, in the following form, using Bayes formula:

$$P[\text{Consequence } e \mid \text{Assumption}] = \text{Estimated probability} \quad (\text{Eq. 1})$$

This equation should be read as, the probability of the ‘Consequence’ happening in the event that the ‘Assumption’ is true, is equal to the ‘Estimated probability’. For example, if one enters the details from the first row in Table A7.1 of the Appendix 7, one gets the “The probability that there is successful declaration of reserves in the event of community agreement, is equal to 80 percent”. The BN model describing the chances of successful Reserves extension is described through a network of 37 such equations, as per Table A7.1 in Appendix 7.

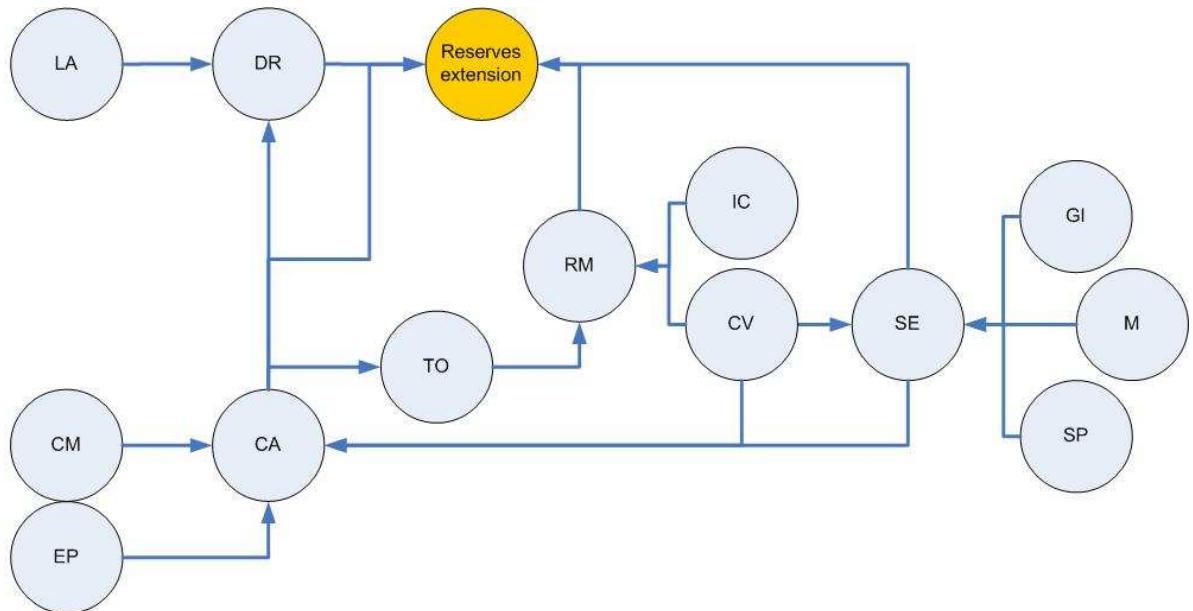


Figure 7-34: BN diagram showing factors influencing successful reserves extension

Notes: DR = Declaration of reserves; CA = Community Agreement; RM = Reserves Management; SE = Sustainable Extraction; LA = Legal Arrangements; EP = Engagement Process; TO = Traditional Sense of Ownership; ICS = Institutional commitment and strength; CV = Clearing of Vegetation; GI = Groundwater Investigation; M = Monitoring; SP = Sustainable Pumping.

7.2.1.4 Data sources

In order to apply the model however, a number of conditions need to be specified, or in other words the State of the Topic domains. This data can be on two different forms:

- Judgments / Assessments of actual conditions at a particular point in time and in a particular situation; or
- Speculative explorations, such as analysing potential scenarios that may happen, or potential management strategies that could be sprung into action.

For example in the ‘Reserves extension’ model, two main data sources were used:

- Data describing the status quo or current situation, or in other words describing the state of topic domains in the reserves extension and management efforts so far; and a
- ‘What-if co-management?’ scenario based on the recommendations from the AtollGame experience.

The data for the Status Quo scenario is shown in Table 7-20. The data for the ‘What-if co-management?’ scenario is shown in Table 7-21. Naturally, judgments/opinions were not originally in quantitative form so these have been translated from qualitative statements into probabilities. It is noted that these estimates are opinions and judgments, and the model simply states another opinion of the chances of success. As such, it is a model of reality but it is not clear how the assumptions of the model can be tested scientifically. The use of the model is rather as a post-normal expression helping us to explore possible realities, and what-if scenarios. Assumptions are socially validated rather than scientifically tested, but allowing for the exploration of multiple possible assumptions.

The certainty column refers to the extent to which each opinion can be trusted, and rather than assessing the reliability of each opinion on its own, a number of blanket rules have been applied:

- Experts’ opinions within their domain expertise, and stated in a publicly available report or publication, are considered 95 percent reliable;
- Experts’ opinions outside their domain expertise, but stated in a publicly available report or publication, is considered 80 percent reliable;

- Government officials' opinions within their domain expertise, and stated in a publicly available report or publication, is considered 85 percent reliable;
- Government officials' opinions outside their domain expertise, and stated in a publicly available report or publication, is considered 70 percent reliable;
- Direct observation are considered 95 percent reliable, and deductions of 15 percent are made if observations have been made by persons other than the analyst;
- If opinions instead have been stated verbally, or in a non-formal manner, 15 percent certainty is being deduced from the above scores.

7.2.1.5 Results

The above model, assumptions and data has been entered into the Bayesian Network analysis software Sheba, and the user interface of this 'Reserves extension' model is shown in Figure 7-35. The assessment results that come out of this model and data consequently depends on the scenario applied, and the results of the two described scenarios are shown in Table 7-22 and Table 7-23. The chances of success in the status quo scenario is poor, at a mere 9 percent, while with a co-management strategy as suggested in the AtollGame project, the chances of success are much better at 63 percent.

It is possible to also get an idea about what contributes the most to the chances of success by exploring which of the contributing opinions has the greatest influence, and this is calculated by the Sheba software for each scenario. The strongest contributing factor to inefficient reserves extension is the poor enforcement of protection of reserves, which in turn is strongly affected by lack of community agreement and illegal activities. It is also worth noting that the existence of community agreement not only impacts on the ability for enforcement of protection but also directly impacts on the chances of efficient reserves extension. Another method for exploring the contribution to the chances of success is to evaluate which of the factors impact on efficient reserves extension. It is therefore useful to explore the marginal contribution of each factor on its own where the starting point is that there is no prior opinion about any of the factors.

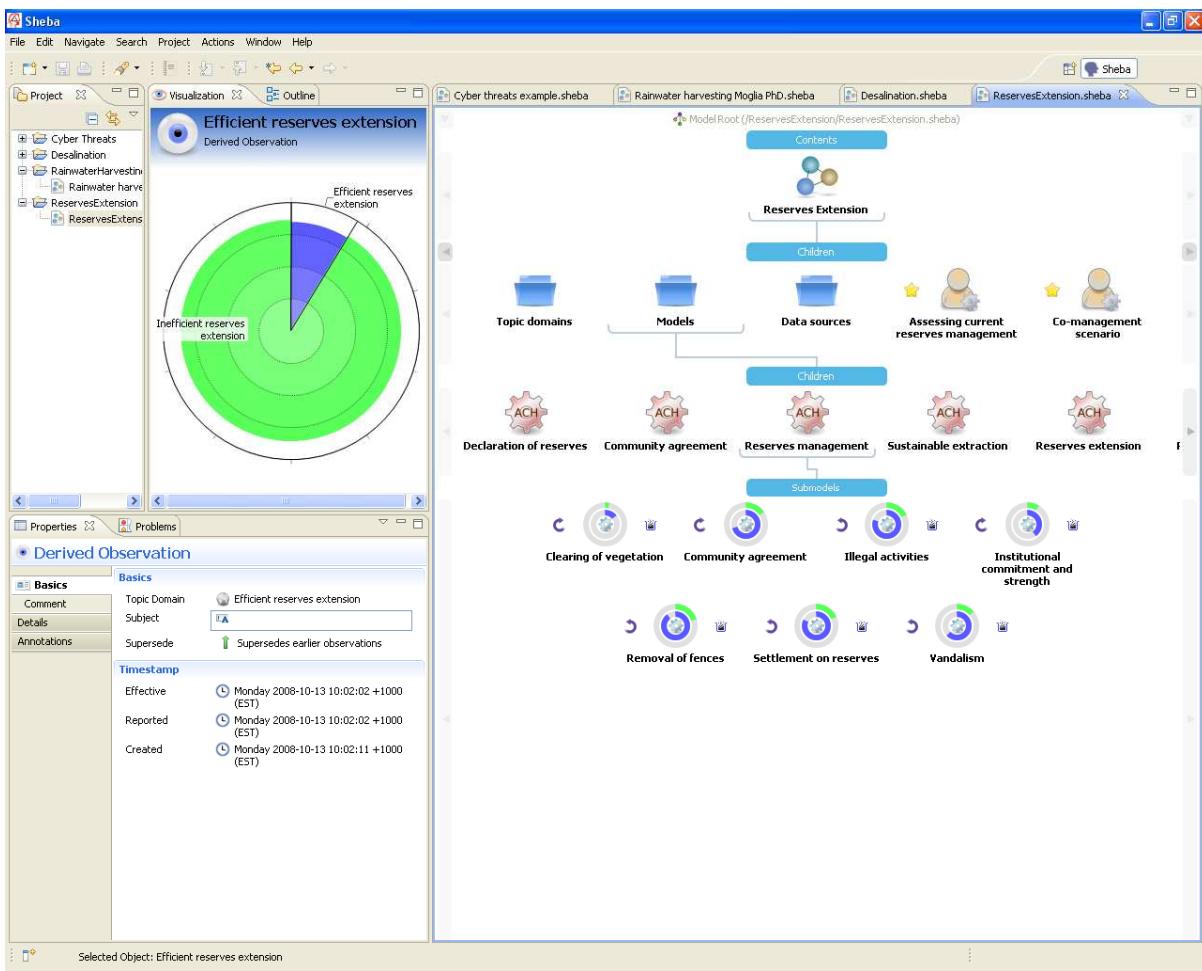


Figure 7-35: BN model of successful Reserves Extension implemented in Sheba

Table 7-20: Data sources for ‘Reserves extensions’ – status quo scenario

Data source	Topic domain	State	Estimated probability (%)	Certainty (%)
Sectoral Strategy and Action Program (Falkland 2004)	Conflicts	Conflicts regarding the reserves	90	80
	Engagement process	Culturally sensitive and flexible process	10	80
	Legal arrangements	Legal arrangements in place	75	80
	Pressure for increasing lease payments	Pressure for increasing lease payments	90	80
GoK staff member #1, WEU	Community agrees	Community agrees	10	70
	Institutional commitment and strength	Institutions are not committed and/or weak	80	70
GoK staff member #2, PUB	Monitoring	Adequate monitoring	80	70
	Sustainable pumping	Sustainable pumping	80	70
GoK staff member #3, Land division	Settlements on reserves	New settlements on reserves	99	80
	Co-management	Co-management	5	95
White <i>et al.</i> 2009 White <i>et al.</i> 1999	Conflicts	Conflicts regarding the reserves	90	95
	Legal arrangements	No legal arrangements in place	90	95
	Traditional sense of ownership	Land owners do not feel a traditional sense of ownership	90	95
	Clearing of vegetation	Clearing of vegetation	10	80
Researcher #1	Enforcement of protection	Inefficient enforcement of protection	90	80
	Groundwater investigations	Adequate groundwater investigations	90	85
	Monitoring	Adequate monitoring	75	85
	Removal of fences	Fences are illegally removed	95	80
AtollGame and AtollScape researchers (personal communication, Pascal Perez and Anne Dray, 2008)	Sustainable extraction	Non-sustainable extraction	75	85
	Conflicts	Conflicts regarding the reserves	90	80
	Enforcement of protection	Inefficient enforcement of protection	90	80
	Engagement process	Technocratic process	90	80
Personal observations (Moglia)	Pressure for increasing lease payments	Pressure for increasing lease payments	90	80
	Traditional sense of ownership	Land owners do not feel a traditional sense of ownership	90	80
	Illegal activities	Illegal activities occur on the reserves	100	95
	Settlements on reserves	New settlements on reserves	100	95
	Vandalism	Vandalism occurs	90	80

It is noted that community agreement is indeed the biggest issue here; however it is not a management alternative but rather an outcome. Out of the management alternatives that are most efficient, the institutional commitment and strength appears to be a key option. However that is worrying given both the current attitude of the key institutions, as well as their strength in terms of vulnerable human resources. The next two options are 1) monitoring of the freshwater lenses, and 2) employing a culturally sensitive and flexible process to allow for negotiation with land owners.

Table 7-21: Data sources for ‘Reserves extensions’ – co-management scenario

Data source	Topic domain	State	Estimated probability	Certainty
AtollGame and AtollScape researchers (personal communication, Pascal Perez and Anne Dray, 2008)	Clearing of vegetation	Clearing of vegetation	90	80
	Co-management	Co-management	90	80
	Community agreement	Community agrees	90	80
	Institutional commitment and strength	Institutions are strong and committed	90	80
	Legal arrangements	Legal arrangements in place	99	95
	Sustainable pumping	Sustainable pumping	90	80
	Traditional sense of ownership	Land owners keep a traditional sense of ownership	90	80

Table 7-22: Results Status quo – reserves extension

Topic domain	State	Opinion (%)	Certainty (%)
Community agreement	Community agrees	9	86
Declaration of reserves	Successful declaration of reserves	17	70
Efficient reserves extension	Efficient reserves extension	9	84
Enforcement of protection	Efficient enforcement of protection	4	93
Sustainable extraction	Sustainable extraction	78	70

Table 7-23: Results Co-management scenario – reserves extension

Topic domain	State	Opinion (%)	Certainty (%)
Community agreement	Community agrees	77	76
Declaration of reserves	Successful declaration of reserves	69	59
Efficient reserves extension	Efficient reserves extension	63	65
Enforcement of protection	Efficient enforcement of protection	83	67
Sustainable extraction	Sustainable extraction	81	74

Table 7-24: Management options and their marginal chance of success

Topic domain / Management option	Chance of success (%)	Certainty (%)
Community agreement (CA)	47	72
Institutional commitment and strength (ICS)	36	73
Monitoring (M)	33	63
Culturally sensitive and flexible process (CS)	31	70
Co-management (CoM)	30	70
Legal arrangements (LA)	30	66
Sustainable extraction (SE)	29	69
Enforcement of protection EP)	28	69
Starting point with maximum entropy (or in other words if each topic domain state is equally probable)	28	69

7.2.1.6 Towards a portfolio of options

Let us now explore combinations of management alternatives and their marginal impact on the chances of success. The results are shown in Table 7-25.

Table 7-25: Combinations of management options and their joint chances of success

	SE (%)	ICS (%)	M (%)	CoM (%)	LA (%)	CS (%)
SE	29	36	34	30	31	32
ICS	36	36	42	37	38	38
M	34	42	33	35	37	37
CoM	30	37	35	30	32	32
LA	31	38	37	32	30	34
CS	32	38	37	32	34	31

A three-factor combination of ICS, M and CS would achieve a combined chance of success at 44 percent; while adding all the factors would bring the chances up to 65 percent. However it is noted that from a water quality point of view this strategy would be largely successful with chances of successful enforcement of protection at 87 percent, and chances of community agreement at 92 percent. However what is reducing the overall probability found in the assessment is the relatively low chance of sustainable extraction at a mere 65 percent. Adding Sustainable pumping and appropriate groundwater investigations to the mixture brings the chances of success to 73 percent, and this means that there is now also sustainable extraction. The reason for the low value of 73 percent remaining means that there would most likely remain some conflict surrounding the reserves. Thus, while from an equity point of view that not ideal; from an engineering and health perspective this solution would be adequate with a high likelihood of success.

It is interesting that the management strategy that is arrived at is in its essence very similar to that developed in the AtollGame experience. This has not been pre-meditated although it is difficult to gauge the sub-conscious influence in model design and how much is skewed by the analyst's individual opinions, background and perceptions. One possible interpretation is that the methods are not only complementary but that they also can be used to achieve the same goal which in this case is the development of a management strategy. Another possible argument is that this may provide a type of validation of both modelling procedures when they reach the same conclusion, despite the level of subjectivity that is inherent in both. This shows that there is robustness in the processes. The BNs do however rely on having a knowledge base to draw from, ideally through reports and publications, and this is fortunately available for Tarawa.

7.2.2 Rainwater harvesting

A similar exercise to that applied to the Reserves extension strategic option, has also been applied to the strategic option of rainwater harvesting in Tarawa. The factors (topic domains) that have been identified to influence the chances of successful rainwater harvesting have been identified on the basis of the rainwater harvesting guidelines from the South Pacific Applied Geoscience Commission (2004), the Kiribati water resources assessment report (Falkland 2003), the SAPHE completion report (Asian Development Bank 2008a), a Kiribati country briefing in 2002 (Government of Kiribati 2002), the draft water master plan (Government of Kiribati 2000), the water sector strategy and action plan, a case study by the acting director of the WEU (Metai 2002), a case study by the director of the PUB (Metutera 2002), a report on Integrated Water Resource Management coordinated by the newly set up National Water and Sanitation Coordination Committee (Ministry of Public Works and Utilities 2007), a report on equitable water and sanitation in PICs (Crennan 2005).

7.2.2.1 Topic domains

The factors in Table 7-26 have been identified to influence the chances of successful rainwater harvesting, according the diagram shown in Figure 7-36. This diagram has been identified on the basis of the interview results described in chapter 7, as well as a number of key documents that mention potential reserves extensions in Tarawa, such as the SOPAC report "Harvesting the

heavens" (South Pacific Applied Geoscience Commission 2004); the Kiribati water resources assessment report (Falkland, 2003); the Government of Kiribati country briefing (Government of Kiribati 2002); the Kiribati water master plan (Government of Kiribati, 2000); the Kiribati water sectoral strategy and action program (Asian Development Bank 2004b); a case study of water management in Kiribati by the current CEO of PUB (Metutera 2002); a report on equitable management of water and sanitation in Pacific Island countries (Crennan 2005).

7.2.2.2 Influence diagram

As per Figure 7-35, the four conditions/factors that are direct requirements for successful rainwater harvesting are 'Use of rainwater', 'Ownership', 'Infrastructure condition' and adequate 'Water quality'. In turn the chances of successful:

- 'Use of rainwater' are improved by a positive perception of taste, non-occurrences of droughts, and the perception of water quality;
- A good sense of 'Ownership' is more likely if an acceptable Implementation approach is applied; if the Role definition is clear and appropriate; if there is Support from institutions and if there is Social and cultural acceptability of the rainwater harvesting technology;
- Adequate 'Infrastructure condition' is more likely if there is sufficient skills and funds available, there are no or infrequent cyclonic events, and if the Design is appropriate;
- Adequate 'Water quality' is more likely if the 'Infrastructure condition' and 'Design' is good

Table 7-26: Descriptions of topic domains impacting on successful water rainwater harvesting

Topic domain / Node	Description
PT: Perception of taste	There may be a preference of other water sources on the basis of taste. For example in Tarawa there is generally a cultural preference for drinking groundwater; and in particular for making traditional toddy.
U: Use of rainwater	An essential criteria for successful rainwater harvesting is that households actually use water, for at least one of their use categories (see categories in ABM section above)
Dr: Drought	Rainwater harvesting is not as efficient in times of drought since because there is simply not enough rainfall to support household water use; at least not if the size of the tank is too small.
WQP: Water quality perception	The perception of whether the quality of water from the rain tanks is good or not, critically influences whether households will use it; in particular for purposes of cooking and drinking.
SI: Support from institutions	Government and key institutions need to support the use of rain tanks; and this support is sometimes symbolical. For example, if government buildings do not have rain tanks, this undermines the regulation to have rain tanks on each new building, and hence may reduce uptake.
RD: Role definition	It has been stated in several reports that for a household to operate a rain tank, clear roles need to be defined within the household members, and possibly even outside the household such as some roles being held by PUB staff.
IA: Implementation approach	Similarly, it is sometimes argued that a top-down approach to implementation, or in other words rain tanks being forced onto the community without first developing community acceptance can significantly negatively impact on the chances of successful rainwater harvesting
O: Uptake and Ownership	Despite being relatively straightforward, ownership over processes, infrastructure and operation is critical for the motivation and ability to manage the rain water harvesting process.
IC: Infrastructure condition	Without having the rain tanks in adequate condition, or in other words clean, structurally sound, and without water safety risks such as overhanging trees, rainwater harvesting will not be successful.
De: Design	The design of the rainwater tank is important for a number of reasons, such as to avoid chemical contamination, to have an adequate size of the tank in relation to the catchment area, design of roof gutters, allowing community to have an input into the design process to ensure the location is appropriate, and that the technical operation will be easy, etc.
WQ: Water quality	The water quality impacts on water safety which impacts on whether and how the households will use the harvested rain water.
SF: Skills and funds	To operate a rain tank, you need the appropriate skills and funds to ensure adequate maintenance and operation.
CE: Cyclonic events	Cyclonic events can damage tanks, and this is obviously a problem; in particular when these events are frequent as they are in some locations.
SCA: Social and cultural acceptability	This relates to whether the technology is generally acceptable or not acceptable, for whatever reason, in the context.

Notes: WQ = Water Quality; IC = Infrastructure Condition; O = Ownership; U = Use of rain water; De = Design; CE = Cyclonic Events; Dr = Drought; WQP = Water Quality Perception; SI = Support from Institutions; IA = Implementation Approach; RD = Role Definition; SF = Skills and Funds; PT = Perception of Taste

7.2.2.3 Conditional probabilities

Similarly to the conditional probabilities for Reserves extension, the BN model describing the chances of successful Rainwater harvesting is described through a network of equations, as per Table A7.3 in Appendix 7.

7.2.2.4 Data sources

For the rainwater harvesting option, two scenarios are explored: the Current situation of rainwater harvesting in Tarawa versus What if there was a better process for implementation which would generate more ownership and better role definition and would also include better institutional support. The data on the states relevant for these scenarios are shown in Tables 7-27 and 7-28.

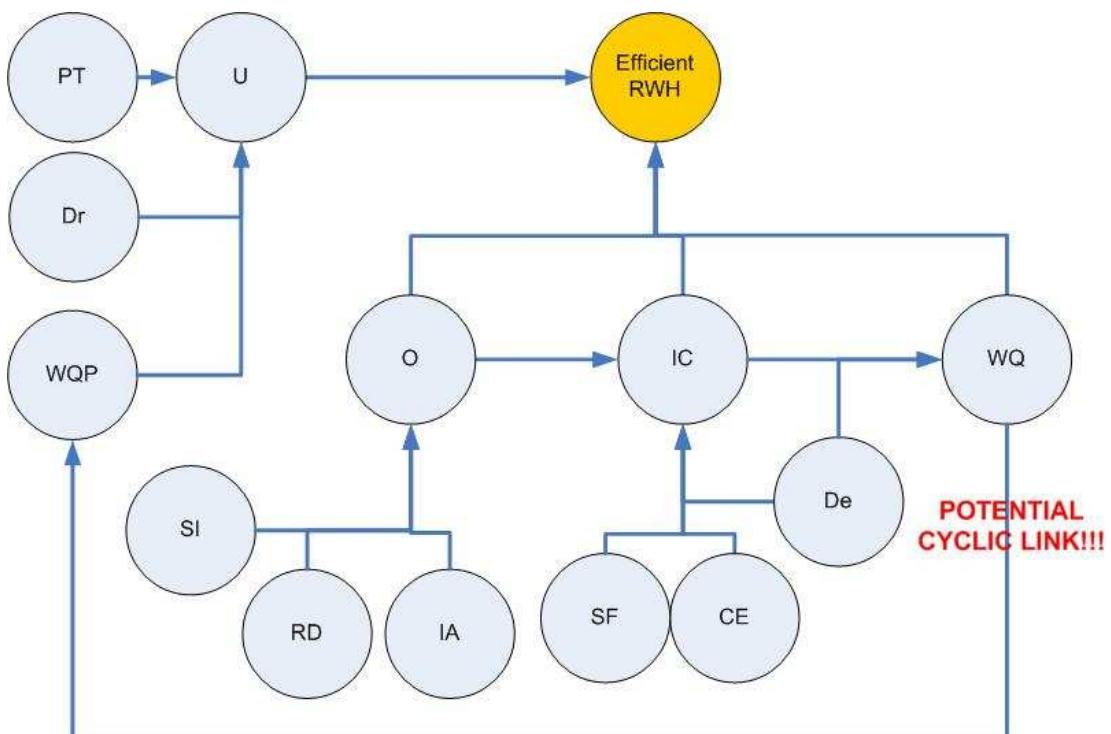


Figure 7-36: BN diagram showing factors influencing successful rainwater harvesting

7.2.2.5 Results

The above model, assumptions and data have been entered into the Bayesian Network analysis software Sheba, and the output of this model is shown in Figure 7-37. The assessment results

that come out of this model and data consequently depends on the scenario applied, and the results of the two described scenarios are shown in Table 7-29 and Table 7-30. The chances of success in the status quo scenario is poor, at a mere 40 percent which is consistent with the SAPHE project (see chapter 6) household survey (Asian Development Bank 2000b), while with a more careful process and more support for households, the chances of success are much better at 66 percent with the remaining concerns being mainly about infrastructure conditions and whether households are willing to use water. Better design and a change in the perception of taste may improve that.

It is found that the what-if scenario, whilst considerably improved on the current state (66% instead of 40%), still does not reach completely satisfactory levels of rainwater harvesting, mainly because of water quality problems and inadequate water use. This points to the fact that an inter-disciplinary approach is required which includes both community participation aspects, and also socio-cultural aspects (such as for example the taste of water), as well as the engineering aspect (such as the design of tanks). In other words, the strategy should be one of Community consultation, Adequate design, and Cultural change. Carrying out a similar exploratory analysis to what was explored in the Reserves extension scenario (see Table A7.2 in Appendix 7) it is found that the strongest contributing factor to inefficient rainwater harvesting is relating to Ownership issues, which contributes 18 percent, followed by Water quality issues which contributes 12 percent, Use of rainwater which contributes 10 percent, and Infrastructure condition which contributes 3 percent.

Table 7-27: Data sources for ‘Rainwater harvesting’ in current situation

Data source	Topic domain	State	Estimated probability (%)	Certainty (%)
IWRM Diagnostic Report (Ministry of Public Works and Utilities 2007)	Drought	Frequent and severe droughts	20	80
	Drought	Occasional drought	60	80
	Implementation approach	Technocratic approach	20	80
	Implementation approach	Integrated approach	80	80

	Perception of taste	Water tastes bad	60	80
	Skills and funds available	Sufficient skills and funds	40	80
	Skills and funds available	Insufficient skills and funds	60	80
	Support from institutions	Inadequate support from institutions	75	80
Engineer #1	Design	Poor design	90	80
	Ownership	Weak ownership	65	80
	Support from institutions	Inadequate support from institutions	90	80
Falkland 2003, Kiribati Water Resources Assessment Report	Drought	Frequent and severe drought	20	80
	Drought	Occasional drought	60	80
	Environmental acceptability	High environmental acceptability	95	80
	Social and cultural acceptability	High social and cultural acceptability	80	80
GoK staff member #1 (conversation)	Design	Poor design	50	80
	Perception of taste	Water tastes good	40	80
	Skills and funds available	Insufficient funds and skills	50	80
Foreign researcher #1	Role definition	Unclear roles	70	60
	Water quality	Poor water quality	80	60
SAPHE Household survey (ADB 2000b)	Infrastructure condition	Inoperable condition	30	100
	Perception of quality	Belief that the quality is good	90	
	Perception of taste	Water tastes good	30	40
	Skills and funds available	Sufficient skills and funds	50	80
GoK staff member #2 (conversation)	Support from institutions	Inadequate support from institutions	40	60
	Support from institutions	Adequate support from institutions	60	60

World Bank 2000	Cyclonic events	Frequent cyclones	2.5	92.5
	Cyclonic events	Occasional cyclones	2.5	92.5
	Cyclonic events	No cyclones	95	92.5

Table 7-28: Data sources for ‘Rainwater harvesting’ if better processes were applied

Data source	Topic domain	State	Estimated probability (%)	Certainty (%)
Hypothetical	Ownership	Strong ownership	100	100
	Implementation approach	Integrated approach	100	100
	Design	Poor design	10	80
	Perception of taste	Water tastes good	80	60
	Role definition	Clear roles	100	100
	Skills and funds available	Sufficient funds and skills	100	100
	Social and cultural acceptability	High social and cultural acceptability	100	100
World Bank, Cities Seas and Storms report	Support from institutions	Adequate support from institutions	100	100
	Cyclonic events	Frequent cyclones	2.5	92.5
	Cyclonic events	Occasional cyclones	2.5	92.5
Falkland 2003, Kiribati Water Resources Assessment Report	Cyclonic events	No cyclones	95	92.5
	Drought	Frequent and severe drought	20	80
	Drought	Occasional drought	60	80

Table 7-29: Results of current approach (rainwater harvesting)

Topic domain	State	Opinion (%)	Certainty (%)
Rainwater harvesting	Efficient rainwater harvesting	40	82
Infrastructure condition	Inoperable infrastructure	54	47
Ownership	Weak ownership	47	87
Use of rainwater	Inadequate use	60	74
Water quality	Poor water quality	43	83

Table 7-30: Results of adequate process and support for households (rainwater harvesting)

Topic domain	State	Opinion (%)	Certainty (%)
Rainwater harvesting	Efficient rainwater harvesting	66	79
Infrastructure condition	Inoperable infrastructure	35	86
Ownership	Weak ownership	14	81
Use of rainwater	Inadequate use	67	37
Water quality	Poor water quality	42	64

7.2.3 Desalination

This methodology has also been applied to the strategic option of *Desalination* in Tarawa which has been adopted in three different locations: 1) by the PUB on the island of Betio, 2) at the location of the main hospital in Tarawa and 3) at the largest hotel, the Otin Tai hotel, with very poor success rates. All these developments have failed.

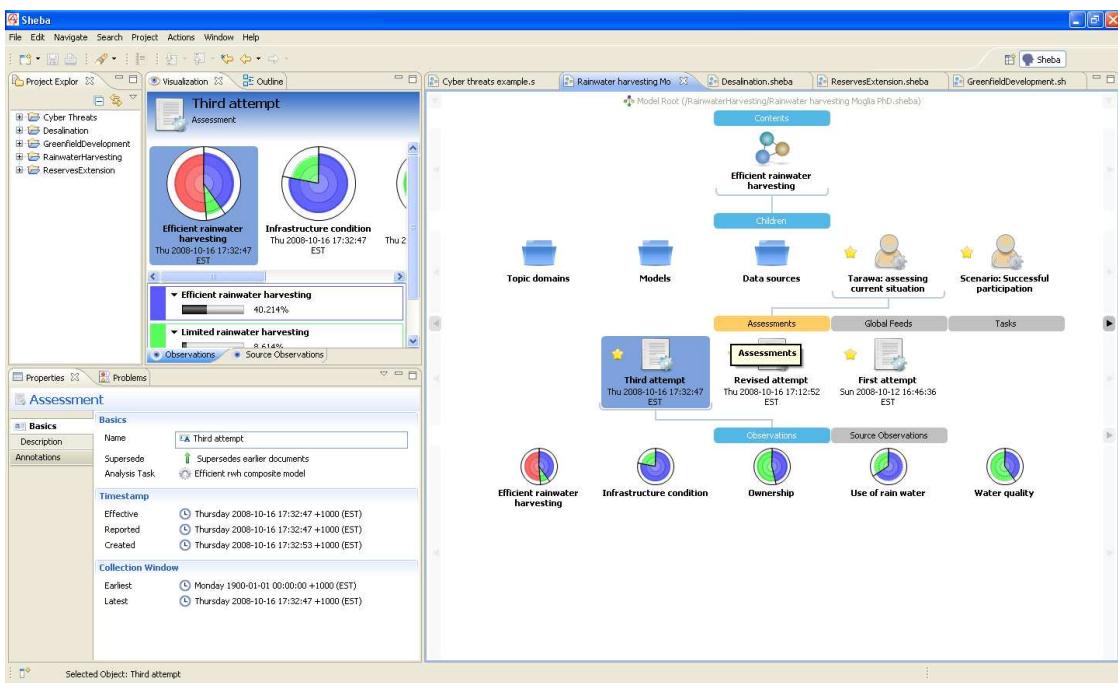


Figure 7-37: BN model of successful Rainwater harvesting implemented in Sheba

7.2.3.1 Topic domains

The factors that have been identified to influence the chances of successful Desalination have been identified using the Kiribati water resources assessment report (Falkland 2003); the SAPHE project completion report (ADB 2008a); a book on hydrology (Falkenmark and Chapman 1989); an article from the Atoll Research Bulletin (Falkland 1994); a case study on water management in Kiribati (Metutera 2002); a report on Integrated Water Resource Management in Kiribati (Ministry of Public Work and Utilities 2007); a UNESCO report on tropical island hydrology (Falkland 2003); and a technical report based on investigations in Banaba (South Pacific Applied Geoscience Commission 2000). These topic domains are described in Table 7-31.

Table 7-31: Descriptions of topic domains impacting on successful desalination

Topic domain / Node	Description
D: Design	Reflecting the suitability of the design given the particular geographical, institutional and socio-cultural context.
PMS:	Preventative maintenance schedule or in other words whether there is a rigorous process for maintaining and replacing spare parts before they fail.
SP:	Spare parts; or in other words whether there is easy or difficult access to spare parts
SS:	Storm surges; or in other words the presence of storm surges potentially flooding the plant
MI: Mechanical integrity	Reflecting whether the plant is mechanically fit for operation
F:	Finance, are there adequate finances to support the plant?
CP:	Capacity to pay, does the community have the capacity to pay for the increased price of water?
E:	Effort, will the responsible organisations and individuals put the effort into operating and maintaining the plan?
AS:	Alternative sources; or in other words are there other better sources available?
SA:	Social acceptability; This relates to whether the technology is generally acceptable or not acceptable, for whatever reason, in the socio-cultural, political and institutional context.
EA:	Environmental acceptability; is the operation of the plant acceptable from an environmental perspective in terms of local damage to ecosystems, and/or global systems impact.
OR:	Operational requirements, is all that is required available for operation?
C:	Chemicals, is there adequate access to necessary chemicals?
ES:	Energy sources, is there adequate access to an appropriate energy source?
SW:	Sea water, is there adequate access to sea water?
TO:	Trained operators, or in other words, is there adequate access to trained operators?

7.2.3.2 Influence diagram

As per Figure 7-38, the three conditions/factors that are direct requirements for successful Desalination are ‘Mechanical Integrity’, ‘Finances’, and ‘Operational requirements’. In turn the chances of successful:

- ‘Mechanical Integrity’ is affected by ‘Design’, having a ‘Preventative Maintenance Schedule, availability of ‘Spare parts’, presence of ‘Trained operators’ and few ‘Storm surges’; while the chances of adequate:
- ‘Finances’ is affected by the community’s ‘Capacity to pay’, and the ‘Effort’;
- ‘Operational requirements’ are affected by ‘Chemicals’, ‘Energy source’, ‘Sea water’ and the presence of ‘Trained operators’.

Similarly the chances of:

- Sufficient ‘Effort’ are influenced by whether there are better ‘Alternative sources’ of water, the ‘Social acceptability’, and the ‘Environmental acceptability’.

7.2.3.3 Conditional probabilities

Similarly to the conditional probabilities for Reserves extension and Rainwater harvesting, the BN model describing the chances of successful Desalination is described through a network of equations, as per Table A7.3 in Appendix 7.

7.2.3.4 Data sources

For the Desalination option, two scenarios have been explored: Firstly the current situation of desalination at Betio in Tarawa; versus a Best-case scenario where almost all factors are conducive for successful Desalination. The data on the states relevant for these scenarios are shown in Table 7-32 and Table 7-33.

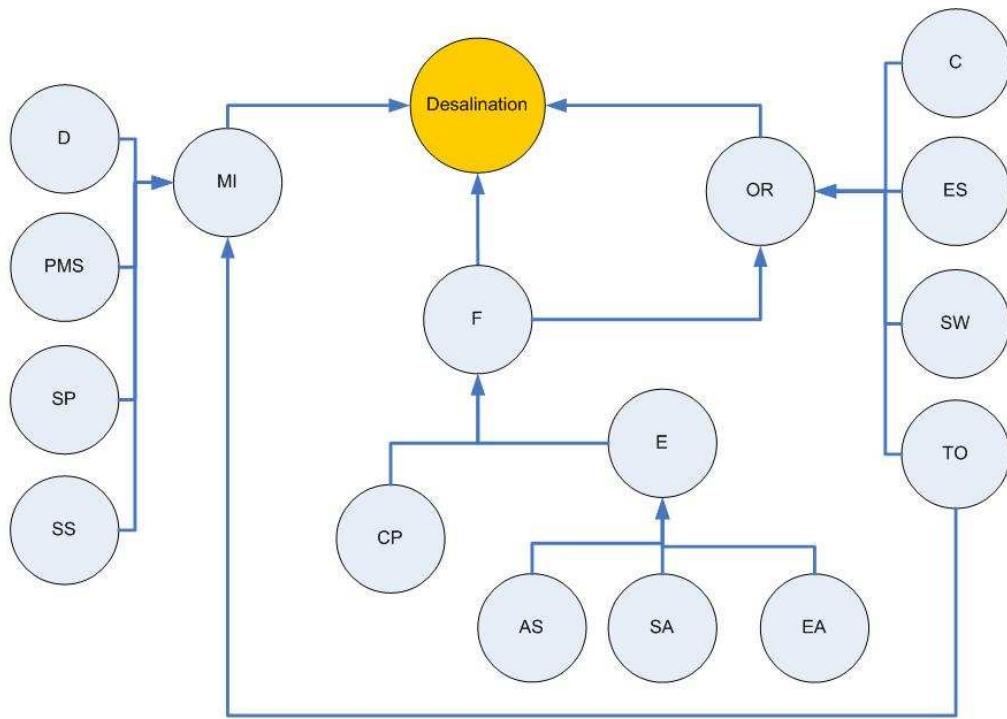


Figure 7-38: BN diagram showing factors influencing successful desalination

Notes: D = Desalination; MI = mechanical Integrity; E = Effort; OR = Operational Requirements; SP = Spare Parts; F = Finances; CP = Capacity to Pay; C = Chemicals; ES = Energy Sources; SW = Source Water; TO = Trained Operators; D = Design; PMS = Preventative Maintenance Schedule; SS = Storm Surges; AS = Alternative Sources; SA = Social Acceptability; EA = Environmental Acceptability.

Table 7-32: Data sources for ‘Desalination’ for current situation in Betio

Data source	Topic domain	State	Estimated probability (%)	Certainty (%)
GoK staff member #1 (conversation)	Chemicals	Poor access to chemicals	75	80
	Energy source	Unreliable energy source	60	80
	Costs	Operation is very expensive	90	80
	Spare parts	Access to spare parts	10	80
Metutera 2002	Alternative sources	Better sources are available	90	90
	Manufacturer	Manufacturer is reliable	50	70
	Source water	There is good access to source water	93	90

	Trained operators	Well trained operators	75	70
Falkland 2003	Alternative sources	Better sources are available	95	95
	Cultural and social acceptability	Medium acceptability	80	80
	Environmental acceptability	High environmental acceptability	87	80
	Finances	Sufficient finances	70	80
	Operational requirements	Adequate availability of operational resources	70	80
White <i>et al.</i> 1999	Energy source	Unreliable energy source	70	80
Engineer #1	Complexity of operation	Complex operation	80	70
	Design	Poor design	70	70
	Trained operators	Poorly trained operators	70	70
ADB 2002	Capacity to pay	Poor capacity to pay	90	90
Kiribati Census 2005	Urbanisation	High level of urbanisation	95	90
World Bank 2000	Storm surges	Frequent storm surges	90	80
SPREP 2002, Kiribati Country Profile	Capacity to pay	Poor capacity to pay	10	85
	Complexity of operation	Simple operation	60	37.5
	Preventative maintenance schedule	No preventative maintenance schedule in place	60	37.5
	Trained operators	Poorly trained operators	69	38

Table 7-33: Data sources for ‘Desalination’ in best-case scenario

Data source	Topic domain	State	Estimated probability (%)	Certainty (%)
Hypothetical scenario	Alternative sources	Better sources are available	10	80
	Capacity to pay	Good capacity to pay	90	80
	Complexity of operation	Simple operation	90	80
	Cultural and social acceptability	High cultural and social acceptability	90	80
	Design	Good design	90	80
	Energy source	Reliable energy source	90	80
	Environmental acceptability	High environmental acceptability	90	80
	Finances	Sufficient finances	90	80
	Preventative maintenance schedule	Schedule in place	90	80
	Source water	Good access to water	90	80
	Spare parts	Access to spare parts	90	80
	Storm surges	Infrequent storm surges	90	80
	Trained operators	Well trained operators	90	80
	Urbanisation	High level of urbanisation	90	80

7.2.3.5 Results

Based on this data, the assessment output is shown in Table 7-34 and Table 7-35. The chance of success for the Betio plant in current conditions is very poor at a mere 7% whilst the chances in the best case scenario are better but still remains at a lowly 49 percent. The output screen in Sheba for this assessment is shown in Figure 7-39.

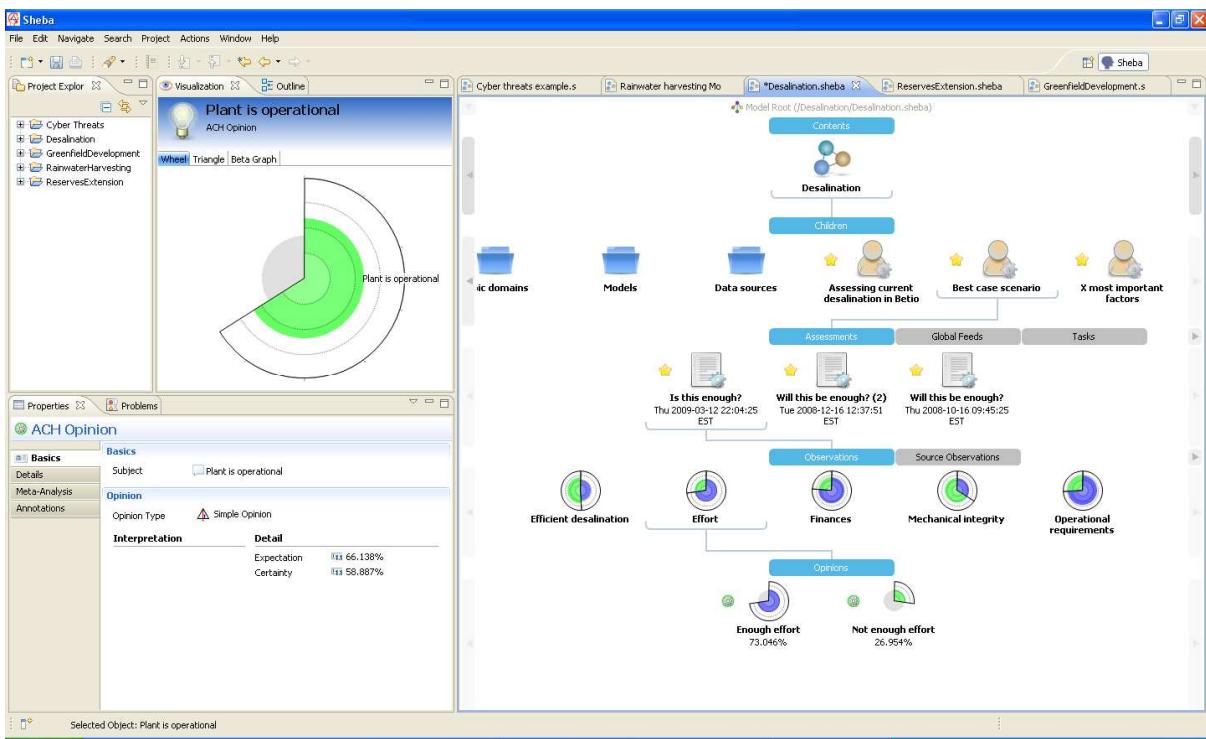


Figure 7-39: BN model of successful Desalination harvesting implemented in Sheba

The main contributing factors in the best-case scenario are Operational requirements (+11.5%); Mechanical integrity (-3.2%); and Finances (-8.2%); whilst for the current situation in Betio, it is Mechanical integrity (41%), Operational requirements (31%) and Finances (21%). It is noticeable that an important factor is the willingness to make the effort to operate the plant; and this is consistent with narratives in literature where islands have installed desalination plants at times of drought, but as soon as an alternative source has materialised which does not require as much work or finances; that water source has been preferred. In the mean time the desalination plant deteriorates beyond repair. Another important and perhaps sometimes ignored factor is the risk of not being able to source spare parts and other essentials that is required for the day to day operation of the plant.

Table 7-34: Results of current approach (desalination)

Topic domain	State	Opinion (%)	Certainty (%)
Efficient desalination	Plant is in operation	7	90
Effort	Not enough effort	67	62
Finances	Insufficient finances	83	78
Mechanical integrity	Plant is not operational	90	87
Operational requirements	Inadequate availability	69	81

Table 7-35: Results of best case scenario (desalination)

Topic domain	State	Opinion (%)	Certainty (%)
Efficient desalination	Plant is in operation	49	52
Effort	Not enough effort	27	54
Finances	Insufficient finances	23	62
Mechanical integrity	Plant is not operational	34	59
Operational requirements	Inadequate availability	74	73

7.3 Modelling chapter summary

This chapter has provided a description of the modelling activities within this study, including the formulation of models (ABM and BN) as well as the simulations created by running these models, and hence generating synthetic data in the form of simulation runs as well as probabilistic descriptions of outcomes. Hence this chapter provides scientific modelling in a situation where direct measurement is problematic, and where expert opinions and theories cannot be directly validated. As such, this chapter provides a causal explanation of the problems of water service provision in Tarawa, which in turn can support theories and synthesis (chapter 8).

This chapter is hence a critical element in this thesis as it takes empirical observations and expert judgment and turns it into theoretical descriptions. In terms of the Cynefin framework, this fits into the exploration of the known, knowable and complex spheres; but in acknowledgment that to the extent that the system is in the complex sphere, causal explanations are only temporary and may need to be updated in order to be useful into the future. This aspect is specifically considered through the formulation of a methodology for rapid development of BNs on the basis of expert judgment, and as such fits into the adaptive learning cycle with rapid turn-around that is necessary in such circumstances.

Chapter 8: Discussion

In this chapter, there is a discussion that will serve as a starting point towards finding ways to help local water managers, by developing tools and frameworks for the water management situation in Tarawa. The discussion takes into account the understanding of the case study (chapter 5), the information that has been generated via interviews and Delphi survey (chapter 6), and the understanding that has been generated in the modelling activities (chapter 7). Hence, this discussion provides the synthesis of all this information and sense-making activity.

To initiate the discussion, the steps in the study are reviewed. Firstly, on the basis of the initial literature review, the Tarawa water system was chosen as a case study. Secondly, the case study was explored from a historical perspective; as well as by using Interviews and a Delphi survey. Thirdly, this information and elicited knowledge was used to develop systems descriptions and causal explanations of system properties via the use of an Agent Based Model as well as a string of Bayesian Network models.

As an outcome of these steps a number of observations and inferences were made. These observations and inferences are discussed in this chapter. On the basis of the observations and inferences, some steps are taken towards developing a framework for management in situations similar to those in Tarawa. Because the system is considered to be in the unordered and complex system domain where prediction is problematic (as per Cynefin framework and descriptions of Complex Adaptive Systems, see chapters 3 and 4), it is acknowledged that this framework is a starting point subject to improvements; in line with the adaptive nature of the proposed framework.

A range of issues and constraints have been identified and explored that are at the core of the difficulties that have been observed in urban water management in Tarawa; some of which are generically applicable to urban areas in PICs or other towns in developing countries. These issues and constraints need to be taken into consideration in the development of processes, tools and governance frameworks for Tarawa.

Furthermore, it seems obvious that the CAS perspective is useful in terms of system description and causal explanation. It has been shown in the study that the current management approaches are inadequate, but this is mainly reinforcing the globally accepted idea that small town management is within a well-known management gap where no appropriate approach is currently available. In this chapter, there is an exploration of what is required of a management framework within the context of Tarawa, and hopefully useful also more generically.

Developing a framework is approached in a step-wise fashion as follows:

1. Identifying key themes based on observations and model inferences,
2. Considering the implications of dealing with a CAS,
3. Discussing the usefulness of modelling in the context; and
4. Integrating all that has been learnt into a coherent framework.

8.1 Key themes

Via the Delphi survey, four themes of issues have been identified that contribute to the difficulties of managing these systems:

- Boundary conditions: including financial and staffing constraints and these provide the foundation on which to operate;
- Technical issues: including suitability to local contexts, and this needs to be adapted to the boundary conditions;

- Socio-technical issues: including inter-dependencies and social complexity, and this relies heavily on the technical and natural systems;
- Policy issues: including institutional problems, dealing particularly with socio-technical issues, but also needs to consider technical issues and boundary conditions.

These themes are described with references to actual observations as well as inferences made based on ABM and BN modelling.

8.1.1 Boundary conditions

Boundary conditions relate to the physical, social and financial constraints of the local situation. Typically these translate to limitations on the types of technology that can be used, constraints on freshwater resources, and the feasibility of more advanced governance strategies.

Boundary conditions are extremely difficult in a location such as Tarawa, because of insufficient freshwater in combination with inadequate finances, staff and skills. This set of severe difficulties means that projects focussing on providing water services have a high failure rate, but also that the service levels are very low and still decreasing.

The Delphi survey identified the key types of boundary conditions, namely 1) Climate change; 2) Extreme events; 3) Sea level rise; 4) Physical conditions; 5) Economies; and 6) Isolation, small scale and scattered nations. These issues are described in Table 8-1 with references to actual observations on the ground, but also inferences made based on ABM and BN modelling.

The observations and inferences relating to this theme are all described in Table 8-1 and are not further described in the text.

Table 8-1: Observations and Model based inferences relating to Boundary conditions

#	Observations (chapters 5 and 6)	Model based inferences (chapter 7)
1.	a) the impact of climate change has so far not been a major factor b) In the rankings by SOPAC Kiribati has been ranked as extremely vulnerable to climate change	c) ABM shows that for most management strategies, including the current management strategy, groundwater supplies are exhausted at times of drought (see Table 7-17) d) BNs have shown that temporary water supply strategies, such as desalination, at times of drought can become irrelevant during more normal times. This shows that dealing with temporary water shortages is often expensive and does not provide long term solutions (see section 7.2.3.5)
2	a) so far there have not been many extreme weather events b) the risk of a Cholera outbreak is high but difficult to assess in an information poor environment	c) storms and cyclones impact on the chances of successful rainwater harvesting, but this is not a concern in Tarawa (see section 7.2.2.3 and 7.2.2.4, and in particular Table A7.3 in Appendix 7)
3	a) sea level rise is likely to cause considerable disturbance to the water system in the long run	N/A
4	a) the small size and hydrology of the islands leads to a very limited supply of freshwater b) the conditions for agriculture are very poor	a) the limited supply is under considerable threat from over-extraction and pollution, in particular during droughts, or with further population growth (see Table 7-17)
5	a) The economy in Tarawa is extremely weak, relying mainly on the public administration and funding from donor agencies. The main income source is from international fishing fleets. This means that the funding of water services is very difficult.	N/A
6	a) Kiribati is an extremely small, remote and isolated country. This means supply of material and products is difficult; b) Management of a diverse and scattered nation over long distances puts great strains on local administrations	c) the impact of isolation impacts on the failure of the desalination plants via poor access to spare parts (see section 7.2.3.5 and Table A7.3 in Appendix 7) d) problems in sourcing energy supplies is a key vulnerability in the system (in relation to desalination, see section 7.2.3.5 and Table A7.3 in Appendix 7)

8.1.2 Technical issues

At the technical level there are some practical problems that have been identified. These are grouped as per the categories identified in the Delphi survey: 1) Appropriate technology, 2) Freshwater availability, 3) Pollution of water resources, 4) Water quality, 5) Maintenance and condition of infrastructure, 6) Adequacy of infrastructure, and 7) Sanitation and waste management. The observations and inferences relating to this theme are all described in Table 8-2 and are not further described in the text.

Table 8-2: Observations and Model based inferences relating to Technical issues

#	Observations (chapters 5 and 6)	Model based inferences (chapter 7)
1	a) it has been found that inappropriate technology has sometimes been chosen for the context, for example desalination is obviously not working, nor are slow-flow tanks	b) the poor risk of technology success is described by the BNs (see section 7.2)
2	a) over-extraction, intermittent water supply, and water related health problems have been observed	b) most of these problems are confirmed by the models (see section 7.1, and in particular Table 7-17)
3	a) pollution in all major freshwater sources; and can visibly see the reasons for pollution have been observed and measured	b) these sources have been modelled using a risk function (see section 7.1.5) and it is possible to explore pollution mitigation strategies using the models (see section 7.1.11)
4	a) see above	b) see above
5	a) three are reported extreme leakage levels of between 30 and 70 percent b) anecdotally there are concerning reports in regards to plumbing practices c) there is an official acceptance of massive levels of illegal connections	a) these leakage levels are modelled by the ABM (see section 7.1.2, 7.1.8 and discussion on leakage management in section 7.1.11)
6	a) see #1 and #5	b) see #1 and #5
7	a) sewer pipe blockages and overflows have been observed b) there is considerable pollution of the lagoon of the atoll, and a main contributor is the sanitation and waste systems c) attempts to improve waste management have partially failed	N/A

It is concluded that much of the technology that is used is inappropriate and problematic. The groundwater extraction and distribution system works to some extent but is fraught with community conflict, pollution and wastage. Desalination is a highly problematic because of costs and inadequate operation and maintenance. Rainwater harvesting is a useful complement to other supply sources but financing is difficult and household use and management is often inadequate.

Further, when researching technological options via publicly available information, it is often difficult to find information and data that is neutral, making it very difficult to assess whether a particular technology is suitable for the context. Often the reasons for technological difficulties reveal themselves in the action based learning, as in the case of composting toilets which are now considered culturally incompatible in Kiribati.

8.1.3 Socio-technical issues

A number of issues were identified in this category as part of the Delphi survey: 1. Groundwater and catchment protection, 2. Ability and willingness to pay for services, 3. Awareness and education, 4. Community participation, 5. Competing water demands, 6. Cultural constraints, 7. Demand management and over-extraction, 8. Human resources, and 9. Community ownership.

The observations and inferences relating to this theme are all described in Table 8-3 and are not further described in the text.

Table 8-3: Observations and Model based inferences relating to Socio-technical issues

#	Observations (chapters 5 and 6)	Model based inferences (chapter 7)
1	<ul style="list-style-type: none"> a) The protection of groundwater reserves is completely inadequate b) High rates of health problems c) Difficult to motivate the landowners to cooperate d) The water in most urban freshwater lenses is usually unfit for human consumption 	<ul style="list-style-type: none"> e) Poor protection of groundwater leads to significant health problems (see sections 7.1.9-7.1.11) f) Incentive structures are complicated but co-management could work in terms of getting landowner cooperation (see sections 7.1.4, 7.1.10 and to some extent section 7.1.11)
2	<ul style="list-style-type: none"> a) Because of organisational difficulties and lack of community cooperation, the water utility is finding it extremely difficult to charge for water b) Many households are unwilling to pay for services because they have other priorities c) Some households are unable to pay for services 	<ul style="list-style-type: none"> d) Due to the adaptive nature of behaviour, payment systems impact on water use, and consequently on health impacts (see section 7.1.3 and 7.1.9-11) e) The impact of how water is paid for depends on the socio-economic status of the household, and consequently hits some islands/villages harder than others (see section 7.1.3)
3	<ul style="list-style-type: none"> a) Awareness and education is considered important by the PUB b) Anecdotally, many community members do not understand the concepts of micro-organisms or shared groundwater c) Operation of even simple infrastructure like rain tanks is often fraught with difficulties due to lack of awareness or education d) Languages issues are making it difficult for locals to undertake training programs in English 	<ul style="list-style-type: none"> e) Awareness and education impacts on the success of engineering solutions and other projects (see section 7.2 and in particular Tables 7-24 and 7-27) f) There is currently not enough information about community behaviour to model the impact of lack of awareness or education (N/A)
4	<ul style="list-style-type: none"> a) The administration is notoriously poor at involving the community b) There are inherent conflicts between the traditional and the modern governance systems 	<ul style="list-style-type: none"> c) Community participation and appropriate engagement practices are often critical for the success of projects (see section 7.2 and in particular Tables 7-24 and 7-27)
5	<ul style="list-style-type: none"> a) Most of the water is used for household use, and only a small amount is used for agriculture b) There is an increasing interest in market gardens 	<ul style="list-style-type: none"> c) Indirectly, the greatest competing water demand is from the sap flow from trees on the water reserves, and by cutting down these trees, the sustainable extraction rates could increase significantly (see sections 7.1.2 and 7.1.9)
6	<ul style="list-style-type: none"> a) A strong reliance on subsistence living even in urban areas means that charging for water is problematic b) Pollution of the atoll significantly impacts on people's livelihoods c) Some traditional practices, such as keeping pigs in urban areas, is irreconcilable with good urban management 	<ul style="list-style-type: none"> d) Behavioural aspects are very influential on the system dynamics, and whilst these are not fully captured due to inadequate information, they are strongly reliant on cultural aspects (generic point discussed throughout sections 7.2 and 7.3)

7	a) Demand management is almost impossible and is only achieved by intermittent supply, which also causes other problems such as back-flow of polluted water into pipes b) Most households don't care about conserving water c) There is frequent over-extraction from freshwater reserves, in particular during droughts	d) Rainwater tanks may reduce the demand for water, but the demand is already inadequate with insufficient volumes of water for most parts of the community (sections 7.1.3 and 7.1.9) e) Leakage management may achieve more for the water balance than demand management, but is also inadequate (sections 7.1.2 and 7.1.9)
8	a) There is a desperate need for qualified people at the tactical and strategic levels b) The skills of plumbers are very poor with most failing basic skills tests c) Succession planning is deeply problematic, partly because of a strong reluctance to share information	d) Skill levels significantly impacts on the chance of success of many projects or supply options (sections 7.2.2 and 7.2.3 and in particular Table A7.3 in Appendix 7)
9	a) Most attempts at improving the system struggle to gain community ownership, and this is strongly linked to a lack of community participation and engagement, and failures to consider the local contexts	b) This is the greatest contributing factor to project failures (see sections 7.2.1.5, 7.2.2.5 and 7.2.3.5)

It is clear that Community ownership and Community participation are issues that are of particular importance for any intervention that requires community cooperation, such as the slow-flow tanks (see historical review), the raintanks (see BN models), demand management programs (see historical review and interviews) and the cooperation of landowners on the water reserves (see historical review and BNs).

For example, on the basis of the historical review, it is argued that there is a need for engagement with the landowners on the water reserves. This involves engagement with traditional decision making processes, but also understanding the complex incentive structures that motivates landowners. Furthermore, based on previous experiences it has been found that the Companion Modelling approach is able to find feasible cooperative (i.e. co-management) approaches in which the water utility and landowners can work together. Whilst efficient, such approaches have also challenged the current mode of operation of public servants in Tarawa who either disagree with, or have little experience in working with the community.

This norm of not working with the community needs to be changed and in its place, there needs to be a real recognition of the need to do so to help operationalise and to gain acceptance for water servicing strategies. Gaining community acceptance usually requires transparent engagement and adoption of socio-culturally sensitive decision processes, as well as sensitivity

to local customs. Such efforts would be supported by a greater focus on social research, local history and an understanding of behaviour.

8.1.4 Policy issues

At the policy and institutional level there are numerous problematic issues that have been identified. These were grouped as per the categories identified in the Delphi survey: 1) Adjusting services to local contexts, 2) Donor agency processes, 3) Information and analysis, 4) Institutional relevance, 5) Legislation, 6) Planning frameworks, 7) Politics, 8) Priorities, 9) Water policy, 10) Dialogue and 11) Funding. The observations and inferences relating to this theme are all described in Table 8-4 and are not further described in the text.

Table 8-4: Observations and Model based inferences relating to Policy issues

#	Observations (chapters 5 and 6)	Model based inferences (chapter 7)
1	<ul style="list-style-type: none"> a) the services are not very well suited to local contexts; for example there is no efficient alternative other than tanker water or rain tanks for segments of the community that do not have tap water; b) the experiments with slow-flow tanks have illustrated that initially a given technology may seem to be appropriate but sometimes the suitability to the local situation is nonetheless inadequate c) providing regular water services to land owners on reserves at a time when there are clear indications of conflict, such as vandalism and complete disregard for the protection of the groundwater 	<ul style="list-style-type: none"> a) landowners on reserves are mostly in a non-cooperative mood with the current structure of incentives, relating to point c under observations (see sections 7.1.4 and 7.1.9-7.1.11) b) there is a huge discrepancy in the service levels from one part of the community to another but health impacts are more evenly spread, albeit somewhat unpredictable (see sections 7.1.3 and 7.1.9-7.1.11)
2	<ul style="list-style-type: none"> a) the SAPHE project has illustrated how the funding mechanisms can be counter-productive, inflexible and insensitive to local circumstances b) anecdotally around the Pacific, stories have been elicited about how donor agencies have been played against each other to maximise aid beneficiaries' share of the aid budget 	N/A
3	<ul style="list-style-type: none"> a) project history information is anecdotal and captured in reports but also in the memories of local stakeholders and experts b) systems specification information is piecewise and focussed mainly on particular elements of the system (i.e. freshwater lenses and water balances) c) systems performance information is very sketchy and unreliable at best d) there are numerous articles and reports written on the topic of the Tarawa water system e) few of these reports are used by local water managers 	<ul style="list-style-type: none"> f) these information deficiencies mean that in particular behavioural aspects are difficult to model accurately (see sections 7.1.3, 7.1.4 and 7.1.11) g) BNs can be used to analyse information gaps (see section 7.2) h) knowledge gaps have been addressed via developing defensible approximations, and applying stakeholder validation processes (see section 7.2)

4	a) institutions are inert and difficult to change b) attempts at creating a National Water Committee have failed c) institutions are not able to cope with traditional governance structures d) anecdotally, corruption sometimes impacts on decisions	N/A
5	a) water related legislation is unclear and fragmented b) the roles for providing water services are unclear in the current legislation c) enforcement of legal requirements, such as relating to rain tanks is poor	N/A
6	a) planning is mainly ad-hoc and based on expert opinion b) planners have inadequate information or time to make good decisions	a) outcomes are unpredictable even if success in a project is achieved (see section 7.1.9) b) managing an intervention is difficult in a situation where context and boundary conditions impact strongly on the chances of success (see sections 7.2.1.5, 7.2.2.5 and 7.2.3.5)
7	a) with the conflicts on the water reserves, it has been seen how water issues have become highly political	b) it has been shown how the incentive structure of landowners is dependent on political outcomes (see section 7.1.4)
8	a) water is not given the adequate priority it needs and other issues are perceived as more importance	N/A
9	a) there is inadequate regulation of the PUB and local councils b) there is a lack of a coordinated policy and vision for the water sector in Tarawa c) there are no clear instructions about what constitutes an acceptable level of service for the urban areas	d) the level of service is both highly variable and at many times inadequate (section 7.1.9)
10	a) the difficulties in establishing and maintaining a functional national water committee are deeply troublesome as it hinders any constructive and much needed dialogue between concerned stakeholders	N/A
11	a) Financing of water services by charging its users is also problematic; at the same time government financial resources are strained	b) lack of funding significantly reduces the chance of success of a number of supply options (sections 7.2.2.5 and 7.2.3.5)

8.1.4.1 Planning and policy

From a planning perspective and based on the theory developed in modelling exercises, it has been found that any attempts to improve the system are fraught with difficulties because firstly the outcomes are unpredictable even if success is achieved, and secondly, managing projects is difficult in a situation where context and boundary conditions impact strongly on the chances of success. From a management perspective, this means that 1) there are no formal goals to achieve, 2) it is unclear who is responsible for achieving those diffuse goals as well as who should pay for services, and 3) planning processes are inadequate in terms of the capacity to

effectively assess projects that may be used to achieve short term goals and that feed into the more strategic visions.

Noting these deficiencies at the strategic and tactical levels, the presence of critical boundary conditions means that it is difficult to define a suitable level of service for the community. In practice, whilst not explicitly formulated or intended, the outcome of all interactions and decisions appears to be an emergent process:

In a highly resource constrained environment, an adequate water service provides the majority of the community with access to chlorinated tap water; and other supply options will be available to those segments of the community which do not have adequate tap water supply. No formal target is set in terms of volumes available per household, or in terms of water quality; but interventions are justified on the basis of crisis or exceptions, i.e. when the quality of water supply services is inadequate for the majority of households and when the number of health problems is unacceptable to bear by the community.

Whilst it is acknowledged that it is not realistic to achieve levels of service such as that in cities in Australia; or water quality standards as recommended by the World Health Organisation, this strategy is obviously inadequate and much less than the global average. Even more concerning is that it lacks an aspirational aspect, i.e. whilst it acknowledges the constraints of the situation; it does not aim for gradual improvements in the service delivery, but focuses at best at maintaining an already low level of service. The challenge is to write an adaptive and realistic goal which acknowledges constraints as well as the fact that there are several different water supply sources for the community, but which is also aspirational in nature, such as for example:

Adequate water service provision in urban Tarawa is access to sufficient water of adequate quality to a significant proportion of all households and customers. Less adequate options will also need to be provided for the remaining households. The definitions of sufficient water, adequate water quality, and the significant proportion of all households is set in a political and transparent process which involves the service

provider, NGOs, community leaders and relevant representatives of the Government of Kiribati. Monitoring of performance against these success criteria is done by an independent regulator and reported annually to the National Water Committee and to Parliament.

However, such a goal is currently not possible because the institutional structure lacks the following important functions: 1) there is not enough constructive, transparent and fair dialogue between key stakeholders, including Government departments, the service provider, NGOs and community leaders; 2) monitoring of performance is inadequate, particularly relating to health impacts, access to water or water quality; 3) It is unclear who would be responsible for delivering against this goal; and 4) there is no independent regulation of the water service provision. These deficiencies need to be addressed in a management framework.

It is also noted that because of the lack of constructive dialogue, most learning about the system happens at the individual level without the stakeholders' critical review that is implicit in the social learning process. Saying that, there may be informal social learning, but there is no formal and transparent social learning. This may be partly due to a cultural reluctance for sharing information that is commonly prevalent in the Pacific Islands cultures, but also because of the collapse of the national water committee and other forums for constructive dialogue. The implications of the lack of social learning are many:

- This is fertile breeding ground for disagreements as each individual is likely to develop their own mental model which will often clash with other stakeholders' mental models, causing time consuming conflicts and misunderstandings;
- This is poor practice in terms of human resource management as the system management becomes highly dependent on the mental models of individuals. In a system where there is not much redundancy, this can be a fatal flaw;
- The system depends on decisions made by individuals based only on their mental models, rather than via a process based on a commonly accepted systems representation. Hence it

relies on the honesty of the individual decision maker, who may or may not be tempted by corruption.

Therefore, it is suggested to set up a formal learning process which informs key decisions about the water system. Such a formal learning process will incorporate performance data, project data and systems specification data (see Table 8-5), but will also include the systems representations that build on these. The social learning process needs to involve the process of theory building, critical peer-review and identification of critical knowledge gaps.

Table 8-5: Information domains

Information domain	Used for
System specification	Understanding system interactions and specifying models
Project history	Understanding context, risk and feasibility
Performance	Monitoring, adaptive management and regulation

Additionally, the application of BNs has further shown how community acceptance and stakeholder engagement issues can be incorporated into planning processes. This is a major advance in the area of assessing water supply options, and should become standard practice in risk and feasibility assessments, not just in Tarawa but in all urban water situations; in particular at a time when novel technical solutions are used which require a higher level of community cooperation.

8.1.4.2 Information sharing

It is noted that in the interviews as well as in a report by Crennan (2001), there is a reluctance to share information and knowledge. It has been identified that traditionally, knowledge and information is generally shared only within the family; which is of course the core unit of I-Kiribati culture. This reluctance for information sharing is endemic and does not only include higher level positions, but also occurs in relation to practical jobs such as plumbing and engine mechanics. This is very detrimental both to the general skills levels as well as to the institutional

memory. However, from a cultural trait point of view it can be understood, along the lines argued by Little and McDonald (2007), on the basis of model inferences, that in a system of resource harvesting and where information is critical for success, information is intrinsically linked with the hierarchy within the community. Another argument that was put forward by locals is that not sharing information is warranted because in an isolated island with cycles of bad times and good times, it is a definite advantage to have information as this will avoid being vulnerable in the community.

However, whilst understandable from a cultural point of view, it is strongly argued that this cultural fact is severely detrimental to water management and there is a strong argument for changing this behaviour or alternatively it needs to be considered both in human resource management (i.e. in training and succession plans etc) as well as in project planning (in terms of composition of teams and recording of experiences).

8.2 Implications of Complexity

This study has been undertaken with the assumption that the observed system can be viewed as a CAS and a number of system features have indeed been observed which partly confirms this intuition, as far as this can at all be confirmed.

Based on the historical review and the interviews, as well as based on ABM inferences, the cooperation of the land owners on reserves with the water utility depends on a complex system of incentives, disincentives as well as personal politics and traditional rituals and processes. This generates a high level of unpredictability due to social complexity and a significant need for negotiation.

Additionally, based on ABM inferences, the way that households choose between multiple sources of water generates dynamic and adaptive systems behaviour and significant impacts on both volumetric supply outcomes as well as health outcomes.

Pollution of freshwater and seawater; and over-extraction of freshwater can and does generate irreversible degradation of the natural systems which affects already tight boundary conditions.

Taken all together, even the intuition and knowledge of experienced professionals is usually not enough to predict the outcomes of interventions into the system. This is partly due to the water use behaviour of households and pollution of water resources; but also due to interactions between many systems that operate in a non-linear fashion, such as infrastructure performance and freshwater lenses;

A conclusion is that this system has elements of social complexity, adaptive behaviour, non-linear interactions, difficult boundary conditions and irreversible changes. In such a situation, it has been found that taking the CAS perspective has been useful, and the following section described how to reduce such complexity, and when that it is not possible, to manage complexity.

8.2.1 Reducing complexity

Taking the CAS perspective, a basic theory is proposed, based on an influence diagram, about factors that increase the social complexity of an urban water system (see Figure 8-1). According to this model, the main drivers leading towards social complexity are a dependency on human behaviour, combined with conflicting goals and variable and heterogeneous preferences in a situation of ambiguous rules and competing formal and informal institutions. This leads to tactical and strategic behaviour from participants, and a strong dependence on incentive structures and preferences. While it is possible to reduce the reliance on human behaviour by a combination of technological solutions, and the provision of an adequate supply, those strategies are not possible in Tarawa due to financial constraints and an endemically limited supply of freshwater and severe organisational capacity problems. Tarawa also suffers from common pool resource lock in situations where current practice and norms reinforce a discrepancy between private and public good, to the detriment of the common pool resource (freshwater), and this is reinforced by existing infrastructure, engineering rules, and consumer expectations.

With this in mind, it may be worthwhile to reduce the complexity and hence make the problem more well-defined. This can be done by:

1. Removing ambiguous rules or competition between institutions;

2. Increasing the supply volumes, and hence reducing the need for efficient allocation of water;
3. Avoiding common pool resource lock in situations; but for water this is difficult using market based mechanisms;
4. Reducing the need for environmental management;
5. Relaxing constraints, such as improvements of skills or finances.

8.2.2 Managing complexity

Whilst well resourced cities can afford to significantly reduce this complexity by introducing technologies like desalination; such opportunities for affordable complexity reduction are typically limited in small towns. As was identified in chapter 2, there is a management gap for small towns, which can now be rephrased as follows:

The small town management gap applies to the situation where due to scale constraints, the complexity and reliance on human behaviour can not be fully removed by clever design; AND where the number of stakeholders and participants is too large for rural participatory approaches to be adequate.

Unfortunately, for historical and institutional reasons, the complexity is often ignored in the management style and the consequences of inadequate management are often wide ranging, as exemplified by the situation in Tarawa described in chapter 4-7. At best, the management style considers multiple goals and multiple constraints, but it does not consider non-linearity, uncertainty, interactions, social complexity or lack of definition.

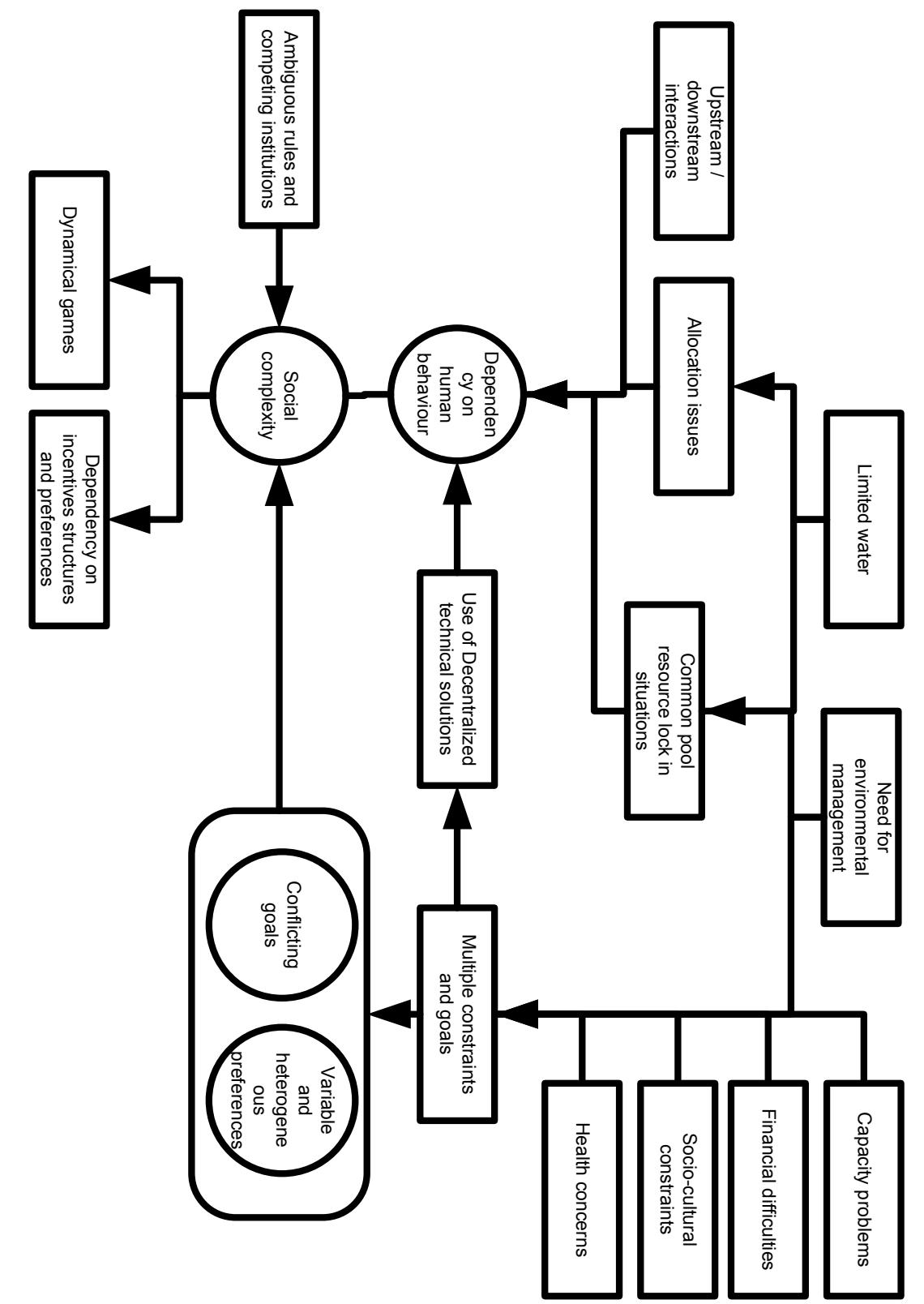


Figure 8-1: Drivers towards social complexity in an urban water system

The Cynefin framework (Kurtz and Snowden 2003) is used as a starting point for managing a CAS. Based on the Cynefin model, there are four system domains, Complex, Complicated, Chaotic and Routine:

- In the ordered routine domain, cause and effect relationships are repeatable and predictable, and here, standards and best practices are applicable;
- In the Complicated ordered domain, cause and effect relationships are knowable but usually not immediately obvious, such as is the case in many physical systems. In this domain, reductionist thinking and scenario planning is applicable;
- In the un-ordered chaotic domain on the other hand, there are no visible cause and effect relationships and the system is turbulent. In this domain, acting decisively may reduce uncertainty, and hence increase the potential for control in the system. This may allow it to be transferred into the complex domain; and
- In the complex domain, cause and effect relationships are dynamically changing and difficult to discover. This is also the domain of complexity science which explores how local interactions lead to emergent system behaviour.

Fortunately, as previously mentioned in the chapter 4, the Cynefin model also suggests that there are some general guidelines for how to operate in the complex domain. It prescribes:

- Analysis of history as a way to understand systemic properties; but this is insufficient in itself as a complex system is evolutionary and dynamic;
- Exploratory analysis in order to temporarily move from the complex domain, where cause and effect relationships are only coherent in retrospect, to the complicated sphere where cause and effect relationships are discoverable;
- Use of a Probe, Sense and Respond approach, where
 - A Probe (an intentional disturbance to the system) can make patterns of behavior in the system apparent or more visible

- Sense means of finding behavioural patterns by inductive reasoning
- Respond means stabilizing desirable patterns and vice versa destabilizing undesirable patterns;
- Use of Multiple perspectives on the nature of the system; because no single perspective is sufficient to fully understand it;
- Use of Narrative techniques, as these are able to capture and convey complexities without necessarily being bound by formalism and simplifying assumptions.

The question is: how are these strategies implemented in a resource constrained environment such as Tarawa where information is scarce, human resources are fragmented and dispersed, local conditions are diverse and unpredictable and financial resources extremely limited? These constraints must be taken into account, or the management framework will fail for the same reasons as many other well-intended strategies. Based on learning in this study, it is believed that for the case study location:

1. Modelling tools such as Agent Based Models, Bayesian networks and practices such as a Delphi process can be used to analyse and understand history and undertake exploratory analysis, although this has not been formally tested and evaluated, and is beyond the capacity and scope of local stakeholders; and
2. A probe-sense and respond approach can be implemented using Adaptive management if combined with a Dialectical process evaluating observations and using multiple perspectives and narratives.

Another question concerns the responsibility for sense-making, i.e. managing and creating an institutional memory, sense-making efforts, adaptive management and dialectical process. Whilst individual departments and stakeholders represent individual interests, no single institution or stakeholder is responsible for the entire system. As has been seen in chapter 6 in the historical review, efforts in Tarawa at setting up a national water committee has failed for a

number of obscure reasons; mainly relating to personal politics. An alternative forum needs to be set up.

8.3 Using models in the context of small town water governance

An approach to sense making in a complex context that has been applied in this thesis is the use of models: Agent Based Modelling for exploring interactions between multiple sub-systems, and Bayesian Networks to understand causal links between inter-related factors. But obviously such modelling efforts require both capacity and skill, especially numerical and IT skills. Those skills may not necessarily be available locally or with donor agencies. This section describes some of the useful aspects of modelling in the context as well as some capacity limitations.

In cases when there are insufficient staffing skills available, as is often the case, capacity building and training needs to be considered, but in the meantime, realistic assessment alternatives need to be used; and this may even be expert judgment. However, if expert judgment is to be used, the output needs to be structured appropriately in a similar fashion as more rigorous approaches, and the results need to be given justification and need to be transparent and publicly available. Spreadsheets and forms need to be set up to support such structured analysis.

If more advanced assessment options are going to be used, this may be enabled via external support from either funding agencies, or regional agencies such as SOPAC. In fact, using regional agencies such as the South Pacific Applied Geoscience Commission may very well create a regional capacity in the Pacific region for assessments and participatory design, supporting the Adaptive water management capacity across the region. This regional economy of scale may also be a pattern to use to support other conglomerates of small towns.

8.3.1 Usefulness of ABM in the context

The Waterscape results show that there is a need for a tailored portfolio of actions and interventions rather than just single strategies. While experts may be able to roughly predict the results of a portfolio of strategies, in order to use their assessments, they in turn need to ask

decision makers and stakeholders to trust them. An ABM, if developed in a transparent and participatory way, may overcome such problems by providing transparency in the assessment methodology, and the underlying assumptions.

Waterscape may also allow decision makers to explore the results of a portfolio of interventions, and use such results in a multi-criteria optimisation or decision making framework where financial and other constraints can be embedded. By doing this, local decision makers may find the most efficient and suitable strategy within the constraints under which they operate. They will also be in a position to show the benefits that can be achieved by any extra funds given to them by funding agencies.

Whilst these results are interesting and potentially useful, more work is needed in order to operationalise the approach and for it to become an important tool in the management of similar systems. To achieve this, the model has been used in the communication with key stakeholders and decision makers in order to assess how it can help. The feedback on the model is that there are a number of key advantages of the approach, and especially:

- Its capacity to embed understanding of human behaviour, which is a critical aspect to consider in management of the urban water system, but which has proven very challenging (Taboia Metutera, PUB; Tererei Abete-Reema, Ministry of Environment Lands and Agricultural Development);
- Its ability to embed multiple perspectives and aspects into a single analysis tool which makes it particularly suitable for facilitating discussions between different departments; and particularly within the National Water Committee, which is being defined with multiple departments and stakeholders (Tianuare Taeuea Ministry of Health & Medical Services);
- Its ability to allow users to quickly improve their intuition and understanding of the overall water system; something which is critical in a situation where formal education and practical experience is constrained to a small number of individuals (Taboia Metutera, PUB;

Tererei Abete-Reema, Land Division; Tianuare Taeuea Ministry of Health & Medical Services).

Unfortunately, there are a number of difficulties to be overcome before the approach can become an operational part of the urban water management regime. Firstly it is a new approach for which there is currently not enough skill, neither locally at departments or the water utility, nor internationally within key agencies such as development banks, consultants or donor agencies; and secondly it requires efficient and systematic knowledge creation and management, which is currently lacking.

8.3.2 Usefulness of BNs in the context

Based on the case study (chapters 5 and 6), it is clear that many attempted management strategies have had weak points that made them unsuccessful and these can be explored using BNs. The reasons are varied, such as lack of consideration of local circumstances and process requirements, and in particular inadequate involvement of affected stakeholders as well as inadequate cross-sectorial coordination. This is not surprising given poor organisational memory combined with decisions being made under time pressure and strict deadlines combined with little adaptive capacity. Additionally, information about the importance of process requirements and engagement is qualitative and as such is unfortunately often given secondary importance. It is also striking that many of the weak spots appear to have been known by at least one individual before the strategy entered into the implementation stage, which begs the questions why this knowledge was not incorporated into the planning process.

To address this, it is suggested that a risk assessment component be included as part of the project design phase based on Bayesian Networks (BNs) utilizing expert, stakeholder and local knowledge. This not only improves organisational memory and transparency but also provides a direct link for assessing cost benefits and minimizing the risk of failure. Most importantly this prioritises engagement, processes and an understanding of the local context. BNs have been developed and tested on water supply interventions in Tarawa and the models have been

populated using data from interviews and literature to evaluate water supply options, i.e. rainwater harvesting, desalination and reserve extensions.

For the three management strategies that have been explored with BNs, the results of these investigations show that the success of the strategies are highly dependent on issues relating to the community involvement and attitudes. In the case of the reserves extension strategy, it was found that the current strategy is doomed to fail whilst the co-management framework (based on cooperative solutions where a more complete set of actors take part in the management) developed through the AtollGame strategy could have potentially succeeded; whilst the rain tank utilisation strategy is dependent on a range of factors, and current strategies only have about a 50-50 chance of success, which is in line with survey results (Asian Development Bank 2000b). Similarly, the chance of successful desalination is very low, and is only ever an option as a last resort in circumstances of tight finances and limited staff resources.

8.3.3 Addressing concerns of the AtollGame and Atollscape studies

In section 5.2.4.3, based on lessons in the AtollScape and AtollGame studies, it was argued that key challenges were to:

1. Increase the ability of international and local agencies to consider local customs, culture and context by embedding more participatory practices into management frameworks;
2. Improve the ability of local agencies to manage the water supply and sanitation despite considerable resource deficiencies;
3. Improve the adaptive and coordination capacity, and embed abilities for negotiation within existing institutional structures.

It is argued that the ABM may help the PUB to define more efficient operational strategies for management of the water system, and to identify strategies that will reduce health impacts and protect water resources (addressing concern 2). It is also argued that the BN models helps to incorporate knowledge of local customs, culture and context into management decision in a risk framework using probabilistic causal effects (addressing concern 1). It is also argued that it both

BNs and ABM can be used to support a better adaptive capacity (via better systems analysis and knowledge management), and that these types of models can help support negotiation as per Companion Modelling principles (addressing concern 3).

8.4 Framework

The word framework means different things to different people. A quick web search shows that in software engineering, it has become a buzzword used mainly for various structures for organizing software programs. Similarly, in literature a framework may be used for organizing a narrative. Wikipedia describes a framework as a basic conceptual structure used to solve or address complex issues. For example, such a conceptual structure has been used within this study via the application of the Cynefin framework for understanding and managing complex and adaptive systems. Various frameworks have been used for systems analysis, such as using ABM and ABS and BNs.

On the basis of this study, and in the spirit of Inductive Theory Building (Locke 2007), a framework for managing urban water situations similar to those in Tarawa is now proposed. Developing such a framework specifically addresses the small town management gap, as identified by Pilgrim and others (2004) in a key report for the World Bank on the basis of a number of conferences on the topic such as the Small Towns conference in Addis Ababa in 2002, which agreed on the following statement for elements of successful management:

Financial and management autonomy, transparency and accountability, professional support, competition, legal framework and regulation, demand responsiveness, and incentives for expansion (Pilgrim *et al.* 2004: iii).

Their report is organised on the basis of addressing these factors, providing a framework of sorts. Along a similar line, the management gap was also recognised by the UN-HABITAT (2006). In fact, this publication takes a number of similar steps towards developing a management framework for small urban centres, focusing on the deficiencies in small urban

centres, monitoring and indicators of performance, financing, integrated water resource management and a pro-poor governance framework.

Hence, it is noted that a number of the key components of a framework that have been identified in the previous sections are already confirmed as important in a small town management framework, i.e. transparency and accountability, regulation and monitoring, professional support and capacity building, legal framework, consideration of difficult boundary conditions, fairness and equity considerations. Other framework considerations are either due to the specific situation in Tarawa, or more broadly related to the situation for communities in the PICs.

Importantly, the available frameworks for small town water governance (Pilgrim *et al.* 2004 and UN-HABITAT 2006) are aspirational and strategic, but as such they do not provide guidance about how these goals and visions can be operationalised. Therefore, to bridge the gap between goals and practice, a tactical management level is introduced which describes how such goals and aspirations can be operationalised. This concerns to a large extent issues of how to deal with CAS features as well as aspects of learning and information.

Below, learning and complexity aspects are re-considered; whilst also building on previous work when appropriate and considering the limitations of the context. This is done by:

1. Introducing a multi-scale perspective, with an operational, tactical and strategic level;
2. Introducing a management process that incorporates learning processes and measures for coping with CAS properties taken into account as well as interactions between these multiple scales;
3. Discussing how this framework can be operationalised in practice.

8.4.1 Multi-scale perspective

So far, it has been identified that in existing management frameworks there is a gap between the aspirational Strategic level, and the practical Operational level. Therefore it is proposed to introduce an intermediate facilitating level, the Tactical level as per Figure 8-2, which shows the roles of each level. It is also suggested to introduce an overarching Regulatory framework that

monitors performance and enforces role compliance using legal mechanisms. Reiterating the information in Figure 8-2, the Operational level considers the day-to-day systems operation using standard procedures, and the implementation of projects. In our framework, this level also feeds into local and operational knowledge at the Tactical level. The Tactical level facilitates the creation and handling of ideas, project design and assessments on a foundation of systems knowledge, social learning and deliberation. It also acts as an intermediate filter before project proposals are submitted to the Strategic level. This level in particular considers issues such as risk, feasibility and human resource management. At the Strategic level managers and political leaders set goals and a vision for the system; and the progress against the goals is monitored using indicators and performance measurements; at this level one is not concerned with practical details but rather system level performance and outcomes. This level also concerns issues such as financing and political approval.

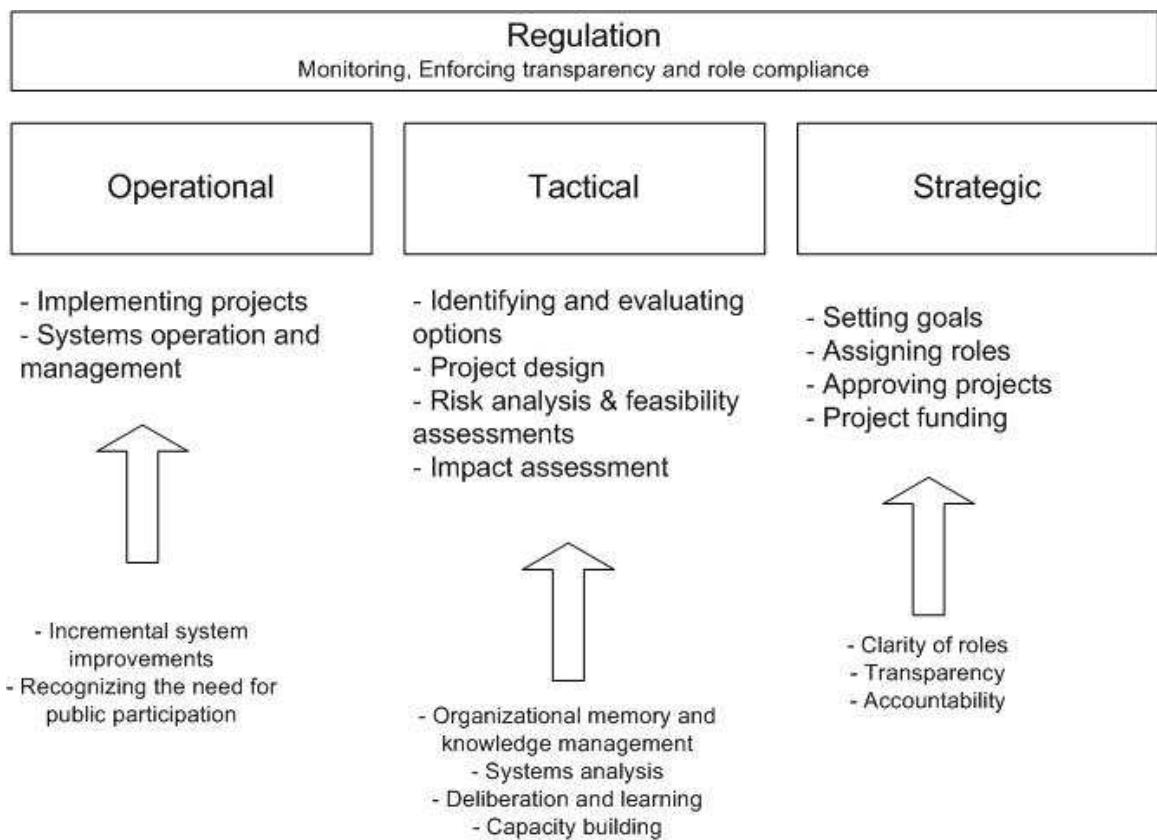


Figure 8-2: Suggested management structure for the Tarawa water system

In terms of the situation in Tarawa, whilst the tactical level is completely ad-hoc in the current system; it is clear from the above discussion that key elements are missing at all levels, for example:

- At the Operational level, there are serious capacity limitations, and a reluctance to work with the community;
- At the Tactical level, the identification, feasibility assessment, risk assessment and impact assessment of projects and options is ad hoc and informal and has been shown to often be inefficient. The arrangements therefore need to be formalised and improved;
- At the Strategic level, there are unclear goals and role assignments, and inefficient interaction with the Tactical level;
- At a higher level, there is no adequate Regulation of the management of the Tarawa urban system which means that there is inadequate accountability, no enforcement of role compliance, and no independent evaluation of project success or failure.

It now remains to specify how these three levels ought to interact, and it is suggested to apply a process as shown in Figure 8-3 that describes the roles and responsibilities of each level. Importantly, this diagram shows how the goals and visions are set at the strategic policy level and how these trickle down to the operational level, facilitated via the tactical level. In the following, the various elements of this process are explored in further detail. In doing so, it is acknowledged that this is not always a linear process, but a process that includes many interactions and cycles. For example there is an Adaptive management cycle embedded in the process.

8.4.2 Goal setting and vision

It is very useful if the goals and visions can be formalised into a number of clear and eligible statements, which indicate the relevant priorities, such as describing:

- What level of service needs to be delivered to the community? For example:

- What proportion of the community ought to have tap water?
 - What is the minimum amount of water that each individual needs?
 - How much money needs to be raised from the customers?
- What is an acceptable water quality for all the different use types?
- What is an acceptable leakage level?
- What levels of pollution are acceptable?
- What level of freshwater extraction from limited groundwater resources is acceptable?
- What is an acceptable success rate of project implementations?
- What minimum level of dialogue between stakeholders, water service providers and government departments is acceptable?

It is noted that as per goal setting theory (Latham and Locke 2002) the goals need to be well-defined and specific, as well as aspirational and difficult to achieve. In this way, the goals can improve performance by 1) prioritizing attention to that which is relevant to achieving the goals, 2) increasing the effort by individuals to reach goals, and 3) will increase the chances of overcoming obstacles, by improving the persistence of organisations and individuals. However, as per the theory by Latham and Locke (2002), for this to happen, individuals need to be committed to reaching the goals, and must be confident and perceive it as realistic to at least partially reach the goals.

Setting the goals and the vision is part of a political process and is inherently linked to political approval and funding sources. It is critical to make sure that the performance against the goals is measurable or that it can be estimated. This is important in order to allow for assessments of improvements and compliance. However, it is also important that the goals and visions are realistic given the strict boundary conditions and other constraints. The goals should be set in order to motivate change, rather than to demoralise individuals by setting too high goals. It is

also important to clearly state which authority is responsible for delivering the goals, and that such an authority has the legal mandate to allow them to reach their goals.

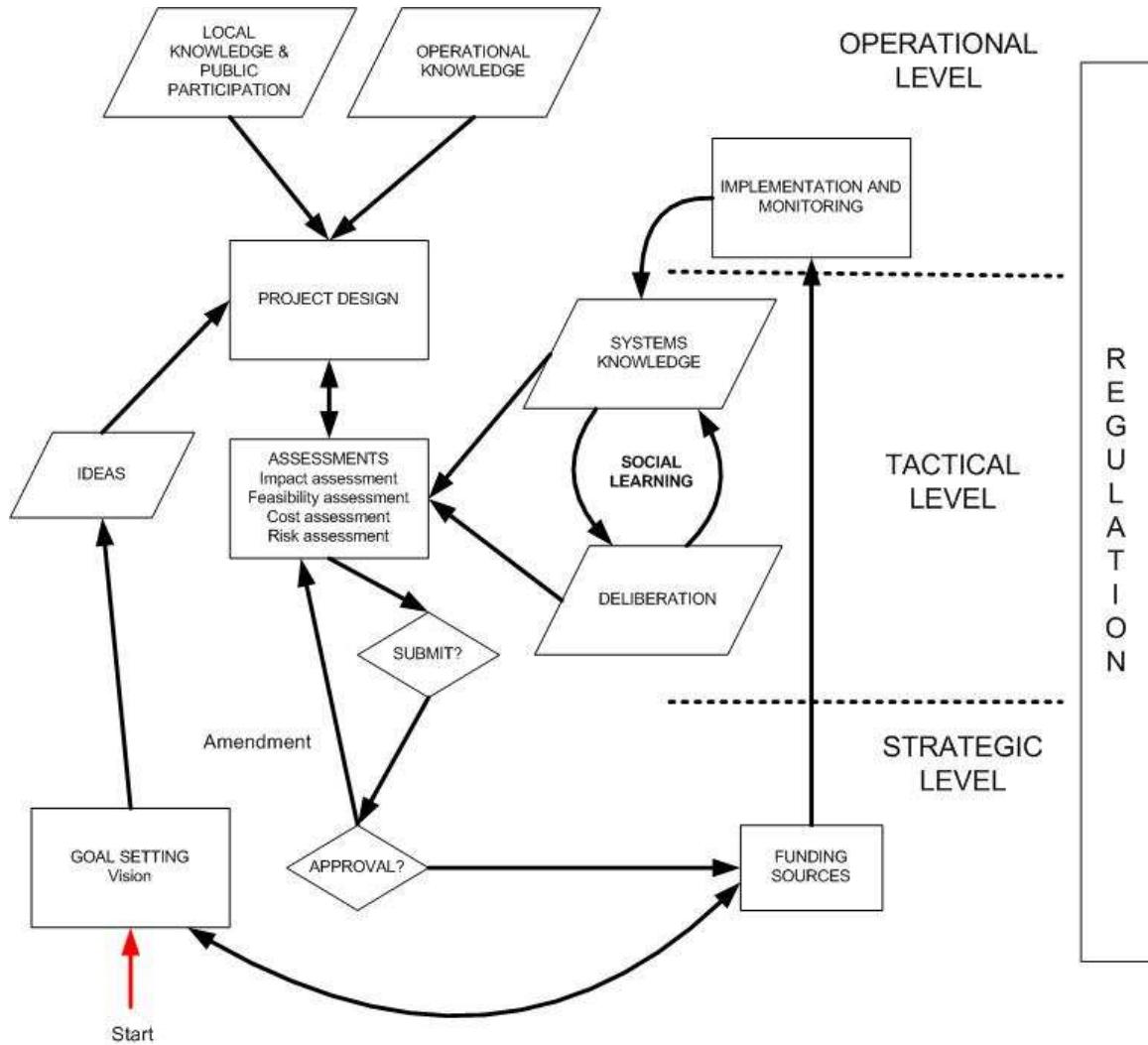


Figure 8-3: New Framework process

8.4.3 Contrast with existing framework

The new framework suggested in Figure 8-3 differs to current practice in a number of ways. Firstly, current practice is a more linear process, where there is a sequence of events going from project conception, to expert consultation, project design, approval and then finally followed by technical implementation and community engagement (see Moglia et al. 2008b). This type of process archetype lacks the learning that is required in a complex and dynamic situation that is

difficult to analyse or evaluate by any single individual. Such situations require collective assessment and adaptive learning. The new framework has an adaptive learning cyclic nature that better enables social learning processes.

Unlike in many more developed locations, the current practice in Tarawa lacks a formal tactical level where feasibility, impacts and risks of various strategic options are assessed. Also unlike many other situations, a range of constraints in Tarawa offer more severe limitations. This means that many projects will fail and/or not deliver the intended effects. Case study review, interviews and Bayesian Networks have all shown the sensitivity of various strategic options to local conditions. Agent-Based Modelling has shown that the outcome of projects is not always predictable or those that were intended. The proposed framework considers such limitations and has a significantly improved tactical capability.

Supporting the tactical level capability there is a need to collect and handle systems knowledge which is currently dispersed amongst a range of stakeholders and professionals. Knowledge management, knowledge mapping, and/or IT systems may be required to improve this capability.

Furthermore, it is considered that local and operational knowledge needs to be taken into account already within project design. This is partly achieved already, but probably needs to be formalised in order for it to be done consistently and adequately.

8.4.4 Generating ideas

A critical part of our process, as it is the starting point, is the generation of good and practical ideas about systems improvements. Throughout the discussion with local stakeholders and professionals, there has been a growing sense that there are many excellent ideas, but those ideas rarely leave dinner table discussions. Part of the reason for why those potentially good ideas are not put into practice appears to be that it is unclear which process to go through in order to get them implemented. Bringing those new ideas into the process will create a greater level of community participation, which may help to make project concepts better grounded in local realities, but also by providing the community with opportunities to improve their own

situation. It is therefore suggested that there is an open forum held bi-annually, or even a ‘suggestion box’⁵ into which anyone can put their ideas. Naturally, if there are too many ideas, the tactical level operators will have to prioritise those ideas that show the greatest promise, and escalate those ideas towards project design. This narrowing down process may be done via a Delphi survey. Descriptions of Project ideas need to answer a set of questions, in order to help an initial evaluation process, i.e.:

- What are the anticipated benefits and how do they align with the strategic vision?
- What can go wrong? And what are the estimated chances of successful implementation?
- What technology would this project rely on?
- Who would be affected by this project?
- Who has come up with the idea?

8.4.5 Project design

Participatory design was identified in the interviews as an important step towards having interventions that are better suited to local contexts, cultures and conditions, and that have a greater level of community acceptance. The benefits stem both from better information as well as from better engagement with the community. These conclusions were strongly supported by the Bayesian Network results, and were supported in principle by both local stakeholders as well as international experts.

In our framework, this means that local knowledge and operational knowledge has to be taken into consideration. This can be done via consultation, or by inviting representatives into a workshop setting to allow for input. For the development of cooperative arrangements, such as co-management frameworks, role-playing games as per Dray *et al.* (2006a, 2006b, 2007) may be suitable to allow for local input, whilst for other more mundane interventions such as rainwater tanks, it is enough to simply identify roles and responsibilities in a workshop setting and to make sure a handful of design features fulfill the needs and requirements of those

⁵ A mechanism, such as a post box, for collecting suggestions about improvements
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involved, as per the rainwater harvesting guidelines developed by the South Pacific Applied Geoscience Commission (2004).

Other more innovative schemes that may support participatory design ought also be considered, such as micro-financing initiatives or distribution of responsibility to the community; but in such cases it is critical to evaluate the efficiency of the participation, as well as any inherent risk or feasibility issues in a critical manner rather than taking it for granted that participation will lead to appropriate design, or efficient management.

8.4.6 Assessment dimensions

It has become obvious via the historical review, interviews, the Agent Based Modelling and the Bayesian Network models that when it comes to projects and interventions there are many levels of uncertainty, both in terms of impacts, but more importantly in terms of risk and feasibility. The Tactical Level Operators facilitate the assessment process.

The information input into assessments comes from the systems representations that are available, just as has been used for the ABM and BNs in our study. Such systems representations are the output of social learning and deliberation which is described further below, but also via adaptive management where projects are seen as experiments and probes into the system, allowing for improvements of the system representation.

Impacts: there is generally some considerable uncertainty about the outcome of projects. It has become clear that there are sometimes surprising effects, unintended effects or lack of effects, both in terms of the range of outcomes for the community but also in terms of inefficiency. Therefore it is prudent to assess the impact before projects are undertaken, and ABMs have been shown to be suitable for this purpose, but other methods may be equally good, such as systems dynamics and perhaps in some cases even spreadsheet models. Using the output of impact assessments, the value of the project may be translated into monetary terms using Triple Bottom Line approaches, taking into account the social, economic and environmental impacts and translating this into monetary terms, as per Maheepala and others (2006).

Triple-Bottom-Line translation: using accounting approaches, but extending the ‘bottom line’ from purely financial measures by also including social and ecological aspects, this approach allows for converting a range of diverse impacts into a single monetary number. From the water service provider’s point of view, this provides a way of taking into account issues that relate to for example pollution, over-extraction and leakage, as well as fairness and equity. A concern in this approach however, is how the social and ecological impacts are translated into monetary terms, and this involves a high level of subjectivity. This translation needs to be transparent, and carried out by the Tactical level operators.

Feasibility: using local knowledge about legislation and customs, each option is assessed to see whether there are any major clashes with traditional decision making structures, or whether there are legal or ethical concerns relating to the proposal. This assessment is completely qualitative and based primarily on local expertise. Local NGOs may become involved to assess feasibility. The outcome of the feasibility assessment may be to reconsider the design (for example if there are ethical or legal concerns), or to feed into risk assessments (if it simply involves community acceptance issues).

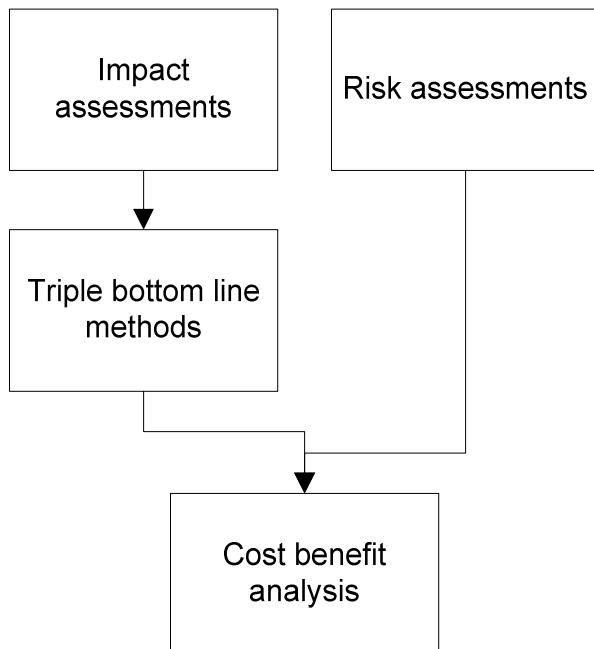


Figure 8-4: Impact and risk assessments and how they feed into cost-benefit analysis

Risk: it has been found that due to the high level of context dependence in a resource constrained and complex environment, there is a very high failure rate for interventions and projects, and there is a need to rigorously assess risk and feasibility as part of standard procedures in project preparation. This can be done via BN analysis as shown in chapter 7; and this may also identify that more information needs to be collected in order to make assessments valid. Once the probability of failure for a number of options has been calculated, this can be translated to costs via a risk calculation as per the Australian and New Zealand Standard for Risk Management (Standards Australia, Standards New Zealand 1999). In line with the spirit of this standard, risk is calculated as the loss if the project fails multiplied with the probability of failure of the project; representing in money terms the statistical expectation value of the loss; with the expectation value defined as per standard probability theory. These numbers can then be used to find the option which has the highest expected return of value.

Cost-benefit analysis: Combining risk assessment output with impact assessment output, and translated into monetary terms using Triple Bottom Line methods, this will then allow for looking at cost-benefit evaluations for various options. Whilst some values could arguably not possibly be monetised, other aspects, for example those relating to the chances of practical performance of strategies and solutions could be entered into the cost-benefit analysis.

Assessments may also be done informally via expert judgment, but that means reducing the level of transparency and it is also difficult to evaluate the validity of assessments. In a resource constrained environment however, this is sometimes the only practical option.

8.4.7 Submit, funding and approval

The Strategic Level has its own set of operators and stakeholders such as funding agencies, high level decision makers and political representatives. In particular, it is critical to involve the Department of Finance at this stage.

For the process of approving proposals and identifying funding, a management board may be set up. On this board, it is suggested to have strategic level operators, but it is also important that there are individual representatives from the operational and the tactical levels. This is in order to bridge the information gap between scales.

By having a rigorous and formal process for the Tactical level, once the proposals reach the Strategic level, they ought to be well designed and assessed. It is also noted that it is however important that this part of the process is not overly time-consuming as it may otherwise become a bottle-neck, and as such may be hindering system improvements.

When the management board assesses intervention options, the decision space for each proposal is:

- Reject, which means that the project proposal is dismissed and will not go any further.
- Suggest amendments, which means that the project proposal goes back to the Assessment and Design stage;
- Delay for a decision at later meetings, in recognition that there are very few funding options available at the particular point in time;
- Approve, which means that the proposal goes further to the funding stage.

The approval process ought to include a discussion about funding sources, and approval would hinge on a reasonable expectance that it will be possible to source funding, and may include in-principle agreement from key funding agencies or the Department of Finance. However, the details of the funding arrangements are only finalised after approval. Funding may be via a consortium or via single contributors. This process will allow funding agencies an obvious forum to act within, and will provide them with an opportunity to fund projects that have risen out of local needs, and that have been designed using input from the local community and the local operators. Hopefully, it will also help avoid 1) duplication of efforts, 2) unintended impacts of projects, and 3) help improve the success rate of projects.

8.4.8 Implementation and monitoring

Once approved and funded, the implementation of projects is carried out at the Operational level, usually by the water service provider, but it may also be done by NGOs or external contractors. On the basis of lessons learnt in the historical review, it is important to design projects with hold points in order to allow for assessing whether they are progressing in the way they should. Such mid-term assessments ought to consider aspects of community acceptance, suitability to local conditions and an update of risk, feasibility and impact assessments. This will allow for an adaptive mechanism also within project implementations, but will also provide information into the systems representation at the Tactical level, and hence contribute to the social learning as well as future assessments.

These measures are to ensure that a high success rate is achieved in this complex and adaptive environment. This is the reason why, despite financial and staffing resource constraints, such measures are warranted.

8.4.9 System representation and deliberation

To create a common ground for decision making, it is important to create a shared and accepted representation of the system as well as its dynamics, actors and boundary conditions. For this reason, it is important to have a local learning process with the key decision makers, whoever they may be. At its foundation, a Hegelian view of dialectic deliberation is applied where there is a continuous iteration between thesis, contradiction and synthesis as shown in Figure 8-5. According to this model, there will be successively less discrepancy between the hypothetical world's Thesis (usually in the form of a model), and real world observations. The critical mechanisms of this learning process are three: formulating a theory (modelling); observing reality and identifying contradictions between models and reality; and the intermediate step of synthesis. Researchers play a key role in the synthesis and modelling, whilst system participants play a key role in identifying contradictions.

It is noted that whilst there can be only one truth, when the system complexity increases to the highest level of complexity, proving or disproving a thesis becomes very difficult and

sometimes impossible. Therefore, for these kinds of systems, multiple perspectives and theories may be accepted as possible realities, and this is a post-normal attitude. Hence, for systems of lower levels of complexity, the dialectic dialogue is relatively straightforward and Hegelian, but for higher levels of complexity, a more post-normal attitude must be taken.

The tactical level operators need to facilitate or carry out the dialectic dialogue involving the relevant actors and need to map out disagreements as well as which mental models that these actors rely on. It may also be useful to keep track of whether such mental models and theories may be disproved or proven.

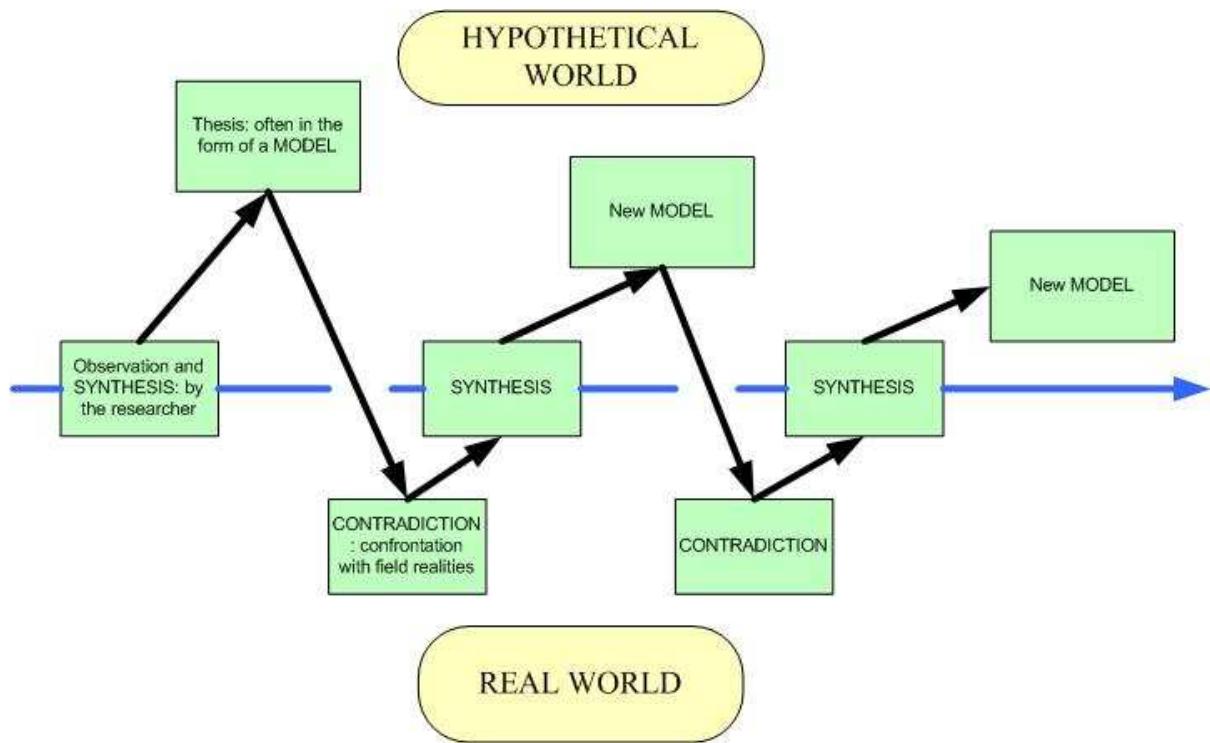


Figure 8-5: Dialectic progression of thesis, contradiction and synthesis

Notes: This diagram shows the progression of learning and the asymptotic convergence of hypothetical models towards being a more accurate representation of the real world. What does not come out of this diagram is the circular nature of this learning process, which becomes evident if the cycle of learning is represented by only its three core mechanisms: modelling, synthesis and contradiction. Suffice to say that this process is a cyclical learning process involving three key mechanisms, and where the goal is that hypothetical models converge towards being accurate representations of the real world.

The following methods are available for supporting dialogue, ranked by increasing difficulty of facilitation:

1. Fishbowl (Smith *et al.* 2003)
2. Spatial mental maps (HarmoniCOP 2005)
3. Delphi consultation (Okoli and Pawlowski 2004; Dick 2002a, c; Linstone and Turoff 2002)
4. Group model building (HarmoniCOP 2005; Dray *et al.* 2006a, 2006b, 2007)
5. Role playing games (Barreteau *et al.* 2001; HarmoniCOP 2005)

8.4.10 Adaptive governance

In Figure 8-3 an Adaptive governance cycle has been embedded in the process via the Implementation and monitoring -> Systems knowledge and social learning -> Assessments -> Project design -> Project submit -> Project approval -> Implementation and monitoring. Together with responsible water utilities and government departments, the tactical level operators will manage this action-based learning cycle. Here, as shown in Figure 8-6, projects are viewed as experiments or probes, and the system response is monitored in order to improve understanding. This in turn feeds back into the project design and assessment processes via the social learning cycle and its systems representation and deliberations.

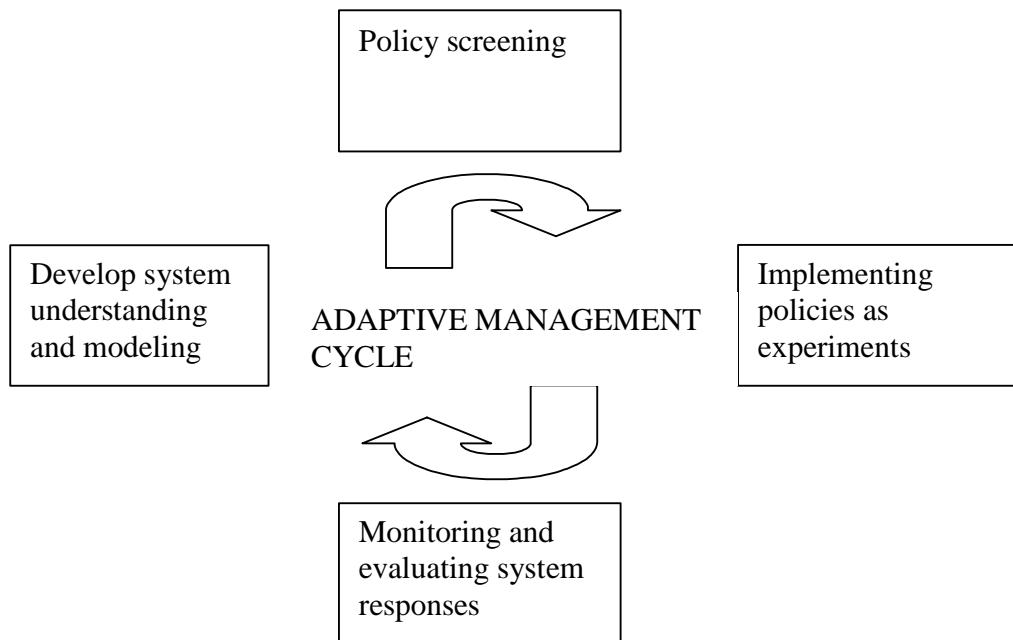


Figure 8-6: Adaptive management cycle

Note: Adapted from Jakeman *et al.* 2007.

8.4.11 Regulation

As identified in previous small town water management frameworks (Pilgrim *et al.* 2004 and UN-HABITAT 2006), regulation is a critical element of successful small town water management, because it helps to enforce roles, improves information and supports transparency.

This is also the case in our framework, where the regulatory body would be responsible for:

- Independent, and publically available assessment of the role compliance of various actors such as the Water Service Provider, the Tactical level operators and the Strategic level management board;
- Assessment of the system performance against the goals that have been set at the Strategic level;
- Assessing the need for changing the institutional structure, rules and regulations, and to submit such suggestions to the Political level for approval.

The regulatory body needs to be independent, and it is noted that it is critical that the regulatory body would not only be responsible for monitoring and assessing the above, but that they also have the power to provide remedial measures when standards are not being met, or when the role compliance is inadequate.

The extent to which the regulatory mechanisms are delegated to various departments is up for discussion, as it is recognised that it has to operate within a severely resource constrained environment. However, a word of warning is that it is of highest importance that there is efficient regulation, and that delegating should not mean a drop in the quality or a reduction in the independence or transparency of the regulation. Another option is that external experts may take the role of independent assessors.

8.5 Prerequisites

The framework that has been described requires a certain capacity to allow for its implementation. There are different ways that this capacity can be generated, but it is likely that this capacity would have certain features and these are further described in the following. In practice, a number of institutional structures doing the following would be required to allow the framework (section 8.4) to be implemented:

- Making the necessary legislative and regulatory changes: without such changes, the tactical and adaptive level actors would not have the legitimacy and support to effectively operate;
- Setting up an inter-departmental and multi-stakeholder board for managing approval and funding processes: or at least some type of forum with wide participation for deliberation and discussion that is open and transparent, and which has adequate influence over management and policy;
- Creating a government department (suggested as the Office for Adaptive Water Management), responsible for facilitating project conceptions, project design, assessments and social learning processes: or at least some method for making staffing resources with adequate skills and status available;

- Creating the appropriate tools necessary for capturing systems representations and for undertaking assessments and these do not have to be computational models but may also be maps, diagrams, processes or tables;
- Creating the capacity for facilitating the participatory design processes and the social learning processes which would be a crucial element to ensure the efficiency of deliberation and dialogue which is a key component in the social learning process.

These tasks need to be done in acknowledgment of limited staff resources and finances.

8.5.1 Strategic level

The strategic management board would be similar to the suggestions for a National Water and Sanitation Committee (White 2006a; Ministry of Public Works and Utilities 2007) as was described in chapter 5, and would have wide representation including that from government departments, the water utility, water management experts, funding agencies, politicians and civil society (NGOs, community representatives and similar).

Such a forum will support the decision making process and would help promote the quality of proposals that reach government. It would also allow both external stakeholders (such as funding agencies), as well as the community to have a voice in the decision making process, hence increasing the level of community participation in line with international guidelines.

Unfortunately, in the case study location Tarawa, previous attempts at establishing such a board have been relatively unsuccessful due to difficulties in getting adequate participation from departments and staff member and problems with inter-departmental and inter-personal conflicts. The problematic issue about who ought to lead the board has also been a stumbling block.

Therefore the following suggestions are made to allow such a strategic management board to be implemented:

- Get an external moderator who will facilitate meetings; and who will use a silent ratings of ‘best contributions’ from the participants within each meeting; and then allocate these to each participant in a cumulative table; the moderator is not rated;
- Select a moderator for the next meeting on the basis of random chance, but weighted on the basis of the cumulative ratings of each participant for the last six months – i.e. a person who made more valuable contributions has a higher chance of being a moderator;
- Make it clear that repeatedly being a moderator within these meetings, and getting high cumulative ratings, will be a critical factor in job applications for senior positions within the water sector. Other privileges may also be linked to high cumulative ratings.

This system is inspired by similar monitoring schemes in online communities (see Johnson 2001: 152-162), and has been found to allow leaders to emerge in a natural fashion. It discourages abuse of the facilitation or moderator role as well as promoting high quality contributions. It also provides a fairer means of distributing the moderator role in an organic fashion which hopefully does not polarise the various participants.

8.5.2 Adaptive and tactical level

The current adaptive and tactical capacity in the Tarawa water system runs with a small number of senior staff members who have to carry out operational, tactical and strategic duties within the same role. This has created unrealistic workloads, and it is our impression that the tactical duties are often under-prioritised. It could be argued that this is one of the reasons for the less than adequate outcomes of many projects. It is therefore argued that there is a need for a special unit, the Office for Adaptive Water Management (OAWM) that would operate purely at the tactical adaptive level, although it would interact with the local and operational levels, and would have a representative at the Strategic management board.

To allow the OAWM to efficiently carry out its roles of facilitation, assessment and participatory design, it also requires compliance from a number of stakeholders as well as powers:

- To demand the access to, and active attendance of key stakeholders at certain meetings and workshops – non-attendance would be reported to the regulator;
- The ability to block project implementations when the evaluated risk of failure exceeds a pre-defined level;
- The ability to block project implementations when they are assessed as non-feasible in terms of ethical or legal requirements;
- The access to interview any key stakeholders that are perceived as critical in terms of a project's assessments or design.

The OAWM would provide the foundation of information collection, knowledge management and skills development required to enable systems representation, assessments, social learning and participatory design. The key required skills bases are: 1) facilitation, 2) IT and knowledge management, and 3) systems analysis including risk assessment.

8.5.3 Performance monitoring

A critical issue in my framework is the ability to monitor performance, which has been identified in the interviews and historical review to be of utmost importance. The performance has to be linked to measurements that are realistic. For example, in terms of water safety, only very basic water quality testing facilities are available, meaning that performance measurements have to rely on proxies. Such proxies may be related to incidences of water borne disease.

If this is the case, the limited facilities for water quality testing can then be utilised for investigative purposes in order to explore and understand sources of water contamination. Such investigations however also need to be prioritised, and at least one staff member ought to have as his sole responsibility the exploration of sources of water contamination. This may be a

rolling position that is supported by external funding agencies, and the results of these investigations ought to feed directly into the decision making processes by the strategic management board. This could ideally be achieved by letting this same person have a role in the strategic management board.

Another concern about the current measurements of performance is that they are often ad hoc and highly unreliable. This problem may however be as much due to a lack of regulation and enforcement of role compliance, as it is due to lack of capacity. The quality of monitoring is hence an area that needs to be monitored and regulated per se.

Furthermore, it is also recommended that capacity for testing and measurements ought to be sought from outsiders, such as at the University of the South Pacific which has a campus in South Tarawa. It is clear however that there is no room for duplicating efforts in terms of laboratory and testing capacity, but it should be centralised into a single location.

8.5.4 Turning weakness into strength

The key weakness of small towns is the lack of financial and staffing resources. It is argued however that this weakness is related to attempts to impose large scale engineering solutions and management approaches that rely on centralised control. The problem is of course that whilst the management capacity is reduced, the management problem is often more difficult due to a higher level of uncertainty, which it is hypothesised comes from Complex and Adaptive features of the system.

I argue that it is prudent in this type of situation to loosen the control, and instead to manage in an adaptive fashion, in particular given that perfect information will very rarely be available. Adaptive management may not be appropriate in large systems because of the onerous measurement task, however in a situation such as that in Tarawa, a staff member may go out in the morning and return in the afternoon with sufficient observations, judgments and measurements in order to inform decision making. If the observations and measurement also come from the community, this may further improve the adaptive management abilities. The

water utility operators may also create strategic alliances with community groups that will help them in collecting sufficient information.

If those very few staff members that are skilled in systems analysis and management are able to distance themselves from the day to day operation, thereby freeing up a lot of their time and effort, they can then focus on the more strategic and adaptive management tasks.

In this way, it is possible to turn the weakness of the smaller scale to strength as it allows for adaptive management; which has been recognised as prudent for socio-technical and socio-ecological systems, within the resilience discourse (Folke *et al.* 2003), in Natural Resource Management (Lynam *et al.* 2002), within integrated water management (Geldof 2005), and indirectly via the concept of adaptive capacity by the International Panel on Climate Change which has been formulated as a key strategy for coping with climate change (IPCC 2008).

8.6 Discussion chapter summary

In this chapter, the results of this study have been explored. Observations and model based inferences have been laid out according to a number of different themes. Issues of complexity have been discussed in terms of the implications for water management. Study outputs in terms of models and analysis tools have been discussed in terms of their potential usefulness. A framework has been defined that takes constraints, complexity and local circumstances into account, focussing particularly on the improvements of adaptive and tactical capacity.

This chapter hence addresses the goals of the study in terms of discussing how it provides description and causal explanations. It also addresses the secondary goal of the study which is to develop a framework for planning and decision making in water management in the local context. It also discusses the extent to which key study outputs (i.e. models) may be useful to local stakeholders.

Chapter 9: Conclusions

This final chapter provides the conclusions of this study – a study which has generated understanding, but most importantly will hopefully have discovered constructive paths forward for water managers in the context of providing small town water services.

This thesis addresses the problems of towns in Pacific Island Countries and the aim is to provide description and causal explanations of the complex dynamics and difficulties in these locations with the subsequent aim to formulate managers and policy-makers with recommendations that recognize local constraints and opportunities to best practice management which aim to promote participation, encourage flexible realizations and rely upon financial prudence. A key recommendation that the thesis aims to deliver is the development a framework that bridges theory and practice in the target location, as a special case of small town urban water management in PICs.

The outcomes of this study can be viewed as causal explanations that allow recommendations and guidelines for sense-making and management in a complex and adaptive situation i.e. that of small town water governance in under-resourced contexts in the PICs, rather than traditional scientific facts and rules. Methods and tools have been developed that are useful for developing understanding of the small town water servicing context, and this has been done with the grounding within a case study situation. The methodology of the study has been designed in acknowledgment that small town water management is carried out in a context which is highly dynamic and which involves complex socio-technical interactions, and for which persistent and consistent system behaviour is rare and unusual. This has warranted the adoption of a Complex Adaptive Systems perspective and a post-modern mindset (for more description of these perspectives see chapters 3 and 4); which acknowledges that the researcher is an actor like any

other and that as such models and theories are merely constructs to be used to provide causal explanations and system projections in a social setting to support collective learning.

Supporting such causal explanations, this study has been carried out with many of the steps used in traditional science, involving data gathering (literature review and knowledge elicitation), followed by statement of a set of hypotheses (by developing models such as an Agent Based Model and Bayesian Networks), and finally to make inferences on the basis of these models. As such, this process can be seen as part of an inductive theory building exercise in the spirit of Locke (2007), where a great deal of creativity and synthesis is a legitimate part of the research process.

The formal testing of this theory is via the application in a real world setting, and a successful implementation would mean that the theory is confirmed. The problem is that in a Complex Adaptive Systems setting, such causal explanations may or may not be temporary, and are difficult to confirm or validate. One way to confirm the explanations is to evaluate the successful use of the recommendations and suggested framework. However, an unsuccessful implementation of the framework does not mean that the theory is not useful, but should be seen as part of an on-going action based learning process. The lessons ought hence to be used to further improve the framework; in a process of progressive correction.

9.1 Contributions to knowledge

This study has been undertaken as an inductive theory building exercise in the spirit of Locke (2007), with the main contribution to knowledge being causal explanations of system properties providing the basis for a framework for urban water management in Tarawa, as representing a kind of worst case of small and resource constrained town in a PIC. The framework (described in chapter 8) has been developed on the basis of experiences and knowledge gained via a case study in Tarawa (see chapters 5 and 6) and modelling exercises (chapter 7) which has helped formalizing this knowledge and allowing more general inferences to be made.

Secondly, this study has also contributed to an increased knowledge about conditions in this particular location (chapters 5 and 6); which has contributed via the generation of rich and concrete context-dependent knowledge (chapter 6). Whilst this is far from the first study of water management in Tarawa, it has hopefully helped provide a more complete picture, allowing for better understanding a very complex situation. It can hence be perceived as better establishing the range of dimensions of a single data point in the bigger study of urban water management.

Thirdly this study has been undertaken using a number of tools from the Complex Systems Science toolbox, such as ABM and BNs (see chapter 7), and integrating the various study components in line with the Cynefin framework (Kurtz and Snowden 2003), in the context of urban water management. The style of their application in the context is novel and has not previously been attempted, and therefore contributes methodologically in terms of their specification as well as in terms of model inferences (see chapter 7). This also contributes methodologically to the emerging science area of how to analyse and understand socio-technical systems.

Fourthly, it has been shown that the CAS perspective is indeed useful for understanding urban water systems, or at least in the particular context of small and under-developed towns. This is in contrast with existing approaches in the urban water field where the best practice, with only very few exceptions, has so far been to apply systems engineering approaches. As such, this study is challenging some of the existing thinking in a field which in the developed world is currently undergoing transition to be able to cope with increasing levels of uncertainty and increasing demands from the community. There are many indications that urban water management in developing contexts tends to be considerably more complex and adaptive.

Finally, the approach which has so far gained the most traction in the urban water field, is that of applying Bayesian Networks for the purpose of risk assessment and this is perceived as very novel and useful not only in the context of small town urban water management, but also in the wider context of urban water management in a general sense (chapter 8). This provides a

practical and holistic risk assessment framework, which complements other emerging approaches such as Multi-Criteria Decision Assessments, Life Cycle Assessments and Triple Bottom Line analysis; all of which do not adequately assess uncertainty aspects, and which are typically inadequate in addressing social and institutional issues.

9.1.1 Framework for small town water management

It has been seen in a case study in Tarawa, Kiribati, (chapters 5 and 6) how funding constraints, staffing constraints, water resource constraints and social complexity have combined to create a difficult situation, with very high rates of water related health problems, severe damage to freshwater sources, and inadequate service provision to most of the community. This is confirming the currently accepted wisdom that the context of small towns is problematic in terms of urban water management (Pilgrim *et al.* 2004; UN-HABITAT 2006). Whilst aspirational guidelines have previously been developed for this context (UN-HABITAT 2006), there is no operational framework for describing how such aspirations can be practically realised. This study has attempted to develop such a framework; albeit specifically designed for a specific location in the PICs, Tarawa.

In chapter 8, this style of framework for adaptive urban water management is described. It has been developed on the basis of taking a Complex and Adaptive Systems perspective, which has among other things depended on viewing the system from a number of different angles. This has proven to be fruitful as it has highlighted aspects contributing to the complexity and uncertainty of the system; and in light of this has allowed us to identify a number of deficiencies in the current management approach.

In particular, this relates to addressing the issue of repeated failure of interventions, which it is argued is due to deficient learning and adaptive management capability where interventions would be assessed before they are approved and implemented, and where lessons are learnt on the basis of previous experiences. In the current management approach, this is only done in an ad hoc manner.

Making a more adaptive management framework difficult, there are deficiencies in the information that is available for monitoring performance, understanding the system and to assess proposed interventions, but it is argued that at this scale weakness can be turned into strength by relying on stakeholder and community observations; something that would be considerably more challenging at a larger scale. In this way, small towns are able to cope with the high level of uncertainty and complexity that they often have to contend with, but at the same time they can operate within the staff and financial resources limits that are available. Operationally, it is suggested that this type of information can be incorporated into the method that has been developed for Risk analysis on the basis of Bayesian Networks.

However there are also deficiencies at the strategic level where inadequate interactions between all stakeholders mean that the water system is essentially operated on the basis of engineering performance rather than using a range of more appropriate measures such as including health and environmental performance, or socio-cultural suitability of the delivery system. Therefore, at this level it is suggested to have more efficient dialogue between relevant stakeholders, and to adopt a more appropriate performance monitoring system, which would also be linked to the adaptive management framework. This would mean a considerable shift in the management mindset towards a more inclusive management approach, that would hopefully also generate more goodwill and trust with the community; an important concern which has been discussed many times by stakeholders.

It is noted however that the framework that is laid out in chapter 8 can in fact be seen as a generic framework for strategic and adaptive management of complex and adaptive socio-technical systems. It is hence not necessarily limited to the context of urban water management, as the key elements of the framework are:

- An adaptive learning cycle facilitated via an ongoing update of knowledge and systems representations;
- A sequence of filters to evaluate the value and the risk space;

- Incorporation of participant knowledge and observations.

As such, this framework may in fact be the starting point in the search for a more generic approach to managing complex and adaptive socio-technical systems.

9.1.2 Knowledge base for understanding the context

It has been acknowledged that the context of small towns is important both in terms of the growing proportion of the world population that lives in these circumstances, but also in terms of the lack of an appropriate management framework for water service delivery. However, there are also very few case studies in the literature which have focussed on these circumstances, and the case studies that do exist are mostly in the developed world. This is maybe not surprising given that most academics and professionals focus on their own territory first, and most development professionals focus primarily on rural issues.

It is therefore not surprising that despite growing focus on small towns in the development sector such as in the recent UN-HABITAT report (2006), the understanding is mostly theoretical. It is argued that to address this dilemma for small towns, there is a need to develop a more grounded understanding of the issues in small towns, and this can only be achieved via case studies. Tarawa in the Republic of Kiribati was chosen as a case study in this thesis, partly because it had already been the target of a handful of studies. However, there were still significant gaps in the understanding, primarily relating to aspects of water service delivery.

This gap in the understanding has been addressed in this thesis through literature review and via interviews and discussions with professionals. This process has allowed a thorough and holistic review of the urban water system, in place of what was previously available, which was a range of assessments of specific aspects of the system. This is the main contribution of pulling together all aspects into a holistic whole; allowing for more integrated water resource management in the urban setting and considering behavioural and social aspects in the planning process. Other outcomes of this case study are the model representations of the system, or in other words, the Agent Based Model based on UML diagrams, and the influence diagrams for the various management strategies, which have served as input into the BNs. These provide a

basis for describing these systems in a way which is communicable to a range of actors and can support the co-learning process of the actors that are involved.

9.1.3 Application of an Agent Based Model

Any urban water system is a socio-technical system by nature, and as such is prone to dynamic interactions between the fast process of human exchanges, slowly changing technical systems, and the cycles and flows of natural systems. For example, in the case study context, human interactions of importance relate to water use behaviour of individual households or to the behaviour of those community members who are landowners on the water reserves, and which may have a considerable impact on the pollution of the main water supply for the town. Similarly, technical system features that are changeable relate to different levels of leakage, or the various possible configurations of water distribution and allocation. The main natural systems of importance are the freshwater lenses on which the town relies for its water supply. All these systems are to some extent understood in isolation, but only a handful of experts have any grasp of the dynamics of the system, with all the interactions taken into account. And even these experts tend to use history as a basis for inferences, rather than a rigorous systems understanding. Unfortunately, in the case of complex systems interactions, history is often poor guidance when attempting to understand future performance.

In attempting to address such concerns, an Agent Based Model has been developed that incorporates the most pertinent aspects in a meaningful manner. The model formulation is based on a range of interviews and discussion with stakeholders, as well as a literature review. The formulation of the model has been done using Unified Modelling Language diagrams which in turn have been assessed by stakeholders. Such diagrams have subsequently been used in order to create a software representation of the system, using the Cormas modelling platform. This model has subsequently been published online, <http://cormas.cirad.fr/en/applica/tarawaWaterScape.htm>; and it has hence contributed to this community as a real-world application of the Cormas software system.

The model has also been used to provide causal explanations of the system, and to discuss management strategies and systems aspects with local stakeholders. It has been found that UML diagrams are useful for supporting this, as are the Agent Based Models. Whilst this conclusion seems valid with relatively well-educated professionals in the water sector in Tarawa, little has however been explored in terms of the usefulness of this type of engagement with other stakeholders. The aspect that is particularly highlighted when discussing this type of model is human behaviour, which is often considered too difficult in many other contexts. Another aspect is that this type of model can facilitate the discussion of diverse and distributed outcomes of management strategies to different community segments.

To summarise, this ABM development has contributed to knowledge via the construction of what is perceived to be a valid representation of a small town urban water system, via developing a real-world application based on the Cormas software platform, and via better understanding how this type of modelling can facilitate discussion with local stakeholders within the particular context.

9.1.4 Integration Approach

From a methodological point of view, a novel integration approach has been used for understanding the context in Tarawa. Whilst initial inspiration was found in the ComMod approach (as per Barreteau 2003a) which had already been applied in the case study location, this approach was not considered completely appropriate, as it is more focussed on collective action. Instead, principles based on the Cynefin framework (Kurtz and Snowden 2003) were used to develop a research process on the basis of 1) historical review, 2) case study, 3) understanding dynamic interactions, and 4) understanding cause-and-effect relationships; but with iterative stakeholder assessment of systems representations.

In this way, the system has been viewed from a number of different angles and perspectives, and whilst no single perspective provides the full picture, as a total a more complete picture emerges. However, it is acknowledged that this research process is not as interactive with

stakeholders as that of the ComMod approach, but the process does allow for the integration of elicited stakeholder knowledge.

The output of the process is also geared towards the learning of the individual researcher, allowing him/her to become immersed in the specific issues at hand, and this makes the process particularly suitable for Inductive theory building (Locke 2007), where the creative process of the researcher on the basis of amassed knowledge and wisdom is critical for the formulation of a successful theory.

9.2 Limitations of the research

The aim of this research has been to develop a framework for the management of small town water systems in PICs that are subject to resource constrained environments. A framework has been developed and as such this research has been successful. Whether or not the framework is truly useful and practical to local water managers remains to be evaluated, and the implementation of the framework is outside the scope of an academic study. The reason why it is outside the scope of the study is that it would require political buy-in and a considerable change in the way that planning is done and key decisions are being made. With likely institutional inertia and ingrained power structures, this can not be achieved as part of a study but would be part of institutional reform.

Furthermore, the following aspects were limited in this study due to constraints:

- The interviews on which the case study review is based (chapter 6) could have been formally transcribed and analysed as per knowledge engineering practices that have been previously applied by Dray and colleagues (2006b; 2007), or Polhill and Zervogel (2006). This would have made the conclusions less subjective and reliant on the observers' skills.
- Within the Agent Based Model (chapter 7), the model for water use behaviour could have been based on knowledge elicitation and knowledge engineering to define the range of mental models employed by the household water users, rather than using a theoretical model (the Consumat model described by Janssen and Jager 1999).

- Whilst this study has focused on just the single case study, it would have been useful to have at least two case studies in order to explore, compare and contrast, or even to identify statistically significant relationships between key variables (as per comparative studies but this would require a larger sample) by estimating a linear model where a response variable is a function of independent covariates, but this was not feasible due to constraints on time and finances.
- Whilst the Agent Based Model was assessed by local stakeholders and experts, this was not done with the Bayesian Networks. This was because the Bayesian Network models were developed after the final field study trip. Stakeholder assessment of the BN models may have helped to make them more grounded and accepted by local water managers.
- Further validation and sensitivity analysis of the Agent Based Model would model results to be more robust, but this has not been done as rigorously as it could have been, due to limitations on time.

In particular, constraints on time and other resources constraints have led to a greater level of subjectivity in the case study assessment and in the model development. This has however been accepted on the basis that this research is one of inductive theory building in order to formulate a framework, rather than one to test a hypothesis.

9.3 Limitations of the framework

The framework of chapter 8 has been developed for Tarawa, Kiribati, as an example of a small town in a developing nation, specifically PIC. Specifically, it has been developed to allow for planning within a CAS in circumstances where most resources are constrained. This is the type of situation where adequate information to allow for the development and assessment of basic management strategies is unavailable, and one instead needs to be adaptive and to rely on up-to-date and current observations and judgments by a range of participants in the system.

The new framework is also designed to be able to deal with situations where, due to the uncertainty and strong context dependency in the system, risk of failure in strategies is tangible

but difficult to evaluate for any given strategy. In other words, the framework is suitable for circumstances where:

- The system has high levels of uncertainty, presumably due to CAS features although this is difficult to establish in real life;
- Certain and adequate information is hard to come by;
- Management strategies are risky, both in terms of unintended outcomes, but also in terms of possible complete failures of strategies.

As such, whilst the framework has its main use in small town water governance, parts of the framework is also useful in other contexts. For example, it is currently being explored how the BNs can be used to assess the inherent risk in the application of novel technologies for water service delivery in urban Australia. This is a developed and highly engineered situation, but where the risk comes from the fact that relatively new technologies have to be implemented within a community which is not used to this style of service delivery, and due to the fact that the applicability of the technology is not yet fully understood in all the situations that are encountered. Hence, it appears that even in large scale developed situations, parts of the framework may be useful in those situations where there are CAS features. Such features can appear for many different reasons, including pending climate change, changing community expectations, introduction of new service delivery methods, socio-culturally complex situations, or simply in situations when there are serious resource constraints.

9.4 Recommendations for future research

On the basis of this research, via case study (chapter 5) and further exploring this context via knowledge elicitation (chapter 6) and modelling (chapter 7); and in combination with the Delphi survey (chapter 6) representing professionals in a wider region, sufficient understanding has been developed to allow the specification of a new water governance framework for small towns (see Chapter 8). Promoting this framework is part of future activities, and via

implementations of the framework in small towns the framework can be improved on the basis of action based learning.

Related to this, there are three distinct areas of future research:

- Implementation of the small town water governance framework and action based learning;
- Tangential and more fundamental research areas that have been identified through this study;
- Further research on the Tarawa water system.

9.4.1 Implementation of governance framework

Implementing the small town water governance framework in Tarawa or in any other location would obviously need considerable stakeholder engagement, political process and validation and assessment to get it accepted by local stakeholders, politicians, development agencies, or international donors. To support implementation there would need to be some initial trials. Training material would also need to be developed, such as computer games and instruction manuals. This is not a feasible inclusion in a PhD study.

9.4.2 Tangential research areas

This research has also unravelled some interesting tangential research areas. Examples of such areas are described in the following.

9.4.2.1 Understanding how water users select between multiple water sources

It was found in Tarawa that one of the critical points in terms of health impacts is the choices that householders make when selecting which water source to use for which purpose. As far as is known there has been no research on this issue around the world, and the decision appears not to be completely straightforward. In the developed world, there is typically only one source of water, but in Tarawa, there are often three or even four different sources to use; each with its particular characteristics.

9.4.2.2 Changing the mindset of water utility professionals

In a situation such as that in Tarawa it seems almost impossible to get anything to work on your own, and you need to work and cooperate with your fellow community members. This is also valid for the water utility; however their attitude is mostly authoritarian in that they tend to operate by telling the community what they want and what to expect. This is an attitudinal issue which appears to be based on norms and culture rooted in colonial administrations. There is a considerable need for research into how the mindset of such administrations can change to be more inclusive and cooperative with the community.

However, this issue is not specific to Tarawa, but there is an increasing need for a change of mindset of water utility professionals around the world, and for example the Water Research Foundation have recently had a call for research in this area.

9.4.2.3 Application of the BNs based for risk assessment in developed contexts

There appears to be a growing need for risk assessment in the urban water sector also in the large scale developed contexts and the Bayesian Network methodology seems perfectly suitable for this. For example this approach is already being trialled, in the case of Greenfield developments in urban Melbourne, in order to include more holistically all aspects of a new development, including social and institutional aspects.

9.4.2.4 Cross validation and comparison between BNs and ComMod

When applying the Bayesian Network methodology to assess the strategies for reserves extension, it was found that the results were very much in line with the outcomes from the AtollGame exercise. This begs the question whether Bayesian Networks, accompanied with the appropriate knowledge elicitation, is as good at finding highly successful cooperative strategies, as is Companion Modelling; although the BNs may not be as appropriate for engaging stakeholders. Using the two methods for cross-validation is another potential application, to help with validation of the models.

9.4.3 Further research on the Tarawa water system

There are still aspects of the Tarawa urban water system which have not been explored and which would warrant further study, such as for example those described in the following sections.

9.4.3.1 Human resources and organisational incentives

A theme that was commonly mentioned during the field study and by stakeholders was that of incentives for various stakeholders to participate in the process and to effectively fulfil their roles something which is critical for success. Organisationally it appears that there is no full consideration of human resources issues within the local organisations and it may be a suitable research topic for someone studying Human Resource Management to do a case study on Tarawa, in order to provide some guidance about what could be changed. This would probably be a difficult task for someone who does not fully understand the I-Kiribati culture, but may be suitable for someone who is somewhat familiar at least with the culture and mentality of the inhabitants of the South Pacific Islands.

9.4.3.2 Modelling the interactions between lagoon, pollution and the economy

The pollution of the lagoon has not been considered in the current study, and it has been suggested that its dynamics could be analysed by employing a Systems Dynamics approach along the lines of the approach by Proust and colleagues (2007) and that it is possible that this would highlight the longer term inter-play between the pollution of the lagoon and the economic potential for the town, as this pollution considerably hinders any tourism or fishing in the lagoon (or perhaps more importantly the health risks of consuming fish and shell fish from the lagoon). In other words, this would highlight a significant externality relating to the pollution of water resources. In other words, this exercise would focus particularly on the perceived positive feedback loop between these key variables. It is worth mentioning that there is high level interest from Australia (the Australian High Commission in Tarawa) in cleaning up the lagoon in Tarawa.

9.4.3.3 Historical analysis of villages and family groups in Tarawa

Whilst it is not usually mentioned explicitly by individuals in Tarawa, there appears to be various underlying interests, alliances and conflicts between people, which outsiders (*I-Matangs*) tend to be unaware of. Some argue that many of these alliances and conflicts are based on historical events and traditional rivalries between villages and family groups. Providing some insights into this confusing world of internal *I-Kiribati* politics and history could provide very useful understanding to those outsiders and professionals that undertake work in Tarawa and in Kiribati, and could also serve as a case study for development workers in a more general sense. This type of study is likely to be carried out by an ethnographer or anthropologist.

9.5 Rapid improvements of the water system in Tarawa

Whilst the main purpose of this study has not been focussed on Tarawa per se, it would be irresponsible after this considerable effort not to provide an opinion about how the situation could be improved in the short term. What is suggested here is simply a number of management interventions that could be proposed within the proposed management framework:

- Better training for plumbers: it was found that a vast majority of plumbers do not have adequate skills and would not pass the normal trade skills tests. However, it was also found that because most of the plumbers do not speak English, they are not eligible or able to take part in training by outsiders. The impacts of having less than adequate plumbing skills are difficult to assess, but it can be assumed that it would lead to high levels of leakage, higher levels of pollution and generally more faulty infrastructure. Increasing the plumbing skill levels would be an easy and efficient way to make the system run smoother.
- Introduce above ground pipes: to reduce leakage and the number of illegal connections, selected pipe sections could be moved to be above ground. This would be relatively cost-efficient because of the relative short length of pipe in Tarawa. An above ground pipe would help ensure that there is no leakage and that there are no illegal connections for this

section. This is important because a considerable amount of water leaks from the system, and it is believed that much of this has to do with illegal connections. Illegal connections serve the purpose of service to a larger number of households, but since there is poor enforcement of payments, there seems to be very little reason for having illegal connections, which usually would be attached with very poor plumbing practices. Illegal connections also set a bad example for the rest of the community.

- Introduce and enforce rain-tank regulation: many rain-tanks are in poor condition and some have poor water quality. This is a problem which needs to be addressed, and it seems it can't be adequately addressed at the household level. Therefore, there is a need for a rain-tank inspection and maintenance services and the financing of this service needs to be identified. This could potentially be a private business, assuming that there is some type of certification, or it could be managed by the PUB.

The main issue in Tarawa is to increase the overall supply volumes to an ever-growing population. Arguably the only available and feasible option is increased groundwater extraction, by utilizing freshwater lenses in North Tarawa. Hence, the issues concerning protection from pollution and dealing with landowners will not go away, and based on the BN analysis there needs to be greater engagement with landowners to identify practical win-win solutions.

Overall, it is my opinion that water issues are not being given sufficient priority in Tarawa. Given the real threat to the water supply, the difficulties in enabling growth, the severe impacts on community health, the pollution of the lagoon, and the threat of a cholera outbreak, it is hard to perceive a more important issue. It is my opinion that whilst water issues have been given a high priority by the community this has not fully permeated into the political sphere.

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