TECHNICAL REPORT: FINAL

SEPTEMBER 2014

Pacific Adaptation (Costs and Benefits) Scenarios

Water Security in Tuvalu

Australian Aid

Australian Government
Department of the Environment

TUVALU MO TE ATUA

PACCSAP

The Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) programme is building the capacity of Pacific Island Countries to manage future climate risks. While there is widespread concern about climate change across Pacific Island Countries, there are still significant gaps in understanding the likely timing, nature and extent of impacts and the types of effective adaptation actions available. Economic analysis of climate change impacts and adaptation options is particularly limited. Such an analysis would assist central agencies and decision makers to make more informed development decisions given competing priorities and constrained resources.

Authors:
Peter Kinrade, Nadja Arold, Phil Pickering (Marsden Jacob Associates); Eric Rooke (Gilbert & Sutherland); Joey Manfredo (DAI)

Contact: Peter Kinrade (peter.kinrade@marsdenjacob.com.au)

Acknowledgements
The authors gratefully acknowledge the assistance and support from the Tuvalu government and regional organisations. We would like to thank the following people in particular:

- Simalua Enele, Assistant Secretary Ministry of Public Utilities and Infrastructure, for support with liaison, workshop organisation and feedback on project structure and report drafts.
- Teuleala Manuella, in-country coordinator USP, EU Global Climate Change Alliance Project, for assistance with liaison, workshop organisation and data collection.
- Petesa Finikaso, Coordinator NAPA Tuvalu, for assistance with data collection.
- Gunter Koepke, Public Works Department Water Officer, for assistance with field trips and water data provision.
- Taiane Amasone, PACC Project Manager, for assistance with field trips and data provision.
- Meelina Ailesi, Tuvalu Met Office, for the provision of rainfall data.
- Staff of the Secretariat of the Pacific Community (SPC) including Marita Manley, Ann Rios Wilks, and Dave Hepplethwaite, for background advice, data provision and review comments.
- Staff from the Ministry of Public Utilities and Infrastructure, Public Works Department, Department of Environment, Planning and Budget Department, Tuvalu Electricity Corporation, Tuvalu Met Office, IWRM Project and SPREP PACC Project, for their active participation at workshops.

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Executive summary

Introduction

The Australian Government Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) programme aims to develop the capacity of Pacific Island Countries (PICs) to manage climate risks. This 'water security' cost-benefit case study was undertaken in Tuvalu with the twin purposes of:

- increasing the capacity of decision makers, in Tuvalu and other PICs, to develop and assess the economics of water security programs - with an emphasis on strategy development in the context of climate and non-climate impacts; and
- improving understanding of the cost and benefits of options to achieve short and longer term water security in the context of climate change.

Background

Tuvalu is a Pacific Island Country comprising 9 atolls and islands. Funafuti is the most populous atoll in Tuvalu and the country's capital. Vaitupu has a substantial population and the country's largest school.

The water supplies of both islands are characterised by being highly rainfall dependent. Nearly all households in Funafuti and Vaitupu have at least one rainwater tank. Each tank typically has a capacity of 10,000 litres, with most households having more than one tank. Household water supplies are backed up by a network of community (Kaupule) and government cisterns, which provide water for community use and on a rationed basis to households when household tanks run dry. Additionally in Funafuti, there is a Government run desalination plant. Water from the plant is provided to households at a subsidised price. During dry periods demand for the desalination water outstrips supply and the water also has to be rationed. At present the desalination plant does not provide long term water security in Funafuti, since there is limited capacity in the country to maintain the plant once maintenance contracts cease in 2015. Significant contamination of groundwater in Funafuti means that it has limited potential as an alternative water supply. Vaitupu has viable supplies of groundwater for non-potable uses, but access is limited.

The 2010-2011drought in Funafuti, Vaitupu and other parts of Tuvalu caused severe strains on water supplies and hardship to households and communities. In most households in Funafuti and Vaitupu rainwater tanks were without water for 180 days or longer over the course of the year. At the height of the drought:

- water from government and community supplies was being rationed to an average of 45 litres/ household/day in Funafuti (equivalent to an average of about 6.5 litres/person);
- water from government and community supplies was being rationed to an average of 25 litres/ household/ day in Vaitupu (equivalent to an average of about 5.5 litres/person).

This situation could worsen in the future given projected population growth and possible changes in rainfall patterns associated with climate change.

Framework applied to the analysis

The framework applied to the analysis quite closely follows the process set out in the guide *Cost-Benefit Analysis for Natural Resource Management in the Pacific* (Buncle et al. 2013) – an important reference guide for decision-makers in PICs. However, the framework applied to this study and recommended for addressing water security in Tuvalu and other PICs contains elements that go further than the guide. This is because the multi-faceted nature of the water security challenges faced by Tuvalu and other PICs, including climate change, means that an integrated, strategic assessment is preferred rather than a project by project assessment.

The integrated approach comprises three main stages – 'structuring of the issue or problem', 'solution analysis' and 'managing the problem' – each of which entail a number of steps in turn. Economic analysis is applied at different steps in the solution analysis stage of the process, with cost-benefit analysis (CBA) being used for the detailed assessment of costs and benefits of options. Key data uncertainties, including uncertainties associated with climate change, are addressed in the CBA process.

Problem analysis

Problem analysis is a crucial early step in the decision making process, being used to establish the nature of the water security issues or problems to be addressed. It is important for informing development of water security objectives and options for dealing with the problem. The problem analysis for Funafuti and Vaitupu was completed through two tasks:

- a background assessment of historic and projected rainfall and current water supplies; and
- an assessment of water security problems and risks in Funafuti and Vaitupu, which was informed by a stakeholder workshop.

Key risks to water security in Funafuti and Vaitupu, identified through these tasks include:

- Insufficient water storage to meet demand during dry spells and droughts necessitates frequent and sometimes severe water rationing from community and government supplies (Funafuti and Vaitupu).
- Lack of responsibility for the maintenance of water tanks and gutters leads to reduced reliability of household and (to a lesser extent) community water supplies (Funafuti and Vaitupu).
- Population growth, combined with changing household practices and limited water demand management, leads to growth in water demand (Funafuti and, to a lesser extent Vaitupu).
- Contamination of groundwater limits access to alternative, non-rainfall dependent water supplies (Funafuti).
- Inadequate training and resources limit the reliability of desalination as an alternative water supply during dry spells (Funafuti).
- Poor water and land management practices threaten viability of groundwater as an alternative, non-rainfall dependent water supply (Vaitupu).

- Changed rainfall patterns due to global climate change leads to an increase in the frequency and/or severity of dry spells and droughts further threatening the reliability of rainfall dependent water supplies (Funafuti and Vaitupu).
- More intense storm surges, driven by increased intensity and frequency of tropical cyclones and sea level rise, could also lead to greater salt water intrusion into groundwater, salinising freshwater lenses (Vaitupu).

Objectives

A hierarchy of water security targets was compiled drawing on discussions about water security objectives, which was held with government stakeholders at a workshop in March 2014. The targets were used as the basis for identifying and assessing water security options in Funafuti and Vaitupu. The hierarchy consists of:

- An emergency target: sufficient potable water supplies to meet all households' emergency water needs (drinking and cooking) during a worst case drought - set at an average minimum of 45 litres/ household/day in Funafuti and 31 litres/ household/ day in Vaitupu (which has a smaller average household size than in Funafuti).
- A critical target: sufficient potable water supplies to meet all households' critical water needs (drinking, cooking and personal hygiene) in a worst case drought - set at an average minimum of 90 litres/ household/ day in Funafuti and 62 litres/ household/day in Vaitupu.
- A longer term target: sufficient potable and non-potable water supplies to provide households with essential water needs (drinking, cooking, personal hygiene, showering, toilet, clothes washing) during a worst case drought – set at an average of 300 litres/ household/ day in Funafuti and 205 litres/ household/day in Vaitupu.

Options and portfolios

A portfolio approach (combinations of complementary options) was used to identify and assess options against the targets. Different portfolios were assessed for each target and for each island. In summary:

- Some generic measures are considered important foundations for all portfolios and targets including implementation of the Tuvalu Water Act and associated measures including a community awareness program.
- A 'gutter maintenance and cleaning program' is the core component of portfolios designed to meet the emergency target in both Funafuti and Vaitupu.
- Additional options for meeting the critical target in both Funafuti and Vaitupu include community/government cisterns, household rainwater tanks and/or composting toilets.
- In Funafuti, two alternative portfolios were assessed for meeting the essential target: 1) comprising a mix of cistern upgrades, rainwater tanks and composting toilets; and 2) a fully functioning desalination plant.
- In Vaitupu, two alternative portfolios assessed for the longer term target focus on: 1) piping water to the villages and school from one of the groundwater sources; and 2) a mix of cistern upgrades, rainwater tanks and composting toilets.

Cost-benefit analysis

Technical assessment and key assumptions

A water supply-demand model was used to support the cost-benefit analysis. A model of this nature is critical to assessing water supply constraints given different rainfall scenarios, and to assessing additional capacity needed to meet the various water security targets. The Excel-based model developed for the case study was designed to reflect conditions in Tuvalu and other Pacific Island Countries and enable alternative options (cisterns, rainwater tanks, desalination, groundwater etc.) to be assessed in an integrated manner. A preliminary assessment was also undertaken to assess sustainable groundwater yields for Vaitupu.

Assumptions' setting was an important aspect of the analysis. Key assumptions that had to be tested include:

- household water demand in drought and non-drought conditions;
- availability and cost of land in Funafuti required for alternative water supply options;
- time spent by householders collecting water and the value of that time;
- health and environmental benefits of some options such as composting toilets.

Considerable time was spent with stakeholders in Tuvalu checking and rechecking these assumptions, although we note that there is still uncertainty around some of the assumptions.

Dealing with uncertainty – threshold and scenario analysis

There are two major sources of uncertainty in the analysis. The first involves the value that should be given to water provided by the options and portfolios. Given the high uncertainty attached to this value and the high cost and often inconclusive outcomes of techniques used to measure this value, a threshold approach was used to address this uncertainty. The threshold value (expressed as $/ household/ year) is the value that households will need to place on the additional water provided by a portfolio of options in order for those options to produce a net benefit overall to the community (i.e. a positive net present value - NPV).

The second major source of uncertainty is future rainfall. Rainfall projections - average rainfall and variability - are very uncertain for Tuvalu. Projections of rainfall variability, covering changes to the frequency and severity of drought, are particularly uncertain. Given this uncertainty, scenario analysis was used, with scenarios being selected so as to provide a realistic indication of the impact of droughts on water security in the future. Three scenarios are modelled:

- A standard drought scenario is modelled on the lowest 12 month rainfall in the historic record, 2010-11 in Funafuti and 1970-71 in Vaitupu.
- A worst case drought scenario is modelled at -10% of the historic low annual rainfall and assumes two consecutive years of this rainfall.
- A best case drought scenario is modelled at +10% of the historic low annual rainfall.

Results

It is important to note that the results outlined below are preliminary and that further work is required on some options and portfolios before they are incorporated into a fully developed water security strategy.

Under the standard scenario, Funafuti has adequate water supplies to meet the emergency water security target until 2021 but has insufficient supplies to meet the emergency target from 2022 onwards. It does not have sufficient water supplies to meet the critical or longer term targets even in the first year, 2014. The worst case drought scenario brings forward the constraint on achieving the emergency target by three years in Funafuti (from 2022 to 2019). The best case drought scenario on the other hand, delays to 2024 the constraint on achieving the emergency target in Funafuti. The critical and longer term targets still cannot be achieved, even in 2014, under the best case scenario there.

The emergency, critical and longer term targets cannot be achieved in Vaitupu at any time under any of the scenarios.

Assessment of portfolios through the CBA modelling and associated water supply-demand modelling suggests that there is ample scope to improve water security in Funafuti and Vaitupu in ways that will bring net benefits to the community overall. In particular it is likely that the emergency target can be achieved with a net benefit overall to the community in Funafuti ($44/household/year threshold value) given evidence that the community there values water at much greater than $44/household/year in drought situations. For example, household and government outlays for the production of desalination water in Funafuti are estimated to be about $420/household/year in a drought year. Achieving the emergency target in Vaitupu is likely to be more costly than in Funafuti ($96/household/year threshold value) but is still likely to produce a net benefit to the community given the high value the community places on the value of water in drought situations.

The critical target could also be achieved with net benefit overall in Funafuti ($101-142/household/year threshold value depending on whether borrow pits are used for cisterns) given the benefits that it will deliver, although the target will be significantly more costly in Vaitupu ($284/household/year threshold value). Again, given household and government outlays for the production of desalination water in a drought year in Funafuti, achieving the critical targets could be a reasonable objective in the short to medium term, producing net benefits overall to communities in Funafuti and Vaitupu.

Achieving the longer term target will be more costly, in both Funafuti and Vaitupu ($307/household/year and $514/household/year threshold values respectively).

Conclusions and next steps

Water security in Tuvalu

Assessment of portfolios through the CBA modelling and associated water supply-demand modelling suggests that long term water security is a realistic and desirable objective for Tuvalu (Funafuti and Vaitupu). However, which of the targets the government chooses to meet (emergency, critical or long term) will require not only a judgement about the value of each target compared with the cost, but will also need to take into account broader considerations such as funding availability and the country's other expenditure priorities.

Options aimed at improving water supply security should be underpinned by improved coordination and management of water. Effective implementation of the Water Act and associated measures, such as improved management of water at the community level (e.g. through careful monitoring and management of community and government water supplies) can help to achieve this. These measures will not necessarily deliver additional water by themselves but are likely to improve effectiveness and efficiency of other options.

A gutter maintenance program should be the foundation of all of the portfolios for achieving the emergency, critical and longer term targets. In Funafuti, a gutter maintenance program has the potential to deliver the emergency target by itself, provided the program is well designed and funding is ongoing.

Cisterns are also important components of cost effective portfolios, especially for delivering the critical and longer term targets. A key potential barrier to the installation of more cisterns in Funafuti is availability of suitable land. Preliminary analysis however, suggests that filling in Funafuti's borrow pits has the potential to provide a relatively low cost means of overcoming these land constraints, as well as providing other community benefits (e.g. health benefits). Significant potential distributional impacts will need to be addressed prior to implementing this option though.

Groundwater has the potential to be an important component of a portfolio of options for achieving the longer term target in Vaitupu. Further assessment of this option is required though, to ensure that it is technically feasible and sustainable.

Rainwater tanks are now the mainstay of household water supply in both Funafuti and Vaitupu and are likely to remain so for the foreseeable future. Relying on increased tank capacity to achieve the water security targets is subject to significant constraints however, especially land availability.

Next steps for pursuing water security in Tuvalu include:

- Implementation of the *Sustainable and Integrated Water and Sanitation Policy 2012-2021* will be enhanced by developing implementation plans for each island.
- Linkages between Government departments and agencies, non-government organisations and communities involved in the management of water in Tuvalu should be strengthened so as to achieve more effective co-ordination of water management.
- Further survey-based research on the levels and patterns of household, government and business water consumption in each of the islands in Tuvalu would be a valuable input to water security strategy development, since better understanding of water consumption can ensure investments are targeted and resources not wasted where they are not required.
- Additional work is needed to ensure a fully-fledged strategy is completed for Funafuti and Vaitupu including:
  - further assessment of the potential health, environmental and food security benefits of composting toilets, noting that the benefits of avoided contamination of lagoon waters and fish stocks were not assessed for this study;
  - further analysis of the viability of groundwater as a long term water resource in Vaitupu;
  - detailed specification of a desalination training and maintenance program to ensure that desalination can be a reliable source of water for meeting the longer term target; and

- the implementation stage of the strategy.

- Notwithstanding the need for further water security strategy development in Funafuti and Vaitupu, assessment for this study suggests that some options and portfolios warrant implementation as soon as is practically feasible. These include the gutter cleaning & maintenance program and the Water Act and associated measures.

Cost benefit analysis

A CBA of water security in Tuvalu is best undertaken in the context of developing an overall water/ drought management strategy for each island. On that point a key recommendation of the *Rapid Drought Assessment*, completed for Tuvalu in 2012 is supported, namely that a 'drought management plan/strategy should be developed at the island scale' (Sinclair et al., 2012, p.38). Based on its application to this study and its extensive application in other contexts, the framework presented here is robust and is likely to be suitable for application to other islands in Tuvalu and other PICs seeking to develop water strategies. The framework also has potential application to the development of strategies for a range of other issues including wastewater/ sanitation, solid waste management, coastal management and energy security.

Next steps for integrating CBA into government decision making include:

- The Tuvalu Government, through the Office of the Prime Minister and the Department of Planning and Budget, should seek to integrate CBA into its decision making on all major investments, policies and programs.
- CBAs should be undertaken at the strategy/planning level where possible and complemented by project level CBAs where needed or where strategic level analysis is not possible.

It is also suggested that the broad framework applied to this water security case study is suitable for assessing costs and benefits of options and for strategy development on a range of other issues including wastewater/ sanitation, solid waste management, coastal management and energy security. However, specific application of the framework will differ according to the issue to which it is applied.

1. Introduction

1.1 Study purpose

The Australian Government Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) programme aims to develop the capacity of Pacific Island Countries (PICs) to manage climate risks. While there is widespread concern about climate change across Pacific Island Countries, there are still significant gaps in understanding the likely timing, nature and extent of impacts and on the types of effective adaptation actions available. Economic and socio-economic analysis of climate change impacts and adaptation options is particularly limited and would assist central agencies and decision makers make informed development decisions given competing priorities and constrained resources.

The Pacific Adaptation (Costs and Benefits) Scenarios study aims to increase the capacity of decision makers in PICs to assess the costs and benefits of adaptation strategies. To that end, a 'water security' cost-benefit case study was undertaken in Tuvalu with the goals of:

- improving understanding of options for achieving short and longer term water security in Tuvalu;
- developing and testing a framework for assessing the costs and benefits of water security options in the context of climate change; and
- increasing the capacity of decision makers in Tuvalu to assess the economics of strategies and investments, with a focus on water security planning.

This report documents outcomes of the study as applied to the first two goals. The third goal – increasing capacity of decision makers in Tuvalu – is outlined in Appendix A.

1.2 Why Cost-Benefit Analysis?

This case study examines the use of cost benefit analysis (CBA) to assess the best course of action for achieving water security in Tuvalu considering the impacts of climate change. CBA is a valuable tool for comparing alternative options at the project, strategy or policy level. Its advantages over other assessment techniques, such as multi-criteria analysis (MCA), are:

- it uses a common unit of measure (dollars) to assess options that have a wide range of costs and benefits; and
- it can also be used to assess options with different scales and over different timeframes.

It can therefore provide an understanding of the course of action that will provide the greatest net benefit to society over time.

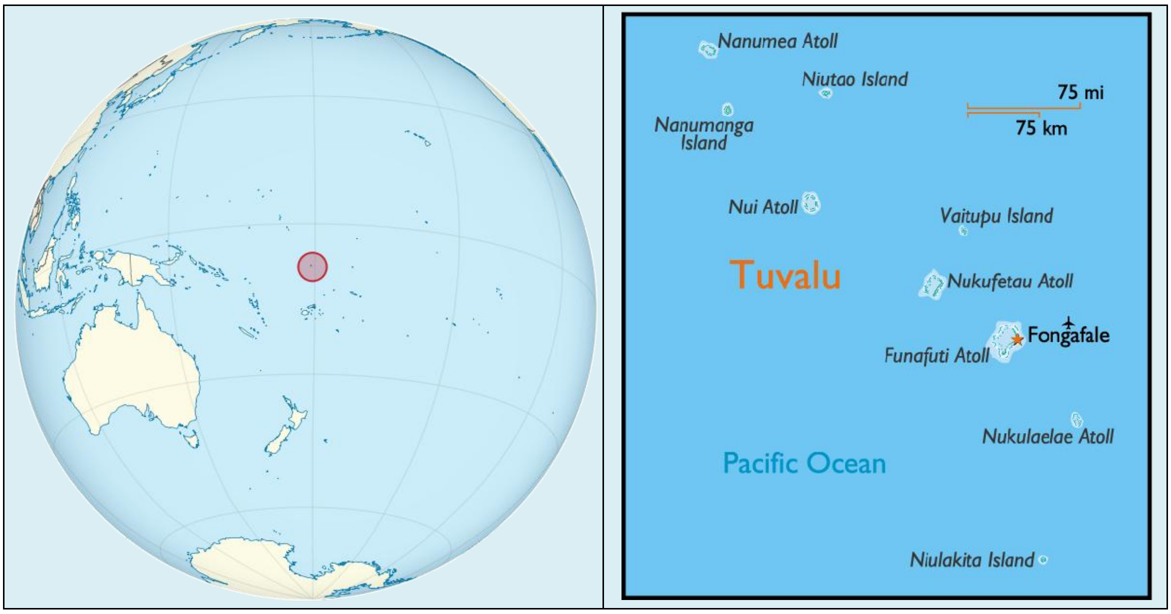
As discussed further in section 1.5, CBA can also be applied to assessing groups of complementary options that deliver different quantities of water over different timeframes (the portfolio approach). Thus it is well suited to strategy development. This contrasts to cost effectiveness assessment, a quantitative assessment technique that is well suited to assessing individual options for addressing a discrete problem, but less well suited to strategic analysis.

1.3 Tuvalu background

1.3.1 Context

Originally settled by seafaring Polynesians approximately 2,000 years ago, Tuvalu is comprised of five coral atolls and four raised limestone islands with a NW to SE orientation between 5° S and 11° S latitude and 176° E to 180° E longitude; it is situated approximately 1,100 km north of Fiji in the Pacific Ocean. A low-lying island nation, Tuvalu's maximum height above sea level is approximately 4 m (Figure 1).

Figure 1: Location of Tuvalu, showing Funafuti, Vaitupu and other atolls and islands



Tuvalu's Gross Domestic Product (GDP) is approximately US$37,500,000, while the GDP per capita is $3,350. The Tuvalu economy is driven by subsistence agriculture, lease of the ".tv" internet domain, and fishing - primarily from sales of fishing rights within its 5,128 sq km exclusive economic zone.

An estimated population of 11,200 resides across Tuvalu's nine islands. Tuvalu's average population density, 427 people/ km^2, is the second highest in the region. This number is driven by the high proportion of citizens who reside in Funafuti – estimated at 46 percent of the population (Department of Statistics, Tuvalu, 2012). Internal migration from outer islands to Funafuti is a product of lifestyle changes, concentration of employment opportunities in the capital, and dependence on imported food (Teii, 2007). Tuvalu's population is projected to increase 10 percent to 12,300 by 2030, driven primarily by higher growth rates in Funafuti (Falkland, 2011).

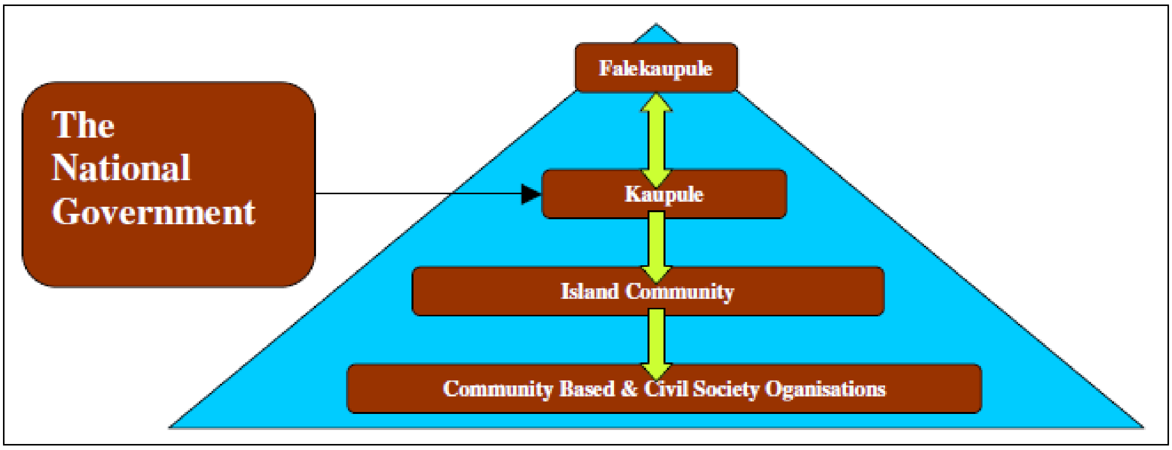
Tuvalu's largest island, Fongafale, is the seat government. While Fongafale is commonly referred to holistically as Funafuti, it is split into three main districts - Funafuti, Lofeagai, and Tekavatoetoe. Fongafale locals are the primary landowners; many lease land in Lofeagai to internal migrants from Tuvalu's outer islands; it is estimated that 74 percent of the Lofeagai's population is from outer islands (Simpson, et al., 2012).

1.3.2 Government structure

On 1 October 1978, Tuvalu gained its independence from Great Britain and established a constitutional monarchy with a national Parliament of 12 elected members, one of whom serves as Prime Minister. Tuvalu remains a Commonwealth nation; the Queen of the United Kingdom is the official Head of State. While the national government is the focal point of all national-level issues, including water security and climate change adaptation, on 12 December 1997, Parliament devolved significant authority for local island governance via the Falekaupule Act of 1997. The Act established a new island community governance system designed to promote decentralization and, by concentrating authority and development on local islands, inspire decreased internal migration to Funafuti. Community governance and island affairs are now led by two bodies within each Tuvalu island – the falekaupule and the kaupule.

As depicted in Figure 2, the falekaupule functions as an island council, the primary decision-making group in each island. The falekaupule is comprised of traditional 'elders,' who are typically men aged 50 and above. The kaupule is the executive arm of the falekaupule, charged with preparing and implementing development plans and other programming such as transportation services, maintenance of public property and infrastructure, and management of land tenure. The kaupule are overseen at the national level by the Tuvalu Ministry of Home Affairs.

Figure 2: Local island governance framework



1.3.3 Culture and lifestyle

Throughout Tuvalu, each island has one primary village. Within villages in the patriarchal society, a traditional household comprises three to four generations, with men having primary decision-making authority. The primary livelihoods in Tuvalu are subsistence farming and fishing. Traditional crops include pit-grown pulaka (swamp taro), breadfruit, coconuts and bananas. Many families also raise pigs and chickens; while chicken is used for everyday cooking, pigs are traditionally conserved for ceremonies and family events.

The primary language of Tuvalu is Tuvaluan, of the Austronesian language family; it is similar to other Polynesian languages including Samoan, Tongan and Hawaiian. While Tuvaluan is the primary language, English is widely used, particularly in Funafuti. Like other Polynesian nations, Tuvalu is a Christian nation; an estimated 90-percent of citizens are members of a local protestant church, Ekalesia Kelisiano Tuvalu (EKT) (Sioni and Paeniu, 2012).

1.3.4 Water security in Tuvalu

Islands throughout Tuvalu have a heavy reliance on rainwater harvesting for potable water, having limited alternative water resources such as surface water and fresh groundwater. This means that Tuvalu can be vulnerable to droughts. In 2010-2011 most islands in Tuvalu experienced a particularly severe drought. In the 12 months from November 2010 to October 2011 for example, Funafuti's total rainfall was only 42% of the long term average. This led to severe shortages of potable water from mid 2011 onwards. In response, the Government of Tuvalu declared a state of emergency and introduced stringent water rationing. Donor countries provided a range of assistance measures including installation of additional rainwater tanks, desalination plants and in one instance, a shipment of bottled water. A drought assessment was also initiated by the Government of Tuvalu and Secretariat of the Pacific Community (SPC) to determine the need for emergency water supplies and identify possible interventions to provide short- and longer-term solutions to ongoing water needs (Sinclair et al. 2012).

Although the drought broke in early 2012, it was apparent that a coordinated long term response to water security would be required involving the supply and management of water. Since then, a range of initiatives have been commenced, building on earlier programs and plans. These include:

- establishing a national steering committee to coordinate water and sanitation policy;
- developing a Draft National Water Policy, Draft National Water Act and building codes;
- additional water infrastructure initiatives such as the construction of new community cisterns in Funafuti through the Pacific Adaptation to Climate Change (PACC) programme; and, more recently, a water and sanitation stocktake undertaken through the SPC Water and Sanitation programme.

1.4 Study approach

Tuvalu was identified for a water security cost-benefit case study due to the Government of Tuvalu signalling interest in drawing on economic analysis to help inform decisions in the water sector, through a CBA working group.

Two islands in Tuvalu were selected as sites for water security cost benefit studies, Funafuti and Vaitupu. Funafuti is the most populous atoll in Tuvalu (estimated 5,200) and the country's capital. Vaitupu has the largest area of the country's nine atolls and a substantial population (estimated 1,600) including over 400 children attending the country's largest school. Selection of these islands was made at the suggestion of the Government of Tuvalu. Factors influencing site selection include:

- together the two atolls contain61% of Tuvalu's total population;
- both islands face regular water shortages notably during a severe drought in 2010-2011; and

- the water supplies of both atolls are characterised by being highly rainfall dependent, but there are contrasts between the islands in terms of stresses and potential additional water supplies[1].

Recognising their contrasting circumstances, separate CBAs were undertaken for the two islands, within a broader decision making framework. Given the capacity building aspect of the project, workshops were used to take officials from Tuvalu government ministries and regional development organisations through the framework applied to the analysis and to validate data used in the analysis. A smaller CBA mentoring group was also set up to review the process outputs in more detail.

1.5 Framework applied to the analysis

The framework applied to the analysis quite closely follows the process set out in the guide *Cost-Benefit Analysis for Natural Resource Management in the Pacific* (Buncle et al. 2013) – an important reference guide for decision-makers in PICs. However, the framework applied to this study and recommended for addressing water security in Tuvalu and other PICs contains elements that go further than the guide. This is because the multi-faceted nature of the water security challenges faced by Tuvalu and other PICs, including climate change, means that a strategic assessment is preferred to a project by project assessment. In practice this means:

- the CBA will be part of an integrated decision making process - useful for developing a (water security) strategy or plan that is intended to cover short and longer term actions;
- the integrated process will comprise three main stages – 'structuring of the issue or problem', 'solution analysis' and 'managing the problem' – each of which will entail a number of steps in turn (see Figure 3);
- rather than assessing individual options to address a discrete problem, multiple options that together can provide an integrated solution to the water security issue will need to be assessed – referred in this assessment as the 'portfolio approach';
- different types and levels of economic analysis can be applied at different steps in the process, although the nature and depth of analysis is likely to differ between the steps (Figure 4);
- water supply-demand analysis will be a key input into the process, being applied at all steps in the structuring and solution analysis stages of the process; and
- the process overall is iterative rather than linear, meaning that the strategy will need to be reviewed from time to time to reflect changed circumstances or information.

[1] For example, whereas Funafuti's groundwater is severely contaminated, effectively ruling it out as a viable water source, available evidence indicates that Vaitupu's groundwater has the potential to be an additional water source provided it is carefully managed.

Figure 3: Stages and steps of water strategy development, indicating where economic analysis is used

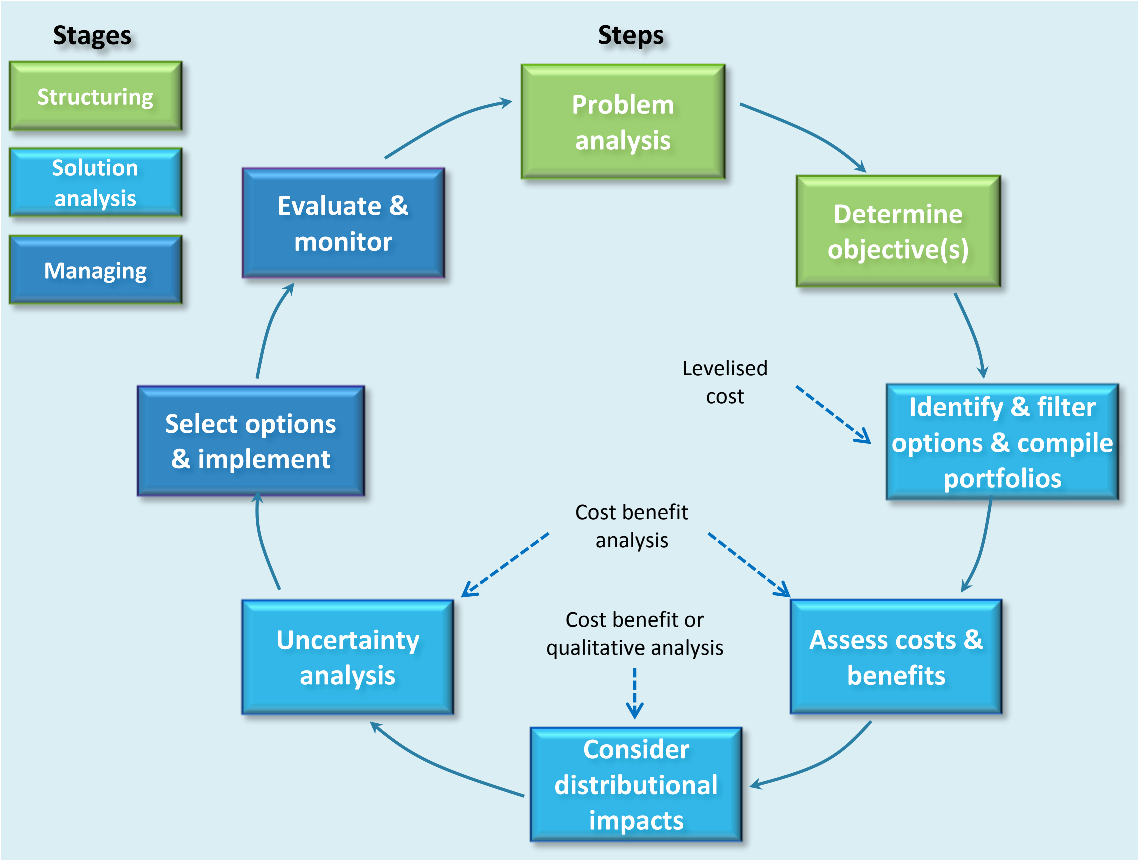
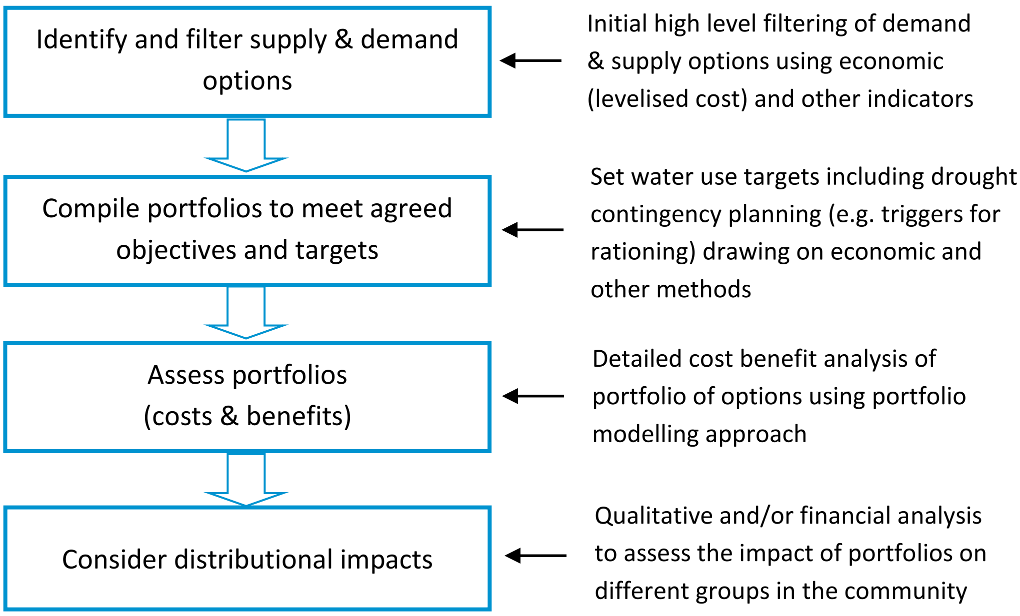


Figure 4: Potential application of economic and other analysis in water security planning



1.6 Study limitations

Data uncertainties

Results of the assessment are dependent on data assumptions that underpin the water supply and demand variables and the cost and benefit variables. Although significant background analysis has gone into assigning suitable values to these (see Sections 2.1/3.3 and 5 respectively), in practice there are still uncertainties around the estimates. Reflecting these uncertainties, we have undertaken scenario analysis of alternative rainfall scenarios to assess the impact on results of different rainfall regimes in the future. We have also undertaken sensitivity analysis of cost and benefit estimates. The scenario and sensitivity analyses are presented in Section 6 and reveal that while different scenarios and different sensitivity values affect the net present value (NPV) estimates of costs and benefits, they do not significantly affect conclusions about preferred options.

Value of water

The difficulty of placing a value on the additional water delivered by options to achieve water security is discussed at length in Section 5.1. To help address this limitation, a threshold analysis was undertaken to demonstrate the value of that the community would need to place on water provided by additional options in order for those options to produce a net benefit overall to the community (i.e. a positive NPV).

1.7 Report outline

The remainder of this report discusses application of the framework, outlined above, to assessing water security in Tuvalu. Each section covers a major step in the process, commencing with a brief discussion of the relevant step, followed by its application to the water security case studies in Funafuti and Vaitupu. We also discuss tasks undertaken in workshops with Tuvalu government stakeholders, specifically where those tasks helped to generate information for the assessments

- Section 2 discusses water security problem analysis for Funafuti and Vaitupu.
- Section 3 reviews water security objectives for the two islands.
- Section 4 discusses the process of identifying, filtering options and compiling alternative portfolios for meeting these objectives.
- Section 5 details the CBA, including scenario analysis and distributional impacts.
- Section 6 provides conclusions from the assessment and makes recommendations on integrating CBA into future decision making and directions for water security in Tuvalu.

Additionally, the report contains two appendices:

- details of the water supply-demand model used in the analysis; and
- a technical report on groundwater supply in Vaitupu.

2. Problem analysis

Problem analysis is a crucial early step in the decision making process. It is used to establish the nature of the water security issues or problems to be addressed and is important for informing development of water security objectives (section 3) and options for dealing with the problem (section 4). Two problem analysis tasks were completed for Funafuti and Vaitupu:

- a background assessment of historic and projected rainfall and current water supplies; and
- an assessment of water security problems and risks in Funafuti and Vaitupu, which in turn was informed by a stakeholder workshop.

2.1 Background assessment of rainfall and water supply

2.1.1 Rainfall in Tuvalu

The climate of Tuvalu is characterised by two distinct seasons:

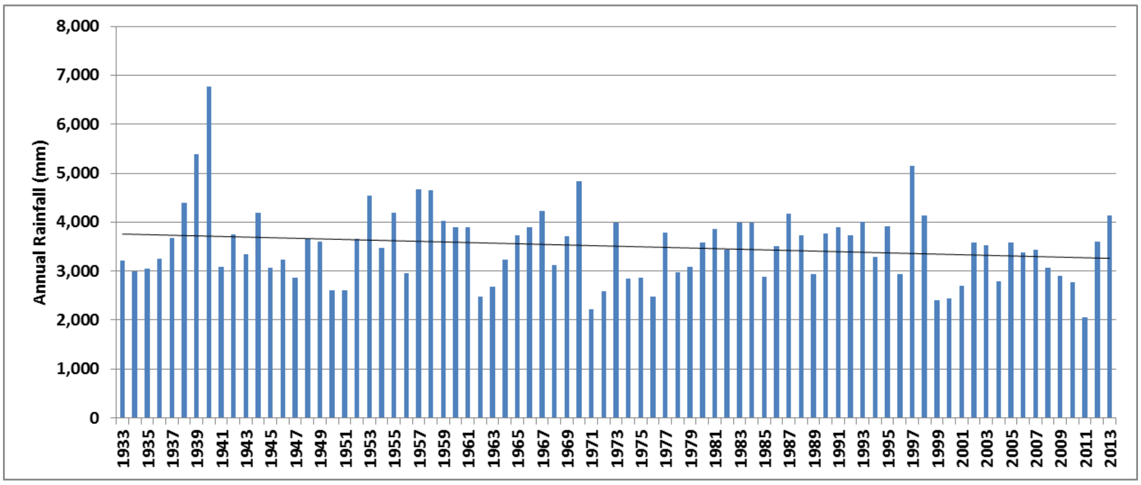
- a wet season from November to April; and
- a dry season from May to October.

This strong seasonal cycle is driven by the strength of the South Pacific Convergence Zone (SPCZ), which is strongest during the wet season. The West Pacific Monsoon can also bring high rainfall to Tuvalu during the wet season (BoM and CSIRO 2014). Average annual rainfall is approximately 3,500 mm in Funafuti and 3,200 mm in Vaitupu, with monthly rainfall generally being more than 200 mm in both islands, reflecting the location of Tuvalu near the West Pacific Warm Pool, where convective rainfall occurs year-round.

Nevertheless, there is high year-to-year variability in rainfall, mostly due to the impact of the El Niño-Southern Oscillation (ENSO). This variability is the primary driver of insecurity for water supplies in most parts of Tuvalu. In the driest years Funafuti and Vaitupu receive only about 25% of the rainfall as in the driest years. In an El Niño year, the SPCZ tends to move to the north-east over Tuvalu and so rainfall is higher. In La Niña years the SPCZ tends to move away to the south-west, bringing severe drought. (BoM and CSIRO 2014)

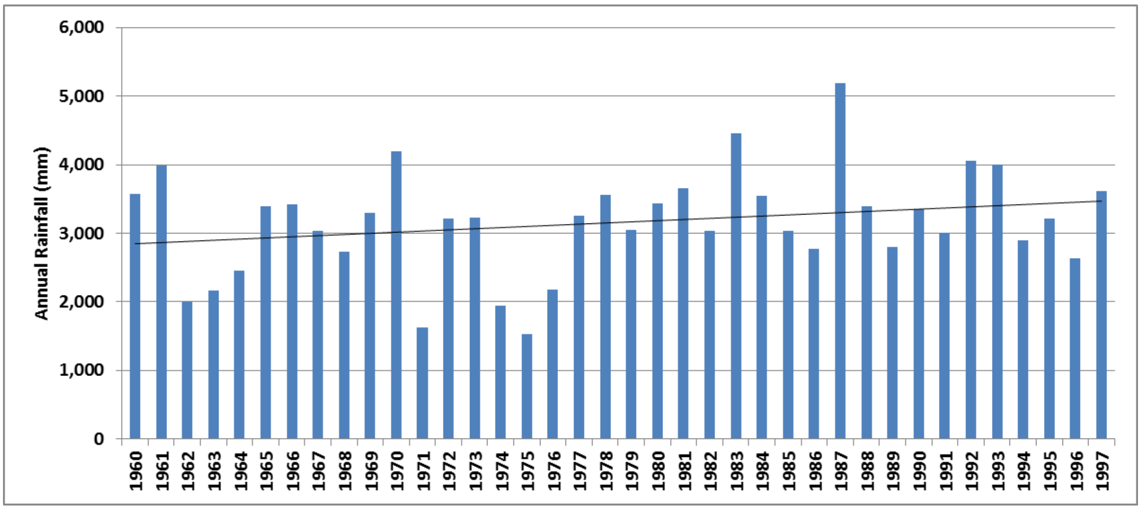
There is considerable decadal variability in rainfall in Tuvalu. Overall, there is a slight downwards annual rainfall trend in Funafuti and a slight upwards trend in Vaitupu, noting that Vaitupu rainfall data does not include the most recent 16 years, which was a relatively dry period in Funafuti and other parts of Tuvalu (Figure 5 and Figure 6). In any case, neither of these trends is statistically significant (R-square values of 0.0364 and 0.0618 for the two trend lines respectively).

Figure 5: Average annual rainfall Funafuti (mm)



Data source: Meteorology Office Tuvalu, 2014

Figure 6: Average annual rainfall Vaitupu (mm)



Data source: Meteorology Office Tuvalu, 2014

2.1.2 Overview of water supplies in Funafuti and Vaitupu

The water supplies of Funafuti and Vaitupu are characterised by being highly rainfall dependent. Nearly all households in Funafuti and Tuvalu have at least one rainwater tank, many of which were supplied through Australian and European aid programs in recent years. Each tank typically has a capacity of 10,000 litres, with most households having more than one tank. Household water supplies are backed up by a network of community and government cisterns, which provide water on a rationed basis when household tanks run dry.

Additionally in Funafuti, there is a Government run desalination plant. Water from the plant is provided to households at a subsidised price. During dry periods demand for the desalination water outstrips supply and the water also has to be rationed. A present the desalination plant does not provide long term water security in Funafuti, since there is limited capacity in the country to maintain the plant once maintenance contracts cease in 2015. Significant contamination of groundwater in Funafuti means it has limited potential as an alternative water supply.

Vaitupu has viable supplies of groundwater for non-potable uses, but access is limited by location of the groundwater lenses away from the main villages and school. Any efforts to increase access to the groundwater would need to ensure that groundwater quality is not compromised and consumption is kept to a level consistent with long term sustainable yields.

2.1.3 Droughts and water security

An analysis of historic monthly rainfall records was undertaken for both Funafuti and Vaitupu. The Funafuti rainfall record extends from 1933-2013, while the Vaitupu rainfall record extends only from 1948-1997[2]. Three month, six month, 12 month and 24 records were reviewed to determine dry periods and the impact of dry periods on water availability given current water storage capacity at both islands. A water supply-demand model linked to rainfall data was used for the analysis. This is discussed in detail in section 3.2.

The period November 2010 to October 2011 was found to be both the driest 12 month period for Funafuti and the period leading to the greatest shortfalls in water availability at the household and community levels. Rainfall in this period was 1488 mm, only 42% of the long term annual average. The driest 12 month period in Vaitupu was November 1970 to October 1971 (noting that 2011 data is not available for Vaitupu). Rainfall in this period was 1403 mm, only 44% of the long term average.

With reference to the 2010-2011 drought, documented evidence (Ministry of Finance & Economic Development Tuvalu 2012; Sinclair et al. 2012) and verbal evidence provided by the Ministry of Public Works[3] supports a conclusion that a ‘worst case drought’, such as the one that occurred in Funafuti, Vaitupu and elsewhere in Tuvalu in 2010-2011, caused severe strains on water security and hardship to households and communities. In most Funafuti and Vaitupu households rainwater tanks were without water for 180 days or longer over the course of the year. At the height of the drought:

- water from government and community supplies was being rationed to an average of 45 litres/ household/day[4] in Funafuti (equivalent to an average of about 6.5 litres/person);
- water from government and community supplies was being rationed to an average of 25 litres/ household/ day in Vaitupu (equivalent to an average of about 5.5 litres/person).

Modelling of water supply-demand undertaken for this project confirms this conclusion. It reveals that, given current storage capacity and in the event of a worst case drought, households run out of tank water about 130 days/ year on average and community and government cisterns come close to running dry (see section 3.2). This situation could worsen in the future given projected population growth and possible changes in rainfall patterns associated with climate change.

[2] Digital rainfall records were provided by the Meteorology Office of Tuvalu in April 2014.

[3] Discussions with officials of the Ministry of Public Works, Tuvalu, were held in March to May 2014.

[4] An average of 45 litres/household/ day is based on 40 litres/household provided to about 90% of households and 80 litres/household/day provided to 10% of households which are large or have special needs.

2.1.4 Climate change

Rainfall projections for Tuvalu

Rainfall projections for Tuvalu are discussed in the report *Climate Change in the Pacific: Scientific Assessment and New Research, Volume 2: Country Reports*, which reports on Coupled Model Intercomparison Project (CMIP) 3 climate models simulations for the Equatorial and South West Pacific regions in which Tuvalu is situated (BoM and CSIRO 2014). *Climate Change in the Pacific* reports that these models project:

- little change (-5% to 5%) in wet season, dry season and annual mean rainfall by 2030;
- a small increase in wet season, dry season and annual mean rainfall, assuming high emissions scenario RCP 8.5 and a neutral ENSO state (-3% to 10%, see Figure 7);
- no consistency regarding future ENSO activity, noting that interannual variability in rainfall over Tuvalu is strongly influenced by ENSO, but the frequency of drought is to remain approximately stable throughout the 21st century, at once to twice every 20 years for moderate drought and once every 20 years for severe drought;
- moderate confidence in projections of average rainfall noting that, on the one hand, the CMIP3 models broadly capture the influence of the West Pacific Monsoon and the South Pacific Convergence Zone on the rainfall, but on the other hand, the CMIP3 models are unable to resolve many of the physical processes involved in producing rainfall; and
- only low confidence in the range and distribution of possible drought futures for Tuvalu.

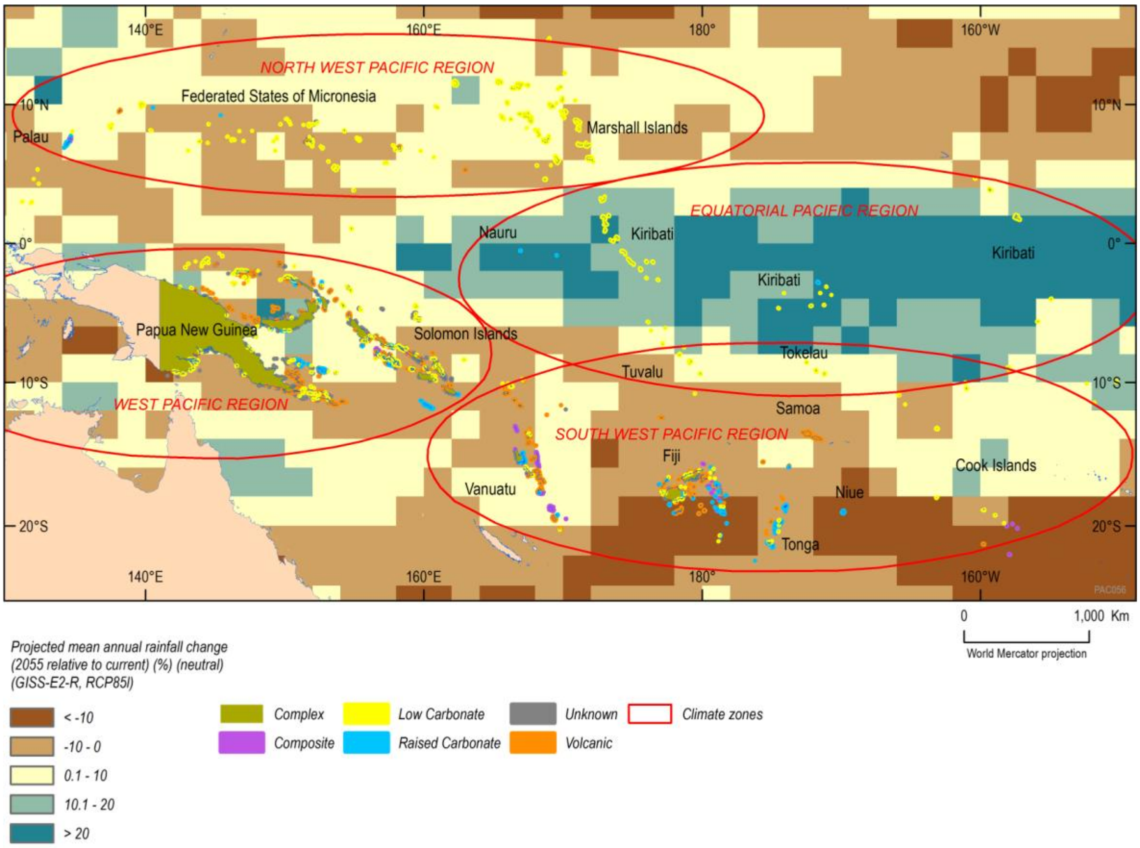
Climate change scenarios

Given these uncertainties, especially with respect to rainfall variability and drought frequency, a decision was made to use scenario analysis in the case study for the purpose of incorporating climate change and variability into the water supply-demand modelling.

Three scenarios were used for the purpose of modelling current and potential future water security, with scenarios being selected so as to provide a realistic indication of the impact of droughts on water security in the future:

- The standard drought scenario was modelled on the lowest 12 month rainfall in the historic record: 2010-11 in Funafuti and 1970-71 in Vaitupu.
- A worst case drought scenario was modelled at -10% of the historic low annual rainfall and assumes two consecutive years of this rainfall.
- A best case drought scenario was modelled at +10% of the historic low annual rainfall.

Figure 7: Projected percentage change in mean annual rainfall for 2055 in PICs relative to current based on the GISS-E2-R model (RCP 8.5) for the neutral ENSO state



Source: Grose and Bedin 2013

2.2 Water security risks in Tuvalu

Risk assessment provides a means of structuring the problem analysis. Risk is defined as *the likelihood and consequence of a hazard*. Thus risk assessment in the context of water security involves quantifying or otherwise validating the likelihood of the climate and non-climate factors driving water shortages or poor water quality and the consequences of water shortages or poor water quality for communities. The risk assessment is best formalised through an established risk assessment process, notably ISO 31000:2009, which goes through structured process of identifying the full range of risks to water security considering key climate and non-climate drivers (e.g. population growth) and then rating each risk based on its likelihood and expected consequences. A formal risk assessment process is not necessarily essential though, to identify the nature and severity of water security problems. Instead, the nature and severity of water security problems can often be identified by drawing on experiential knowledge.

This was the approach applied to the Tuvalu case study. At a workshop held in Funafuti on March 2014, stakeholders from Tuvalu Government departments and regional organisations were asked to consider the underlying problems driving water insecurity in Funafuti and Vaitupu (see Appendix A). Questions they were asked to consider include:

- Which communities and individuals are being impacted by problems with water shortage or water quality? When are they being impacted and how severe are the impacts?

- What are the main causes or drivers of the problems – climate and non-climate?
- How do existing water supplies address or fail to address current and projected water security needs?

These questions were discussed in four small groups, two of which focussed specifically on water security in Funafuti and two on water security in Vaitupu. Based on responses to these questions, which were broadly consistent between Funafuti and Vaitupu groups, the following key risks to water security were identified and subsequently formalised and validated:

1. Insufficient water storage to meet demand during dry spells and droughts necessitates frequent and sometimes severe water rationing from community and government supplies (Funafuti and Vaitupu).
2. Lack of responsibility for the maintenance of water tanks and gutters leads to reduced reliability of household and (to a lesser extent) community water supplies (Funafuti and Vaitupu).
3. Population growth, combined with changing household practices and limited water demand management, leads to growth in water demand (Funafuti and, to a lesser extent Vaitupu).
4. Contamination of groundwater limits access to alternative, non-rainfall dependent water supplies (Funafuti).
5. Inadequate training and resources limit the reliability of desalination as an alternative water supply during dry spells (Funafuti).
6. Poor water and land management practices threaten viability of groundwater as an alternative, non-rainfall dependent water supply (Vaitupu).
7. Changed rainfall patterns due to global climate change leads to an increase in the frequency and/or severity of dry spells and droughts further threatening the reliability of rainfall dependent water supplies (Funafuti and Vaitupu).
8. More intense storm surges, driven by increased intensity and frequency of tropical cyclones and sea level rise, could also lead to greater salt water intrusion into groundwater, salinising freshwater lenses (Vaitupu).

It should be noted that risks 1-4 are already being experienced, implying that their future likelihood is essentially certain.

These risks considered together point to the desirability of taking a strategic approach to water security planning in Funafuti and Vaitupu. This approach will combine increased water supply capacity with improved management of resources, both at the household and community levels. Risk 5 (reliability of desalination) is less certain but still very likely. It points to the need to move away from dependence on desalination, at least for emergency water supplies, unless the necessary training and resources can be found to ensure its total reliability. Similarly, threats to groundwater in Vaitupu, although not certain are at least possible, suggesting that any move to increase reliance on groundwater needs to be very carefully managed.

3. Water security objectives

A well-defined objective or objectives will provide the foundation for a water security strategy. Objectives will be critical to understanding where water planning should be heading and for assisting with the process of identifying and assessing water security options.

Noting earlier discussion of the benefits of a strategic approach to water security planning in Tuvalu (see section 1.5), it may be useful to have multiple objectives, e.g. a short term objective addressing critical problems followed by longer term, more aspirational objectives.

Water supply-demand modelling can help to refine objectives based on what is practically achievable (section 3.2).

3.1 Water security objectives for Tuvalu

At the March 2014 workshop, discussed previously, stakeholders were asked to agree on an objective or objectives for water security Tuvalu. Discussions on objectives were undertaken in small groups, which were asked to identify objectives for Funafuti and Vaitupu respectively considering the mission of Tuvalu's *Sustainable and Integrated Water and Sanitation Policy 2013-2021* (Government of Tuvalu 2013) and its *Draft Tuvalu Integrated Water Resources Plan* (Government of Tuvalu 2013b). That Draft Plan has the following goals:

1. Provide sufficient good quality freshwater for all Tuvaluans to enjoy; and
2. Protect all water resources to enhance the health of our environment and our people.

Groups were asked to expand these goals into more specific, possibly measurable water security objectives (Figure 8).

What emerged from their discussions and subsequent iterations is a water security vision supported by a series of immediate and longer term targets. These are outlined below.

Figure 8: Discussion of water security objectives, Funafuti, March 2014

3.1.2 Water security vision

Ensure all households have adequate clean, accessible and affordable water to meet essential uses at all times.

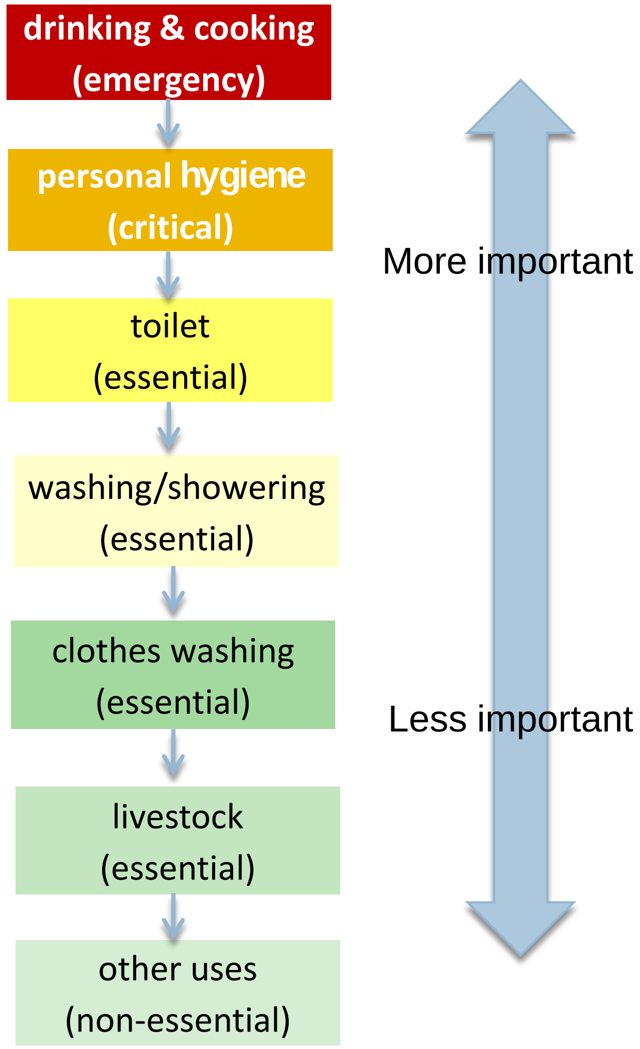
3.1.3 Drought targets

- Emergency target: Sufficient clean and reliable water supplies to meet all households' emergency water needs in the event of a worst case drought.
- Critical target: Sufficient clean and reliable water supplies to meet all households' critical water needs in the event of a worst case drought,
- Longer term target: Sufficient clean and reliable water supplies to provide all households with essential water needs in the event of a worst case drought.

These targets are informed by a hierarchy of water use needs for households in Tuvalu. Moving from emergency to critical to essential water needs, this hierarchy would look similar to that outlined in Figure 9, with the following target levels being relevant:

- Emergency needs: At the height of the 2011 drought water for emergency uses was rationed to as little as 31 and 45 litres/household/day in Vaitupu and Funafuti respectively (~6-7 litres/ person/day assuming an average household size of 5-7 people).
- Critical needs: These are defined as water required for drinking, cooking and personal hygiene - estimated to be about 62 and 90 litres/ household/day of potable water in Vaitupu and Funafuti respectively (~12-15 litres/person/day assuming an average household size of 5-7 people).
- Essential needs: These are defined as water required for all internal household needs including critical uses (as defined above), as well as water for washing, clothes washing, toilet flushing and animals (potable or non-potable quality). Essential needs are estimated to be approximately 205 and 300 litres/household/day in Vaitupu and Funafuti respectively (60 litres/person/day).

Figure 9: A hierarchy of water needs



3.2 Base case water supply and demand modelling

3.2.1 Model overview

In the context of water security planning, supply-demand modelling is an important aspect of the analysis, providing a means of validating risks (section 2.2) by quantifying the balance between existing water supplies and demand, including in times of drought. The supply-demand modelling can then be used to help set achievable water security objectives and identify portfolios for meeting those objectives (section 4). Supply demand modelling can be (and is generally) undertaken as an Excel spreadsheet based model that captures key variables such as:

- storage capacity (e.g. water tanks and cisterns);
- water yield given rainfall and run-off (which in the case of household tanks and community cisterns is primarily determined by roof collection area and gutter condition); and
- household/ community water demand.

An Excel-based water supply-demand model was developed specifically for this study to reflect conditions in Tuvalu and other Pacific Island Countries. The model was used to assess shortfalls in water supply in Funafuti and Vaitupu relative to the emergency, critical and longer term water security targets, under the standard, worst case and best case drought scenarios.

The model was also used to assess additional capacity required to meet the water security targets. It enables portfolios containing different types of options (cisterns, rainwater tanks, desalination, groundwater etc.) to be assessed in an integrated manner (see section 4).

Other features of the model include:

- Key assumptions relating to rainfall, household numbers, household water demand, run-off coefficients, house size and roof area etc. can be changed to determine their impacts on water yields under different options.
- The same assumptions can be changed to enable modelling of water security outcomes for different islands or modelling of water security at the village level.

Further details of the model are provided in Appendix B.

3.2.2 Application of model to Funafuti

Initial modelling was undertaken to determine shortfalls in water supply in Funafuti under the standard, low and high rainfall scenarios relative to the water security targets.

Assumptions

As previously noted the standard drought scenario is set at the lowest 12 months of rainfall in the historic record (2010-2011). It also assumes that the existing storage capacity of household tanks and community and government cisterns is in place (Table 1).

Table 1: Estimated rainwater storage in Funafuti (excluding commercial storage)

Storage type	Capacity (kl)	Litres/ person[1]	Litres/ household[1]
Household rainwater tanks	20,449[2]	3,932	24,200
Community cisterns[3]	4,018	773	4,755
Government cisterns	6,298	1,211	7,453
Total rainwater storage	30,765	5,916	36,409

Sources: Government of Tuvalu and SPC 2014, Department of Statistics Tuvalu 2014

Notes:

1. *Based on an estimated population of 5,200 across 845 households*
2. *Assumes only 95% of tanks are connected*
3. *Includes established cisterns plus two currently under construction, a 750 kl cistern at Lofeagai village and another 288 kl cistern*

Other important assumptions include:

- Seventy percent (70%) of households live in dwellings that have a small roof area ($62m^2$), an average of 1.8 (10kL) rainwater tanks and an **average daily consumption of 350 litres/ household/day** when there is no rationing.
- The remaining 30% of households are assumed to live in larger dwellings (roof area of $155m^2$), with an average of 3.85 rainwater tanks and an **average daily water consumption of 550 litres/household/ day when there is no rationing**.
- Once household rainwater tanks run out of water and a drought is declared, water is rationed at either the 'emergency', 'critical' or 'longer term' target level (with the outcomes of the different target levels then being modelled separately).
- Small household numbers are growing at the rate 1.15% per annum and larger household numbers are growing at the rate of 0.6% per annum.
- Household water demand is growing at the rate of 0.75%/ year/household in small households and 0.25%/ year/ household in larger households, reflecting changes to the circumstances and lifestyle of householders.
- The runoff coefficient[5] for household rainwater tanks is only 0.65 – 0.72 and declines in future years, reflecting a relatively poor status of gutter maintenance and cleaning.
- Similarly, the runoff coefficient for government and community cisterns is only 0.75 and declines in future years.
- Water from desalination plants is not available to meet emergency or critical targets in Funafuti – noting an earlier comment that desalination water is not a reliable supply in the future given uncertainty at present about long term plant maintenance.

Outputs

Applying these assumptions, under the standard drought scenario (i.e. a drought equivalent to 2010-11):

- Small households run out of water from their tanks for about 162 days of the year in the first year (2014), struggling to meet their water needs for up to six months (see Figure 10)[6]. This increases to greater than 250 days by 2035 reflecting increased household demand over time and a reduction in the runoff coefficient of household tanks (in the absence of gutter maintenance and cleaning). Larger households run out of water from their tanks for about 44 days of the year in 2014, increasing to almost 130 days of the year by 2035.
- Once rainwater tanks run dry community and government cisterns are accessed. In the first year, and a few subsequent years, these cisterns are able to supply water across Funafuti for the remainder of the year, provided water is rationed at the emergency level of (average) 45 litres/ household/ day (a rationing regime that was in place at the height of the 2011 drought).

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5 The proportion of rainwater that falls on a roof that gets into a tank.

6 This is consistent with reports from workshop participants and others as to the situation in Funafuti in low rainfall years.

- However, even in the first year, the critical target of 90 litres/ household/ day (sufficient water for drinking, cooking and personal hygiene) cannot be met if a drought year similar to 2010-11 were to eventuate.
- Furthermore, without additional capacity, even the emergency target of 45 litres/ household/ day cannot be met for the entire year if a drought similar to 2010-11 were to eventuate in 2022 or later. This situation reflects population growth, increased household water demand and a reduction in the runoff coefficient of cisterns.

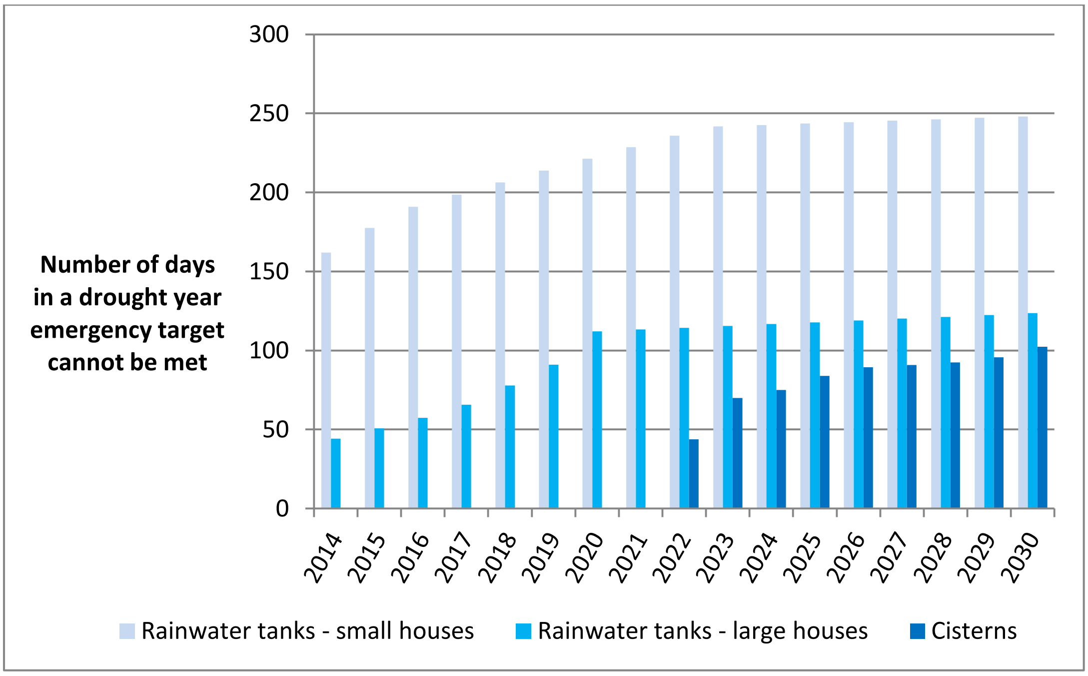
Under the worst case drought scenario water storage shortfalls are exacerbated:

- Small households run out of water from their tanks for about 194 days of the year in the first year (2014), increasing to 264 days by 2035. Larger households run out of water from their tanks for about 120 days of the year in 2014, increasing to almost 186 days of the year by 2035.
- By 2019 community and government cisterns do not have sufficient capacity to meet the emergency target for the entire year.

Under the best case drought scenario water storage shortfalls are eased, although only slightly:

- Small households run out of water from their tanks for about 125 days of the year in 2014, increasing to 241 days by 2035. Larger households run out of water from their tanks for about 31 days of the year in 2014, increasing to 91 days of the year by 2035.
- Community and government cisterns have sufficient capacity to meet the emergency target for the entire year, but only until 2024.
- The critical and emergency targets still cannot be met in any year.

Figure 10: Number of days in a drought year storages in Funafuti run out of water (emergency target)



3.2.3 Application of model to Vaitupu

Initial modelling was undertaken to determine shortfalls in water supply in Vaitupu under the standard, low and high rainfall scenarios relative to the water security targets.

Assumptions

As previously noted the standard drought scenario is set at the lowest 12 months of rainfall in the historic record (1970-1971). It also assumes that the existing storage capacity of household tanks and community and government cisterns is in place (Table 2).

Table 2: Estimated rainwater storage in Vaitupu (excluding commercial storage)

Storage type	Capacity (kl)	Litres/ person[1]	Litres/ household[1]
Household rainwater tanks	4,458	3,998	19,751
Community and government cisterns	1,006	902	4,457
Motufoua School[2]	1,616	3,332	
Total rainwater storage	7,080	4,425	

Source: Department of Statistics Tuvalu 2014

Notes:

1. *Based on an estimated population of 1,115 across 260 households and 485 students and teachers at the school.*
2. *Includes 400 kL of constructed or under construction since 2012.*

Other important assumptions include:

- Seventy percent (70%) of households live in dwellings that have a small roof area (62m^2), an average of 1.8 (10kL) rainwater tanks and **an average daily consumption of 240 litres/ household/day when there is no rationing**.
- The remaining 30% of households are assumed to live in larger dwellings (roof area of 155m^2), with an average of 2.5 rainwater tanks and **an average daily water consumption of 380 litres/household/day when there is no rationing**.
- Small household numbers are growing at the rate 1.15% per annum and larger household numbers are growing at the rate of 0.6% per annum.
- Household water demand is growing at the rate of 0.75%/ year/household in small households and 0.25%/ year/ household in larger households, reflecting changes to the circumstances and lifestyle of householders.
- The runoff coefficient for household rainwater tanks is only 0.65 – 0.72 and declines in future years, reflecting a relatively poor status of gutter maintenance and cleaning.

- Similarly, the runoff coefficient for government and community cisterns is only 0.75 and declines in future years.
- Water from desalination plants is not available to meet emergency or critical targets.

Outputs

Applying these assumptions, under the standard drought scenario (i.e. a drought equivalent to 1970-71):

- Small households run out of water from their tanks for about 114 days of the year in the first year, 2014 (see Figure 11). This increases to 167 days by 2035 reflecting increased household demand over time and a reduction in the runoff coefficient of household tanks (in the absence of gutter maintenance and cleaning). Larger households run out of water from their tanks for about 64 days of the year in 2014, increasing to 106 days of the year by 2035. The school runs out of water from its tanks for about 135 days of the year in 2014, increasing to 275 days of the year by 2035.
- Once rainwater tanks have run dry, community and government cisterns are accessed. However, they unable to supply water across Vaitupu for the remainder of the year. A drought similar to the 1970-71 drought would leave cisterns dry for 41 days, even if water was rationed to the 2011 level of 31/litres/ household/day. By 2035 the number of days of shortfall with cistern water supply will have extended to 139 days in the year, reflecting some population growth and a decline in the runoff coefficient.
- The critical target of 90 litres/ household/ day (sufficient water for drinking, cooking and personal hygiene) also cannot be met if a drought year similar to 1970-71 were to eventuate.

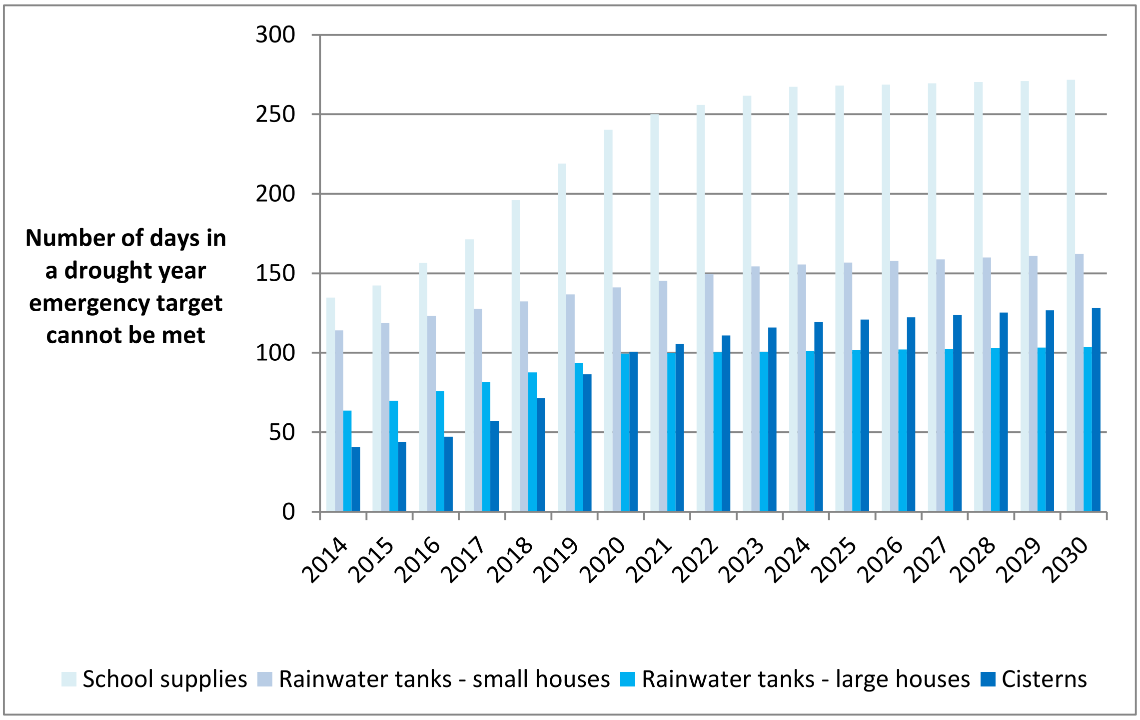
Under the worst case rainfall climate change scenario water storage shortfalls are exacerbated:

- Small households run out of water from their tanks for about 130 days of the year in 2014, increasing to 225 days by 2035. Larger households run out of water from their tanks for about 78 days of the year in 2014, increasing to almost 120 days of the year by 2035. The school runs out of water from its tanks for about 223 days of the year in 2014, increasing to 284 days of the year by 2035.
- Community and government cisterns do not have sufficient capacity to meet the emergency target in 2014, with the shortfall being for 83 days of the year in 2014, increasing to 200 days by 2035.

Under the best case rainfall climate change scenario water storage shortfalls are eased:

- Small households run out of water from their tanks for about 103 days of the year in the first year (2014), increasing to 159 days by 2035. Larger households run out of water from their tanks for about 49 days of the year in 2014, increasing to 95 days of the year by 2035. The school runs out of water from its tanks for about 126 days of the year in 2014, increasing to 266 days of the year by 2035.
- Community and government cisterns still have insufficient capacity to meet the emergency target in the first year, 2014.

Figure 11: Number of days in a drought year water storages in Vaitupu run out of water (emergency target)



4. Options and portfolios

As previously discussed (section 1.5), a portfolio approach is proposed as the most suitable approach to addressing water security issues in an integrated manner. It can be contrasted with a site- or project-based approach which tends to be more piecemeal in nature. The portfolio approach involves combining and assessing multiple, complimentary options into alternative portfolios for meeting the water security objectives or targets. There are no hard and fast rules for completing this step but the following tasks are suggested as a means of approaching the task and were applied to the Funafuti and Vaitupu case studies:

- identify a long list of potential options for meeting targets;
- use a 'filtering' process to reduce the long list of options into a more manageable shortlist of options; and
- combine the shortlist of options into a small number of alternative portfolios for meeting each of the targets in Funafuti and Vaitupu respectively.

The process of compiling portfolios is not a fixed one but there are some simple rules that are useful to follow:

- One or more portfolios can be compiled for each objective or target, with the purpose of estimating the different net cost/benefit associated with each portfolio configuration.
- Each portfolio will contain one or more complementary options that meet, but do not significantly exceed, the relevant objective.
- Some portfolios may contain two or more of the same options.

Cost-effectiveness assessment can be used to rank options (from lowest to highest cost) and thus determine the order in which options are included in a portfolio to meet a given objective or target. This is typically calculated as a 'cost per kilolitre' – also referred to as 'levelised cost'. Levelised cost allows options of different sizes (for example rainwater tanks and desalination plants) to be compared on a like-for-like basis and is calculated as the present value cost of the water source divided by the present value of water that will be supplied by that water source. This approach was used implicitly to assist with the configuration of alternative portfolios for Funafuti and Vaitupu.

4.1 Options identification and filtering

At the March 2014 workshop, previously discussed, stakeholders were asked, in small groups, to identify potential water security options, both demand and supply. A long list of options was compiled by the groups for Funafuti and Vaitupu and then further developed by the project team. These are set out in

Table 3 overpage.

Table 3: Long list of options for advancing water security in Funafuti and Vaitupu

Demand-Side Measures	Location
Implementation of Water Act and associated measures: - Improved building codes (covering RWT and septic tanks) - Integrated / centralised water and waste water coordination - Land use / catchment planning	Funafuti and Vaitupu
Water pricing for desalinated water and other communal water sources, such as cisterns (e.g. full cost pricing)	Funafuti and Vaitupu
Gutter cleaning and maintenance program	Funafuti and Vaitupu
Behavioural change (e.g. rescheduling of	Funafuti and Vaitupu
Demand Management, including - Water efficiency education program - (Retro) fitting of water efficient devices (composting toilets, taps, showerheads)	Funafuti and Vaitupu
Leakage reduction program (e.g. pipes into houses)	Funafuti and Vaitupu
Improved data gathering and management (e.g. water demand, groundwater studies of the freshwater lens and fresh-saline interface, individual islands water mass balance)	Funafuti and Vaitupu
Supply-Side Measures	**Location**
Installation of additional rainwater tanks at private or public dwellings	Funafuti and Vaitupu
Construction of additional community or government water storages (cisterns)	Funafuti and Vaitupu
Filling of 'borrow pits' to provide land for construction of cisterns	Funafuti
Installation of groundwater pumps and header tanks, with water piped to villages and school	Vaitupu
Installation of groundwater pumps and header tanks, with water trucked to villages and school	Vaitupu
Recycling of greywater for irrigation and/or re-use in toilets and laundry	Funafuti and Vaitupu
Stormwater harvesting from airport runway	Funafuti
Solar distillation systems	Funafuti and Vaitupu
Improved waste water management: - septic tanks (improved installation, improved technology types, semi-centralised systems (STEDS) / full centralisation via sewers) - composting toilets - infiltrate and recover via Soil Aquifer Treatment technology - improved solids / sludge management	Funafuti

- centralised sewage treatment system	
Desalination units, new or upgraded	Funafuti and Vaitupu
Groundwater filtration / purification	Funafuti and Vaitupu
Upgrade of existing water supply infrastructure (e.g. increase capacity of cisterns)	Funafuti and Vaitupu

As can be seen from the table, a wide range of potential options were identified for Funafuti and Vaitupu. It was not feasible to assess all of these options in detail however, so a filtering process was applied, using a series of criteria, to exclude options from further analysis that failed to meet one or more of the criteria. Criteria applied to the filtering process were:

- Cost effectiveness. Will the capital and/ or operating cost of the option be likely to be cost prohibitive?
- Effectiveness. Will the option deliver significant water security benefits?
- Feasibility. Is the option likely to be technically feasible, reliable and compatible with established water supply options?
- Acceptability. Will the option have environmental, health or cultural impacts that are likely to be unacceptable to the community?

Applying these criteria a number of the options were excluded from further analysis:

- Options for groundwater development in Funafuti were excluded on grounds that they are likely to have unacceptable health impacts due to groundwater contamination and the cost of purifying the water to an acceptable standard is likely to be cost prohibitive.
- Stormwater harvesting from the airport runway was excluded on the grounds that it is likely to have a very high capital cost and there are significant question marks over its feasibility – water would need to be purified and a distribution system would need be developed for the water; both of these requirements are likely to entail significant operating and maintenance costs.
- A centralised sewerage treatment system for Funafuti was excluded on grounds that the water security benefits would be minimal. There are also question marks over the long term maintenance and operating costs of this option. Nevertheless, this option deserves more detailed assessment in the future as one of a number of alternatives (including composting toilets) for improving sanitation and groundwater quality in Funafuti.
- Solar distillation was excluded on grounds of capital cost and technical feasibility, especially question marks over long term maintenance.
- Leakage reduction was not examined further due to lack of data regarding the extent and condition of water pipes but noting that many households do not have water piped to inside.
- Greywater recycling systems were not examined further noting that anecdotal evidence suggests that many households already undertake manual greywater recycling, using water from kitchens for watering of gardens and animals.

4.2 Short list of options and portfolios

Upon completion of the filtering process, a final list of options was established. The final options were then compiled into portfolios designed to meet the emergency, critical and longer term targets for Funafuti and Vaitupu respectively. Two to three alternative portfolios were designed for each target, reflecting discussions held with stakeholders in the March workshop. A summary of the portfolios is set out in Table 4.

Table 4: Summary of water security portfolios for Funafuti and Vaitupu

Funafuti	Vaitupu
Portfolio 1a (to meet emergency target) ▪ gutter maintenance and cleaning program (houses and community centres) ▪ water act and associated measures ***Portfolio 1b (to meet emergency target)*** ▪ additional cisterns (2250 kL) ▪ water act and associated measures ***Portfolio 1c (to meet emergency target)*** ▪ composting toilets (80% of households) ▪ water act and associated measures	***Portfolio 1a (to meet emergency target)*** ▪ gutter maintenance and cleaning program (houses and community centres) ▪ additional cisterns (750 kL) ▪ water act and associated measures ***Portfolio 1b (to meet emergency target)*** ▪ gutter maintenance and cleaning program ▪ additional cisterns (750 kL) ▪ RWTs (4.5 kL/ house added to small houses) ▪ water act and associated measures ***Portfolio 1c (to meet emergency target)*** ▪ additional cisterns (1250 kL) ▪ water act and associated measures
Portfolio 2a (to meet critical target) ▪ Portfolio 1a Plus ▪ additional cisterns (2250 kL) ***Portfolio 2b (to meet critical target)*** ▪ Portfolio 1a Plus ▪ Rainwater tanks (RWTs) (2.6 kL/ house added to small houses)	***Portfolio 2a (to meet critical target)*** ▪ Portfolio 1a Plus ▪ additional cisterns (2000 kL) ***Portfolio 2b (to meet critical target)*** ▪ Portfolio 1a Plus ▪ additional cisterns (1250 kL) ▪ RWTs (1.5 kL/ house added to small houses) ▪ composting toilets (50% of households)
Portfolio 3a (to meet longer term target) ▪ Portfolio 2a Plus ▪ additional cisterns (3750 kL) ▪ RWTs (10 kL/ house added to small houses) ▪ composting toilets (40% of households) ***Portfolio 3b (to meet longer term target)*** ▪ Portfolio 2a Plus ▪ fully functioning desalination plant (130 kL/ day with ongoing maintenance and repair support)	***Portfolio 3a (to meet longer term target)*** ▪ Portfolio 2a Plus ▪ additional cisterns (1250 kL) ▪ RWTs (10 kL/ house added to small houses) ▪ composting toilets (24% of households) ***Portfolio 3b (to meet longer term target)*** ▪ Portfolio 2a Plus ▪ groundwater piped to villages and school

Full details of the portfolios, including timing and capacity (where applicable) of the individual options in each portfolio, are provided in Table 6 and Table 7 for Funafuti and Vaitupu respectively. Individual options are discussed below.

4.2.1 Water Act and associated measures

Implementation of the Tuvalu Water Act is considered an important option to underpin implementation of other options. The Water Act was developed as part of Tuvalu's Integrated

Water Management Plan (IWMP) but (to our understanding) has never been fully implemented. Other measures that have been bundled up with this option and which have been allowed for in the costing of the option are:

- community education and awareness programs, targeting water use in non-drought periods and water rationing arrangements in non-drought periods; and
- regular monitoring/soundings of community and government water cisterns during dry periods, with centralised (island level) databases to ensure there is reasonably accurate information on available water supplies and trends.

Implementation of these measures is not assumed in the analysis to deliver any additional water by themselves. However, their implementation will help to improve the effectiveness and efficiency of other options by:

- improving coordination and management of water resources at the national, island and community levels; and
- requiring new buildings to meet minimum standards with respect to water provision and use, including properly installed gutters and tanks.

4.2.2 Gutter cleaning & maintenance

A gutter cleaning & maintenance program (covering gutter cleaning, repairs and replacement for households as well as government and commercial buildings) is an important element of most portfolios considered for Funafuti and Vaitupu. There is no ideal program model. Ultimately, design of the program needs be based on what is most likely to work to ensure household and public building gutters and pipes connected to rainwater tanks and cisterns are kept clean, clear of overhanging branches and are well maintained over the long term. To that end two important aspects of any gutter maintenance program are:

- ensuring that the program is ongoing – it can't be developed, implemented and then left to its own devices;
- ensuring that householders and communities are engaged in the program.

The program designed and costed for this case study is assumed to contain the following elements:

- a gutter maintenance education program held early on at the community/ village level to increase awareness of the importance of keeping gutters and roofs clean and well maintained;
- incentives (financial or other) to encourage householders to keep their gutters clean and well maintained;
- an ongoing (government) position (one part time position on each island) whose role will be to centrally coordinate the program, to undertake regular inspections of gutters and to liaise with Kaupules;
- involvement of Kaupules in the implementation of the program at the community/ village level on education and to coordinate maintenance of gutters on public buildings and minor repairs;
- householders to be responsible for cleaning their own gutters;

- an ongoing gutter maintenance budget to pay for contractors and materials to cover substantial repairs to gutters on houses and public buildings;
- households and communities to pay a nominal sum to cover at least some of the repair costs.

The gutter maintenance program is expected increase both the volume and (and to a limited extent) the quality of rainwater collected. In Funafuti, during a drought year similar to 2010-11 the total yield increase, including from all household tanks, community or government cisterns, amounts to 13,600kL in 2014, increasing to 47,000 kL in 2035.

In Vaitupu, during a drought year similar to 1970-71, the gutter maintenance program is expected to increase the yield, including from all household tanks, community or government cisterns, and tanks and cisterns at the school to 2,300 kL in 2014 rising to 7,200 kL in 2035.

4.2.3 Cisterns

In the event of a drought community and government cisterns provide a 'last line of defence' to ensure that householders have access to a minimum level of potable water to meet their needs. Thus they are likely to be important components of portfolios required to meet emergency or critical targets in Funafuti or Vaitupu. The advantage of cisterns over other supply options is that the Government (or Kaupules) can coordinate distribution of water from cisterns during a drought by means of a rationing system. One disadvantage of cisterns though, particularly in Funafuti, is that they can take up a quite a large area of land.

Two variations of cisterns were assessed for the case study.

'Standard' cisterns

The design and cost of 'standard' cisterns is based on two cisterns currently under construction in Funafuti, a 750 kilolitre (kL) cistern in Lofeagai village (see Figure 12) and a 288 kL cistern in a 'new village' at the southern end of Funafuti. Additional standard cisterns for Funafuti and Vaitupu are assumed to be either 750 kL or 250 kL capacity. No assumptions are made about where these will be located, other than noting that they should be located where they are most needed subject to availability of land. Data for Funafuti and Vaitupu indicates that the roof area of many government and community buildings, which already have cisterns, is great enough to allow for significant increase in the capacity of existing cisterns. In a number of villages it is likely that this will be a preferable option to building new cisterns, especially in Funafuti.

'Borrow pit' cisterns

A second category of cisterns, assessed only for Funafuti, is cisterns that are located on land reclaimed by filling in the island's borrow pits. Borrow pits were created during World War II when the pits were dug to provide a base for the construction of the island's runway. The pits were never refilled, instead filling with brackish groundwater (see Figure 13).

This has created two significant problems for Funafuti:

- There are ten borrow pits on Fongafale islet (the main inhabited land area of Funafuti), which cover an estimated area of 174,178 square metres, or around 8% of Fongafale's total land area (Spiire New Zealand 2013). This 'lost' land is a significant problem for Funafuti, which is experiencing significant internal migration from the country's other islands. Most of the migrants are have to ‘new villages’ which are located in the vicinity of the borrow pits.

- Available evidence indicates that the stagnant and contaminated water in the borrow pits is a significant source of health problems including gastrointestinal illnesses arising from children swimming in the pits, and water from the pits being used at times as a water source by households living in the vicinity of the pits (Lal et al. 2006). Anecdotal evidence also indicates that mosquitos breeding in one of the borrow pits were the source of an outbreak of dengue fever which affected communities in Funafuti for the first time in 2014.

Figure 12: A 750 kL cistern under construction in Lofeagai village, Funafuti

Figure 13: A borrow pit in Funafuti

A preliminary study undertaken into the feasibility of filling in the borrow pits indicates that this is technically feasible (Spiire New Zealand 2013). It also presents options for the location of cisterns. Indeed, at least five of the ten borrow pits (numbers 1, 4, 7, 8 and 10) would appear be suitable sites for large (750 kL) cisterns once they have been filled in (Table 5). With each cistern taking an estimated land area of approximately 400 m^2, five cisterns would require only about 2.5% of the 91,000 m^2 of reclaimed land available from these five pits.

Thus location of additional cisterns on reclaimed borrow pits could offer the potential for 'win-win' outcomes, addressing multiple issues – water security, land scarcity and health.

Table 5: Dimensions of borrow pits in Funafuti

	Estimated dimensions	
Pit number	Volume (m^3)	Area (m^2)
1	45,360	23,110
2	97,617	45,580
3	3,854	2,580
4	47,226	31,080
5	412	571
6	15,913	15,870
7	27,115	14,990
8	3,935	6,440
9	8,220	3,420
10	33,066	16,330
Total	**282,718**	**159,971**

Source: Spiire New Zealand 2013

4.2.4 Rainwater tanks

Data acquired through a recent stocktake of water supplies in Tuvalu indicates that average rainwater tank capacity is over 24,000 litres/ household in Funafuti (Government of Tuvalu and SPC 2014 – see Table 1). This is made up a large proportion of households (approximately 70%) that typically have one or two 10,000 litre rainwater tanks (average 1.8), and a smaller proportion that typically have three or more 10,000 litre tanks (average 3.85). Similarly in Vaitupu, average rainwater tank capacity is just under 20,000 litres/ household in Funafuti (see Table 2), with approximately 70% having one to two rainwater tanks (average 1.4) and a smaller proportion that have two to three tanks (average 2.5).

Large numbers of tanks have been installed in Funafuti, Vaitupu and other islands in Tuvalu over the past decade. An EU aid program installed tanks prior to the 2010-11 drought, with an Australian Government aid program installing many more following the drought. The tanks installed through both programs are typically 10,000 litre polyethylene tanks. The Australian tanks were produced by a semi-portable rotational moulding facility that was located in Funafuti. A small stock of tanks, estimated at 12-18 months of supply, is still available from the Australian program for installation in new houses (see Figure 14).[7] The portable tank moulding facility is no longer in production but a private facility is now producing tanks of the same capacity and design in Funafuti. Cost estimates of tanks used for this assessment are based in continued tank production at this facility.

Figure 14: Rainwater tanks in storage at the Public Works Department depot, Vaiaku Funafuti

[7] Public Works Department of Tuvalu, personal communication March 2014.

Rainwater tanks are now the primary source of potable water for virtually all households in Funafuti and Vaitupu for the majority of the year, especially during the wet season. An advantage of rainwater tanks is that the cost of water supplied through tanks can be very low, provided the tank water is in continuous use[8]. Rainwater tanks will fill quickly with relatively small rainfall, provided gutters are kept well maintained and clean. On the other hand, in the absence of rain, tanks will empty very quickly. For most households, which have only one or two tanks, tank water will run out within 30 days when there has been little or no rainfall (especially if gutters are not well maintained). Only households with four or even five tanks are likely to achieve long term water security of water from their tanks.

Having that many tanks is unlikely to be realistic for many households due to lack of available land. Also, having that many tanks greatly increases the levelised cost of water that they supply, since households with large numbers of tanks will only occasionally need to use the water from the fourth and fifth tanks. A comparison of the costs of Portfolio 2B (which relies significantly on additional rainwater tanks, with the lower costs Portfolio 2A (which relies on additional cisterns) highlights this second problem (see section 5.3.1).

Due to these problems we have assumed that the use of household rainwater tanks to meet targets is limited.

4.2.5 Composting toilets

Flushing of toilets is estimated to use approximately 30% of all water in households that have flush toilets (Sinclair et al. 2012). Flush toilets, linked to poorly designed or maintained septic systems have also been a major source of groundwater and lagoon contamination in Funafuti.

It is this second factor that was the driver behind studies into options for improving liquid waste management and sanitation in Funafuti (Lal et al. 2006). These studies found that composting toilets (dry sanitation technology toilets) have economic and other benefits over alternative options for improving sanitation in Funafuti and other parts of Tuvalu (e.g. improved septic tank systems). As a consequence, a pilot program was introduced to install approximately 40 composting toilets in volunteer homes and public places from 2009 (Seleganiu et al. 2009). At the time the program was introduced householders in Funafuti were apparently resistant to the new technology due to concerns about the cleanliness and hygiene of the toilets (Seleganiu et al. 2009). Anecdotal evidence provided to the project team more recently suggests that although resistance to the toilets has declined, there is still reluctance on the part of the community to fully embrace them. Furthermore, there is anecdotal evidence that the toilets are not achieving the level of water savings that had been hoped because householders who have both a flush toilet and a composting toilet often prefer to use the former.[9]

Notwithstanding these potential drawbacks composting toilets were included in a number of the portfolios due to their potential to provide water security, health, environmental and food security benefits.

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8 The levelised cost of tank water, used on a continuous basis, has been estimated for this study at $2.30/ kL. By comparison, the levelised cost of cistern water is estimated at approximately $5.30/ kL, while the levelised cost of desalination water is over $19/ kL.

9 Evidence provided to the project team at the second project workshop held on 6 & 9 June 2014.

4.2.6 Desalination

Two JICA Hitachi desalination units are currently in operation in Funafuti, operated by the Public Works Department (Figure 15). One plant has a maximum capacity of 50 kL/ day, the other 100 kL/ day.

During dry periods, water from the plant is sold and delivered to householders on a rationed basis – generally 2228 litres (500 gallons)/ household/fortnight. Water from the desalination plant is sold at a subsidised price of approximately $6/ kL less than one third of the estimated cost of production and delivery of $19/ kL. Thus there is a significant cost borne by the Tuvalu government in providing this water. Even so, many poorer households still cannot afford to purchase the desalination water.

Figure 15: Desalination plant at the Public Works Department depot

Desalination water has a major potential drawback as an option for achieving water security – substantial expertise is required to keep the plant maintained and fully operational, expertise that is not available in Tuvalu. This means that should the plant have a breakdown it will be unable to supply water, possibly for extended period. This could be a critical failing during a severe drought. At present, maintenance of the JICA Hitachi desalination units is governed by a three year warranty. That warranty is due to expire within the next 12 months however, and it is unclear how the units will continue to be maintained after the warranty expires.

Given the potential unreliability of desalination, a decision was made not to include it in portfolios for achieving the emergency or critical targets in either Funafuti or Vaitupu. Given that a desalination plant is established and operating in Funafuti, desalination water was included in one of the portfolios for achieving the longer term target. Inclusion of desalination in the portfolio however, is conditional on ensuring that the plant is fully operational into the long term. This is likely to require:

- desalination plant maintenance and repair training for Public Works Department staff, to ensure that there is sufficient knowledge on the ground to carry out emergency repairs should the desalination units break down during a dry period; and
- funding to cover the costs of more extensive plant maintenance and repairs in the future (after expiry of the maintenance warranty); this could possibility be done on a shared basis with other PICs.

4.2.7 Groundwater

A small number of households in Funafuti access groundwater via wells for non-potable uses during dry period. Groundwater is also the source of water for the JICA Hitachi desalination units discussed above. As previously noted however, groundwater is not considered a viable water security option for Funafuti due to contamination.

In Vaitupu groundwater is used for non-potable purposes such as washing, bathing and toilet flushing. The school at Motufoua uses a pump to access groundwater from a nearby well but problems are often experienced with the pump due to silt and the high salinity level of the water at the access point. Households in the villages of Tumaseu and Asau also sometimes use groundwater for non-potable uses but this requires them to travel 3 km across the island or pay to have water collected for them. Given this, a drought assessment undertaken in late 2011 in Vaitupu and other locations in Tuvalu recommended that consideration should be given to constructing a header tank and pipe to bring groundwater closer to the villages (Sinclair et al. 2012).

A comprehensive but preliminary desktop assessment of the groundwater resources in Vaitupu was undertaken for this case study by project team member Eric Rooke, a hydrogeologist with Gilbert & Sutherland (G&S). The assessment considered the quality and extent of the groundwater resources in Vaitupu, the feasibility of increasing use of the resources and options for accessing the resources. The Vaitupu groundwater study is contained in the appendices.

It is emphasised that this was a preliminary study only and that a far more extensive assessment is needed before any decision is made to proceed with an option or options for exploiting the groundwater. Nevertheless, the preliminary study indicates that the groundwater resources at Motufoua and Te Pela are of suitable quality and quantity to enable increased use by the villages and the school for non-potable and possibly potable purposes.

Options considered for accessing the groundwater include:

- Scenario 1: construct an infiltration gallery at Te Pela and connect it by buried pipeline (50 or 75mm diameter HDPE) to Tumaseu and Asau.
- Scenario 2: construct an infiltration gallery at Motufoua and connect it by buried pipeline (50 or 75mm diameter HDPE) to Tumaseu and Asau.
- Scenario 3: construct an infiltration gallery at Motufoua and connect it by buried pipeline (50 or 75mm diameter HDPE) to Motufoua School.
- Scenario 4: construct an infiltration gallery at Te Pela and cart water to Tumaseu and Asau.

- Scenario 5: construct an infiltration gallery at Motufoua and cart water to Tumaseu and Asau.
- Scenario 6: construct an infiltration gallery at Motufoua and cart water to Motufoua School.

Scenarios 2 and 3 were included in Portfolio 3B and assessed for the CBA.

Table 6: Water security portfolios assessed for Funafuti

Target	Portfolio	Options included	Base Case Rainfall Scenario		Worst case drought scenario		Best case drought scenario	
			Additional Capacity	Timing	Additional Capacity	Timing	Additional Capacity	Timing
Emergency (45 litres/ household/ day)	**1A**	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
	1B	**Water Act**		2014		2014		2014
		Additional Cisterns (including increasing the capacity of existing cisterns)	3,750 kL	2021 (750kL) 2023 (750 kL) 2025 (750 kL) 2029 (750 kL) 2034 (750 kL)	4,500 kL	2018 (750 kL) 2020 (750 kL) 2022 (750 kL) 2025 (750 kL) 2030(750 kL) 2034 (750 kL)	2,250 kL	2023 (750 kL) 2028 (750 kL) 2032 (750 kL)
	1C	**Water Act**		2014		2014		2014
		Composting Toilets	Installed in 80% of households, water savings: 45 kL per HH p.a. / max. 38 ML p.a.	Starting with 10% in 2021 up to 85% in 2034	Installed in 100% of households, water savings of 45 kL per HH p.a. / max. 47 ML p.a.	Starting with 5% in 2018 up to 100% in 2025	Installed in 60% of households, water savings of 45 kL per HH p.a. / max. 28 ML p.a.	Starting with 5% in 2023 up to 60% in 2034
Critical (90 litres/ household/ day)	**2A**	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
		Additional Cisterns (including increasing the capacity of existing cisterns)	2,250 kL	2020 (750kL) 2024 (750 kL) 2030 (750 kL)	6,750 kL	2014 (3,000 kL) 2019 (750 kL) 2024 (750 kL) 2028 (750 kL) 2031 (750 kL) 2034 (750 kL)	2,250 kL	2029 (750kL) 2032 (750 kL) 2034 (750 kL)

Target	Portfolio	Options included	Base Case Rainfall Scenario		Worst case drought scenario		Best case drought scenario	
			Additional Capacity	Timing	Additional Capacity	Timing	Additional Capacity	Timing
	2B	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
		Additional Rainwater Tanks (RWT)	on average 2.6 RWTs (26 kL) added to small houses	Starting with (on average) 0.10 RWTs in 2021 up to 2.60 RWTs in 2035	on average 2.0 RWTs (20 kL) added to small houses	Starting with (on average) 1.0 RWT in 2021 up to 2.0 RWTs in 2035	on average 1.25 RWTs (12.5 kL) added to small houses	Starting with (on average) 0.1 RWT in 2029 up to 1.25 RWTs in 2035
		Additional Cisterns (including increasing the capacity of existing cisterns)			4,500 kL	2014 (1,500 kL) 2027 (750 kL) 2029 (750 kL) 2032 (750 kL) 2034 (750 kL)		
		Composting Toilets			Installed in 60% of households, water savings of 45 kL per HH p.a. / max. 28 ML p.a.	Starting with 20% in 2014 up to 60% in 2035		
Longer term (300 litres/ household/ day)	3A	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
		Additional Cisterns (including increasing the capacity of existing cisterns)	6,000 kL	2014 (1,500 kL) 2021 (750 kL) 2027 (750 kL) 2029 (750 kL) 2031 (750 kL) 2032 (750 kL) 2034 (750 kL)	9,750 kL	2014 (3,000 kL) 2019 (750 kL) 2024 (750 kL) 2028 (750 kL) 2031 (750 kL) 2032 (750 kL) 2033 (1,500 kL) 2034 (750 kL) 2035 (750 kL)	3,750 kL	2014 (750 kL) 2019 (750 kL) 2024 (750 kL) 2029 (750 kL) 2034(750 kL)

Target	Portfolio	Options included	Base Case Rainfall Scenario		Worst case drought scenario		Best case drought scenario	
			Additional Capacity	Timing	Additional Capacity	Timing	Additional Capacity	Timing
		Additional Rainwater Tanks (RWT)	on average 1.0 RWTs (10 kL) added to small houses	Starting with (on average) 0.20 RWTs in 2014 up to 1.0 RWTs in 2032	on average 2.0 RWTs (20 kL) added to small houses	Starting with (on average) 1.0 RWTs in 2014 up to 2.0 RWTs in 2024	on average 1.0 RWTs (10 kL) added to small houses	Starting with (on average) 0.10 RWTs in 2014 up to 1.0 RWTs in 2032
		Composting Toilets	Installed in 40% of households, water savings of 45 kL per HH p.a. / max. 19 ML p.a.	Starting with 12% in 2014 up to 40% in 2035	Installed in 80% of households, water savings of 45 kL per HH p.a. / max. 38 ML p.a	Starting with 45% in 2014 up to 80% in 2033	Installed in 32% of households, water savings of 45 kL per HH p.a. / max. 15 ML p.a	Starting with 5% in 2015 up to 32% in 2035
	3B	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
		Additional Cisterns (including increasing the capacity of existing cisterns)	2,250 kL	2020 (750 kL) 2024 (750 kL) 2030 (750 kL)	6,750 kL	2014 (3,000 kL) 2019 (750 kL) 2024 (750 kL) 2028 (750 kL) 2031 (750 kL) 2034 (750 kL)	2,250 kL	2029 (750kL) 2032 (750 kL) 2034 (750 kL)
		Desalination	Max. capacity 130 kL per day	2014	Max. capacity 130 kL per day	2014	Max. capacity 130 kL per day	2014

Table 7: Water security portfolios assessed for Vaitupu

Target	Portfolio	Options included	Base Case		Worst Case		Best Case	
			Additional Capacity	Timing	Additional Capacity	Timing	Additional Capacity	Timing
Emergency (31 litres/ household/ day)	**1A**	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
		Additional Cisterns	750 kL	2014 (500kL) 2028 (750 kL)	1,250 kL	2014 (750 kL) 2018 (250 kL) 2027 (250 kL)	750 kL	2017 (250 kL) 2020 (250 kL) 2034 (250 kL)
	1B	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
		Additional Cisterns	750 kL	2014 (250kL) 2019 (250 kL) 2030 (250 kL)	1,250 kL	2014 (750 kL) 2018 (250 kL) 2027 (250 kL)	750 kL	2017 (250 kL) 2025 (250 kL) 2034 (250 kL)
		Additional Rainwater Tanks (RWT)	on average 0.45 RWTs (4.5 kL) added to small houses	Starting with (on average) 0.10 RWT in 2014 up to 0.45 RWTs in 2027			on average 0.20 RWTs (2 kL) added to small houses	Starting with (on average) 0.15 RWT in 2020 up to 0.20 RWTs in 2023
	1C	**Water Act**		2014		2014		2014
		Additional Cisterns	1,250 kL	2014 (500kL) 2017 (250 kL) 2019 (250 kL) 2024 (250 kL)	2,250 kL	2014 (1,000 kL) 2016 (250 kL) 2020 (250 kL) 2022 (250 kL) 2027 (250 kL) 2035 (250 kL)	1,250 kL	2014 (500kL) 2020 (250 kL) 2022 (250 kL) 2030 (250 kL)
Critical (62 litres/ household/	**2A**	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014

Target	Portfolio	Options included	Base Case		Worst Case		Best Case	
			Additional Capacity	Timing	Additional Capacity	Timing	Additional Capacity	Timing
day)		**Additional Cisterns**	2,750 kL	2014 (1,500kL) 2016 (250 kL) 2019 (250 kL) 2022 (250 kL) 2028 (250 kL) 2034 (250 kL)	3,500 kL	2014 (2,500 kL) 2017 (250 kL) 2022 (250 kL) 2027 (250 kL) 2032 (250 kL)	2,500 kL	2014 (1,000kL) 2016 (250 kL) 2019 (250 kL) 2022 (250 kL) 2025 (250 kL) 2029 (250 kL) 2035 (250 kL)
	2B	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
		Additional Rainwater Tanks (RWT)	on average 0.15 RWTs (1.5 kL) added to small houses	Starting with (on average) 0.15 RWTs in 2014	on average 1.0 RWTs (10 kL) added to small houses	Starting with (on average) 1.0 RWT in 2014	on average 0.90 RWTs (9 kL) added to small houses	Starting with (on average) 0.5 RWT in 2014 up to 0.9 RWTs in 2034
		Additional Cisterns	2,000 kL	2014 (750 kL) 2016 (250 kL) 2023 (250 kL) 2028 (250 kL) 2031 (250 kL) 2033 (250 kL)	2,500 kL	2014 (1,500 kL) 2016 (250 kL) 2023 (250 kL) 2030 (250 kL) 2034 (250 kL)	1,250 kL	2014 (500kL) 2017 (250 kL) 2024 (250 kL) 2031 (250 kL)
		Composting Toilets	Installed in 50% of households, water savings of 45 kL per HH p.a. / max. 7 ML p.a.	Starting with 40% in 2014 up to 50% in 2022	Installed in 75% of households, water savings of 45 kL per HH p.a. / max. 11 ML p.a.	Starting with 50% in 2014 up to 75% in 2033	Installed in 45% of households, water savings of 45 kL per HH p.a. / max. 6.5 ML p.a.	Starting with 30% in 2014 up to 45% in 2035
Longer term (205 litres/ household/	**3A**	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014

Target	Portfolio	Options included	Base Case		Worst Case		Best Case	
			Additional Capacity	Timing	Additional Capacity	Timing	Additional Capacity	Timing
day)		**Additional Cisterns**	4,000 kL	2014 (2,500 kL) 2018 (250 kL) 2021 (250 kL) 2024 (250 kL) 2028 (250 kL) 2031 (250 kL) 2033 (250 kL)	3,500 kL	2014 (2,500 kL) 2017 (250 kL) 2022 (250 kL) 2027 (250 kL) 2032 (250 kL)	2.500 kL	2014 (1,000 kL) 2016 (250 kL) 2019 (250 kL) 2022 (250 kL) 2025 (250 kL) 2029 (250 kL) 2033 (250 kL)
		Additional Rainwater Tanks (RWT)	on average 1.0 RWTs (10 kL) added to small houses	Starting with (on average) 1 RWTs in 2014	on average 1.3 RWTs (13 kL) added to small houses	Starting with (on average) 1.0 RWTs in 2014 up to 1.3 RWTs in 2033	on average 1.3 RWTs (13 kL) added to small houses	Starting with (on average) 1.0 RWTs in 2014 up to 1.3 RWTs in 2027
			on average 0.5 RWTs (5 kL) added to large houses	Starting with (on average) 0.5 RWTs in 2014			on average 0.1 RWTs (1 kL) added to large houses	Starting with (on average) 0.1 RWTs in 2014
		Composting Toilets	Installed in 24% of households, water savings of 45 kL per HH p.a. / max. 3.5 ML p.a.	Starting with 10% in 2014 up to 24% in 2035	Installed in 62% of households, water savings of 45 kL per HH p.a. / max. 9 ML p.a	Starting with 35% in 2014 up to 62% in 2035	Installed in 26% of households, water savings of 45 kL per HH p.a. / max. 3.8 ML p.a	Starting with 20% in 2015 up to 26% in 2032
	3B	**Water Act**		2014		2014		2014
		Gutter Maintenance		2014		2014		2014
		Additional Cisterns	2,750 kL	2014 (1,500kL) 2016 (250 kL) 2019 (250 kL) 2022 (250 kL) 2028 (250 kL) 2034 (250 kL)	3,500 kL	2014 (2,500 kL) 2017 (250 kL) 2022 (250 kL) 2027 (250 kL) 2032 (250 kL)	2,500 kL	2014 (1,000kL) 2016 (250 kL) 2019 (250 kL) 2022 (250 kL) 2025 (250 kL) 2029 (250 kL) 2035 (250 kL)
		Groundwater supply from (Motufoua to villages and the school)	Max. capacity 66 ML per year	2014	Max. capacity 29 ML per year	2014	Max. capacity 66 ML per year	2014

5. Cost benefit analysis

Once a set of feasible portfolios has been has been identified, more detailed CBA is required using the portfolio modelling approach. This entails modelling the costs and benefits and performance of each portfolio relative to the base case[10]. The steps applied to assessing costs and benefits essentially follows the 'with and without' steps detailed in *Cost-Benefit Analysis for Natural Resource Management in the Pacific: A Guide*:

- Identify the costs and benefits (Step 2);
- Value the costs and benefits (Step 3); and
- Aggregate the costs and benefits (Step 4).

These steps are not discussed further here. However, there are two aspects of the modelling approach applied to this CBA that should be noted:

- First, portfolios are modelled in their entirety not just their individual components. This means that the economic and hydrological interactions between options within each portfolio are taken into account.
- Second, major sources of uncertainty are considered and addressed in the analysis.

The remainder of this section provides an assessment of the costs and benefits of portfolios for achieving water security:

- Section 5.1 discusses application of uncertainty analysis in the CBA.
- Section 5.2 details the data assumptions that underpin the valuation of costs and benefits.
- Section 5.3 presents results of the CBA for Funafuti and Vaitupu respectively, including outcomes of scenario and sensitivity analysis.
- Section 5.4 explores the distributional impacts of some of the key options assessed for Funafuti and Vaitupu.

5.1 Application of uncertainty analysis in the CBA

As previously noted, risk is defined as the likelihood and consequence of a hazard or unfavourable event. Uncertainty can be defined as a poor knowledge of the likelihood (or probability) that the event will occur and/or poor knowledge of the consequence of the event should it occur. Sources of uncertainty include:

- data problems such as data errors, missing data, out-of-date data (e.g. the number of people experiencing gastro-intestinal illness in Funafuti due to poor water quality);
- problems with model outputs (physical and/or economic) such as structure, parameter values, or dynamic and poorly understood systems (e.g. projections of changes to average rainfall in the Pacific); and
- human behaviour (e.g. current and future water demand in Tuvalu).

10 The base case represents the current suite of actions (water supplies, demand management initiatives and associated policies) through which water is currently supplied as discussed in section 3.2.

There are numerous uncertainties with variables used in the analysis of water security costs and benefits in Tuvalu. Principal amongst these are:

- projections of average rainfall, and rainfall variability (including frequency and severity of droughts);
- the value that accrues to water delivered through options and portfolios;
- the potential for outages or failure of plant (in particular desalination plants);
- demand projections, including population growth and the household characteristics that affect either demand or supply (such as the number of people in the house and the condition of tanks and gutters); and
- estimates associated with other benefits such as health and environmental benefits of some options.

Techniques are available for dealing with these uncertainties are summarised in Table 8 (with the techniques applied to this CBA highlighted). Selection of the most suitable technique will primarily be driven by the nature of the variable and associated uncertainty. If confidence intervals can reasonably be estimated for a particular uncertain variable or suite of variables then sensitivity analysis should be used. This is the approach applied to some key uncertain variables in the Tuvalu case study such as the capital and operating costs and health benefits of some options.

If confidence intervals for the uncertain variable cannot be estimated with any confidence then scenario analysis should be used. This is the approach applied to climate change projections in Tuvalu (see section 2.1.4). More sophisticated techniques such as Monte Carlo simulation and real options analysis should only be used if the probability distribution for values of the uncertain variable can be reliably estimated. This was not the case for key uncertain variables in the Tuvalu case study and we suggest that application of the advanced modelling and statistics required of these techniques is unlikely to be justified for water security CBA in many PICs. As discussed in Box 1, we suggest that threshold analysis is an appropriate technique for addressing uncertainty about the value of water in Tuvalu and other PICs.

Table 8: Overview of techniques for addressing uncertainty in a CBA

Method	Situations where technique is suitable	Example
Scenario analysis	A range of values for the uncertain variable cannot be estimated with confidence but a set of *plausible* outcomes can be constructed.	A *plausible* picture can be painted of the 'best case' and 'worst case' change to the severity of an extreme dry year under climate change.
Sensitivity analysis	A range of outcomes for the uncertain variables can be estimated with confidence.	A reliable range of changes to the severity of an extreme dry year under climate change can be estimated.
Sensitivity analysis with 'correlations'	Same circumstances where a standard sensitivity analysis would be used but also the interaction between the different uncertain variables can be estimated.	A numerical link can be established between projected rainfall changes and sea level rise on the volume of the freshwater lens in groundwater.
Threshold analysis	It is useful to understand at what value for an uncertain variable a particular objective can be achieved or at what value the best course of action changes.	The minimum value that a community would need to attach to rationed water to justify pursuing the minimum water security target. To see how threshold analysis has been applied to the Tuvalu water security CBA, refer Box 1.
Monte Carlo simulation*	Same circumstances where a standard sensitivity analysis would be used but also the *probability distribution* for values of the uncertain variable can be estimated.	The probability distribution of the range of changes to the severity of an extreme dry year can be estimated given climate change projections.
Real Options*	When the value in having flexibility to respond to uncertain variables as and when they become more certain is useful to quantify.	It would useful to quantify the value of deferring a decision on water security investments until the direction of likely changes to rainfall under climate change become clearer

*As discussed in the text, it is unlikely that Monte Carlo simulation or Real Options would be applied to a water security CBA in PICs.

Box 1. What is the value of a secure water supply?

What value should be attached to the extra security of water delivered through portfolios? This extra security is the primary benefit of the portfolios being assessed, so the answer to the question is critical to results of the analysis.

In some earlier cost benefit studies of water options undertaken in Tuvalu other PICs the assumed value of water was the production and delivery cost of desalination water. This value (or more correctly the variable component of the production and delivery cost) would be appropriate if the CBA were considering only a single option (e.g. a water cistern) rather than a portfolio, and the water provided by that option resulted in a proportionate reduction in demand for desalination water. However, when the portfolio *includes* a desalination plant, this approach is inappropriate. Even when examining a single option, note that valuing water with reference to reduced desalination costs will only be appropriate *if and when demand for desalinated water reduces*. During times of drought it is feasible that demand for desalination water will not fall but will be reallocated to other families or shifted to alternative uses. In addition, should desalination water become unavailable during a drought and severe water rationing is required, the amenity value of water will increase significantly because essential water uses will be affected.

In Australia, uncertainty over the value that should be attached to a secure water supply is often addressed through surveys of households and other water consumers to establish their willingness to pay (WTP) to achieve different levels of water security and to avoid water rationing/ restrictions. WTP values are commonly used in CBA as a way of quantifying the value of an outcome that is not traded in a market (i.e. a non-market value), such as the value of taking a shower or washing clothes at home. The difficulty with this approach for Tuvalu and other PICs is that WTP studies can be very time and resource intensive exercises. Also, the results of the survey can still be subject to considerable uncertainty and are often open to interpretation. For this reason, a WTP survey was not considered for the Tuvalu case study and we consider it unlikely to be appropriate for water strategy studies in other PICs within the foreseeable future.

Rather than establishing the value of water through WTP studies, it is recommended that a threshold approach be used. This is the approach applied to the CBA's in Tuvalu. In the context of water security, the threshold value for each portfolio would be the cost per household of implementing that portfolio. Unless there are overriding qualitative considerations (such as environmental impacts), the preferred portfolio will generally be the portfolio that results in the lowest cost per household for each of the water security 'targets'.

Decision makers can then assess whether meeting each progressively higher target would be worth the additional cost per household. Without survey information, this 'threshold' decision will necessarily be subjective, but the magnitude of the increments (whether very large or very small) can often be enough to make the decision self-evident.

5.2 Data assumptions

Tables 9 and 10 detail the cost and benefit data assumptions that underpin the costs benefit analysis of water security options and portfolios for Funafuti and Vaitupu respectively. Following are discussion points accompanying the cost and benefit assumptions for each option.

5.2.1 General

- All values are in Australian dollars, 2013 prices.
- The default discount rate applied to the analysis is 8%. Discount rates of 5% and 10% are applied in sensitivity analysis. The default rate reflects the discount rate that is typically applied to investment analysis in Tuvalu and is also quite consistent with rates applied in other PICs (see for example Buncle et al. 2013).
- For options included in both Funafuti and Vaitupu portfolios, capital costs are based on estimates for Funafuti. A 10% loading is then applied to capital cost estimates for Vaitupu.
- A wide range of sources are used for cost and benefit estimates. Staff from Tuvalu government departments including the Public Works Department, Statistics Department and Finance Department, were valuable sources of information. Staff from the Pacific Adaptation to Climate Change (PACC) program and SPC were also important sources of information. Other sources of information include Lal et al. 2006, MFED 2012, Sinclair et al. 2012 and Spiire New Zealand Ltd 2013.

5.2.2 Rainwater tanks

- All tanks are assumed to be 10kL in capacity and are assumed to have a life of 25 years.
- The cost of the tank is for the tank unit only. Installation costs include cost of constructing a concrete tank base, additional roofing (in 20% of cases), guttering, stormwater pipes, a first flush diverter, other fittings, delivery and labour.
- The value of private land has been estimated at $4.69/m2/year ($19,000/acre/year). With the area for a 10,000 litre tank being 10m^2, (1m^2/kL), this is equivalent to an opportunity cost of land for tanks of $47/year.
- Avoided illness and trauma associated with water restrictions is relevant to all options considered. This benefit was not quantified however.

5.2.3 Cisterns

- The cost of cistern construction was based principally on estimates developed in detail in MFED 2012. These were reviewed, some small adjustments made and costs inflated to 2013 prices.
- A basic structure is assumed for the collection of stormwater directed into a cistern. In many cases a public building (e.g. community hall) will be constructed with a cistern but the costs and benefits of those types of community facilities are not included in the assessment. The material costs were calculated based on costs of materials in Fiji, with a 15% loading applied for transport to Funafuti.
- The assumed life of cisterns is 30 years.

- As noted in section 4.2.3, it is likely that increasing the capacity of standard cisterns will in many cases be feasible through expanding the capacity of existing cisterns. Whether this will result in cost savings compared to building new cisterns is uncertain though. Cost savings are not therefore assumed for this sub-option.
- Cisterns are assumed to be on land used for public purposes. The value of this land is estimated at $1.48/m^2/yr ($6,000/acre/yr). With area of a 750 kL tank typically being 375m^2 (0.5 m^2/kL), this is equivalent to an opportunity cost of land for a 750 kL cistern of $555/year.
- The cost associated with collecting water from cisterns of $8.21/kL in Funafuti is based on an assumed collection time of 25 minutes/trip and a value of time of $2.63/hour. Workshop participants indicated that water is generally collected by teenagers. The cost associated with collecting water from cisterns of $8.21/kL in Vaitupu is based on an assumed collection time of 45 minutes/trip.
- The costs of filling in the borrow pits was sourced primarily from Spiire 2013. These are preliminary only.
- The cost of land for house relocation is based on public use value of land of $1.48/m^2/year and an assumed land area of 250m^2 required for each house.
- The cost of constructing a house is based on estimated price of constructing a house in Fiji and Tuvalu of $550/square metre, with each house being 110 square metres. Ten tenants are assumed to require relocation for each pit that is filled.
- Avoided illness of residents exposed to contaminated water in pits of $20,477/ pit/ year is based on the following assumptions:
  - In drought periods local residents are known to source water from borrow pits for bathing and cooking. This water is contaminated with human and pig faecal matter, rotting biological matter and heavy metals and is saline (especially after king tides) and is thought to be one of the leading causes of gastro.
  - Gerber et al. 2011 estimate annual health costs from measures which improve water supply of approximately $216,000 based on a reduction of 6-25% (15.5% average) in water-borne disease related health costs arising from the implementation of composting toilets and water supply measures.
  - Arguably filling in borrow pits could achieve this level of benefit, but only for that portion of the population living in the vicinity of the pits and directly benefiting from curtailing access to groundwater and access to cistern water instead.
  - The estimate of beneficiaries is 70-100 households/pit.
  - The estimated benefit is subject to a high degree of uncertainty.
- The value of restored land from filling in borrow pits is a weighted average of the value of public land use estimated at $1.48/m^2/yr ($6,000/acre/year) (33% of the total) and $4.69/m^2/year ($19,000/acre/year) for private land (67% of the total).

5.2.4 Composting toilets

- The cost of constructing a toilet at estimated at $4,135/ unit drawing on information presented in Lal et al. 2006 and discussion with the Public Works Department. Costs are assessed to be approximately 25% less (in real terms) than estimated in Lal et al. 2006, assuming lower costs of materials sourced from Fiji, lower locally sourced labour costs and some economies of scale.

- The assumed life of a toilet is 15 years.
- The value of health benefits of composting toilets is based on a reduction in contamination of groundwater and the following assumptions:
  - Gerber et al. 2011 estimate annual health costs from measures which improve water supply of approx. $216,000 based on a reduction of 6-25% (15.5% average) in water-borne disease related health costs arising from the implementation of composting toilets and water supply measures.
  - Arguably composting toilets would not achieve improvements of that significance since even a 100% household take-up of composting toilets would still leave groundwater contaminated from other sources (e.g. piggeries).
  - The low end estimate is used instead (6% reduction). To avoid double counting, this benefit is assumed to only apply in communities that don’t live close to areas where borrow pits have been filled in.
  - The potential environmental benefits of composting toilets on lagoon water quality and fish stocks were not estimated.

5.2.5 Gutter maintenance program

The gutter maintenance program has a number of cost elements:

- Program development, which requires 2 people full time for 12 months in Funafuti and 1 person full-time for 12 months in Vaitupu.
- Implementation, including education materials and the conduct of 9 community workshops in Funafuti and 3 workshops in Vaitupu.
- Ongoing staff costs of 0.5 persons in Funafuti and 0.25 persons in Vaitupu to inspect gutters and tanks, advise Kaupule and follow-up. Vehicle and other operating expenses are also required.
- Annual maintenance costs of $13,525 in Funafuti and $4,446 in Vaitupu include:
  - time spent cleaning gutters by householders;
  - replacement materials including new guttering, stormwater piping and stop ends (7.5% of houses/year, based on an assumed lifetime of 15 years), first flush devices (installed/replaced in 5% of houses each year), and contract labour of 600 hours/ year in Funafuti and 200 hours/ year in Vaitupu at $4/ hour.

5.2.6 Groundwater

- The costed options are a piped system from Motufoua to the villages and Motufoua to the school. Major capital costs include pumps and header tanks and the cost of the PVC piping. These are detailed in Appendix C.

- Land lost for the pipeline is assumed to be 3000m^2 for the pipeline to the villages and 3000m^2 for the pipeline to the school. This land is valued at the public use value of \$1.48/m^2/year.

5.2.7 Desalination

- The variable cost of producing desalination water from the JICA Hitachi desalination units located in Funafuti is estimated to be \$19.30/kL. This estimated draws on MFED 2012 and discussions with the Public Works Department.
- The cost of a desalination maintenance & training program is assumed to include:
  - Training of two Public Works Department (PWD) staff in plant maintenance in Australia or New Zealand for one month full time (including salaries and costs).
  - Costs associated with setting up a training program (including. salaries, on-costs, facilities and recruitment in the host country), with costs potentially shared with at least one other PIC.
  - Costs associated with recruiting and establishing a permanent maintenance taskforce, with costs shared with a number of other PICs.
  - The costs of running the taskforce, comprising a permanent staff of two, again shared between a number of PICs.
  - Taskforce expenses based on two maintenance visits to each PIC each year, including Tuvalu.
  - A one week training refresher course for PWD staff every two years.

Table 9: Cost and benefit data assumptions, Funafuti

Option	Relevant portfolios	Category	Sub-category	Data variable	Assumed cost/benefit	Unit
Rainwater tanks	**2b, 3a**	**Costs**	Upfront costs	Tank cost	1,530	$/tank
				Installation cost	714	$/tank
			Ongoing costs	Maintenance costs	See gutter maintenance program	
				Opportunity cost of land	4.69	$/m2/year
		Benefits	Health	Avoided illness & trauma	Not quantified	
Cisterns (standard)	**1b, 2a, 3a**	**Costs**	Upfront costs	Cost of constructing cistern	167,250	$/cistern
				Cost of constructing stormwater collection roof	24,426	$/cistern
			Ongoing costs	Maintenance costs	8,363	$/year
				Opportunity cost of land	1.48	$/m2/year
			Water collection	Additional costs associated with collecting water	8.21	$/kL
		Benefits	Health	Avoided illness & trauma	Not quantified	
Cisterns (borrow pits)	**1b, 2a, 3a**	**Costs**	Upfront costs	Cost of infilling borrow pit	26.10	$/m3 of pit
				Cost of constructing cistern	167,250	$/cistern
				Cost of constructing stormwater collection roof	24,426	$/cistern

Option	Relevant portfolios	Category	Sub-category	Data variable	Assumed cost/benefit	Unit
				Relocation of tenants	60,500	$/house
			Ongoing costs	Maintenance costs	8,363	$/year
				Opportunity cost of land	1.48	$/m2/year
				Cost of land for house relocation (tenants)	370.00	$/house/yr
			Water collection	Additional costs associated with collecting water	8.21	$/kL
		Benefits	Restored land	Opportunity value of restored land	3.63	$/m2/year
			Health	Avoided illness of residents exposed to contaminated water in pits	20,477	$/yr/pit
Composting toilets (dry sanitation)	**1c, 3a**	**Costs**	Upfront costs	Cost of constructing unit	4,135	$/unit
			Ongoing costs	Operating & maintenance	124	$/year
				Opportunity cost of land	0.00	$/yr
		Benefits	Health & environ't	Avoided illness of residents exposed to contaminated groundwater water	93.25	$/yr/unit
				Avoided contamination of lagoon and fish stocks	Not quantified	
				Avoided illness & trauma	Not quantified	
				Value of compost produced	25.0	$/yr/unit
Gutter maintenance program	**1a, 2a, 2b, 3a, 3b**	**Costs**	Develop't costs	Program development	22,509	$
				Implementation - workshops and materials	27,000	$
			Ongoing costs	Administration (incl. inspection)	7,663	$/yr
				Maintenance costs (materials and labour)	13,525	$/yr
		Benefits	Health	Avoided illness of residents exposed to contaminated tank water	3,349	$/yr
				Avoided illness & trauma	Not quantified	
Water Act & associated measures	**all**	**Costs**	Develop't costs	Policy development	11,254	$
			Ongoing costs	Implementation	22,509	$/yr
		Benefits		Not quantified		
Desalination training & maintenance program	**3b**	**Costs**	Develop't costs	Staff training	10,376	$
				Establishing training program	25,500	$
				Set up taskforce	5,000	$
			Ongoing costs	Desal. maintenance taskforce	43,333	$/yr
				Taskforce expenses	52,333	$/yr
				Training refresher course	8,969	$/ 2 yrs
		Benefits	Water reliability	Long term reliability in delivery of desal. water	Not quantified	

Table 10: Cost and benefit data assumptions, Vaitupu

Option	Relevant portfolios	Category	Sub-category	Data variable	Assumed cost/benefit	Unit
Rainwater tanks	**1b, 2b, 3a**	**Costs**	Upfront costs	Tank	1,683	$/tank
				Installation cost	785	$/tank
			Ongoing costs	Maintenance costs	See gutter maintenance program	
				Opportunity cost of land	1.48	$/m2/year
		Benefits	Health	Avoided illness & trauma		Not quantified
Cisterns (standard)	**1a, 1b, 1c, 2a, 2b, 3a**	**Costs**	Upfront costs	Cost of constructing cistern	183,975	$/cistern
				Cost of constructing stormwater collection roof	11,415	$/cistern
			Ongoing costs	Maintenance costs	9,199	$/year
				Opportunity cost of land	1.48	$/m2/year
			Water collection	Additional costs associated with collecting water	14.77	$/kL
		Benefits	Health	Avoided illness & trauma		Not quantified
Composting toilets (dry sanitation)	**2b, 3a**	**Costs**	Upfront costs	Cost of constructing unit	4,549	$/unit
			Ongoing costs	Operating & maintenance	136	$/year
				Opportunity cost of land	0.00	$/yr
		Benefits	Health & environ't	Avoided illness of residents exposed to contaminated groundwater	0.00	$/yr/unit
				Avoided contamination of coastal waters and fish stocks		Not quantified
				Avoided illness & trauma		Not quantified
				Value of compost	25.0	$/yr/unit
Gutter maintenance program	**1a, 1b, 2a, 2b, 3a, 3b**	**Costs**	Develop't costs	Program development	11,254	$
				Implementation - workshops and materials	9,000	$
			Ongoing costs	Administration (incl. inspection)	3,831	$/yr
				Maintenance costs (materials and labour)	4,446	$/yr
		Benefits	Health	Avoided illness of residents exposed to contaminated tank water	1,030	$/yr
				Avoided illness & trauma		Not quantified
Water Act & associated measures	**all**	**Costs**	Develop't costs	Policy development	2,814	$
			Ongoing costs	Implementation	11,254	$/yr
		Benefits				Not quantified
Groundwater (Scenario 2 - Motufoua to villages)	**3b**	**Costs**	Upfront costs	Construction of pipeline	156,816	$
			Ongoing costs	Operating & maintenance	4,704	$/year
				Opportunity cost of land	4,440	$/yr
				Avoided illness & trauma		Not quantified
Groundwater (Scenario 3 - Motufoua to school)	**3b**	**Costs**	Upfront costs	Construction of pipeline	251,196	$
			Ongoing costs	Operating & maintenance	7,536	$/year
				Opportunity cost of land	4,440	$/yr
				Avoided illness & trauma		Not quantified

5.3 Costs & benefits of options and portfolios, Funafuti

5.3.1 Results

Results of the CBA of water security portfolios for Funafuti are presented in Table 11 below for the standard drought scenario.

Table 11: CBA of water security portfolios for Funafuti, standard drought scenario ($A)

	Emergency Target Portfolios			Critical Target Portfolios		Long Term Target Portfolios	
Options	**1A**	**1B**	**1C**	**2A**	**2B**	**3A**	**3B**
Water Act							
Development Cost	-11,254	-11,254	-11,254	-11,254	-11,254	-11,254	-11,254
Ongoing Cost	-274,879	-274,879	-274,879	-274,879	-274,879	-274,879	-274,879
Gutter Maintenance							
Development Cost	-47,509			-47,509	-47,509	-47,509	-47,509
Admin, Materials, Labour	-258,746			-258,746	-258,746	-258,746	-259,198
Health Benefits	44,247			44,247	44,247	44,247	44,247
Cisterns							
Capital Expenditure		-3,464,926		-2,632,523		-5,105,526	-2,636,089
Maintenance		-218,540		-149,165		-432,488	-149,700
Water Collection				-273,133	-213,942	-452,658	-256,238
Land Opportunity Cost		1,802,052		1,485,688		2,401,659	1,491,008
Health Benefit		535,132		365,256		788,472	365,256
Additional RWTs							
Tank, Delivery, Labour					-1,785,330	-1,120,595	
Land Opportunity Cost					-413,593	-266,022	
Composting Toilets							
Construction Cost			-1,681,364			-1,889,641	
Maintenance			-562,640			-645,602	
Health Benefits			422,933			324,668	
Value of Compost			113,382			87,039	
Desalination							
Development Cost (Task Force & Training)							-39,737
Ongoing (Taskforce & Training)							-1,225,268
Water Production							-785,536
Water Collection							-57,869
NPV excluding value of water ($)	**-548,141**	**-1,632,415**	**-1,993,821**	**-1,752,018**	**-2,961,007**	**-6,858,834**	**-3,784,896**
Threshold value of water ($/household/year)	**44.47**	**132.44**	**161.56**	**141.97**	**239.93**	**555.77**	**307.23**

Our analysis suggests that Portfolio 1A (combining a gutter maintenance program with implementation of the Water Act and associated measures) is likely to provide the most cost effective pathway for achieving the emergency target[11]. Furthermore, it is likely to produce a net benefit overall to the community. A threshold value of just $44/household/year is required for

11 Emergency target - sufficient clean and reliable potable water to meet all households' emergency water needs for drinking and cooking, including in the event of a worst case drought

Portfolio 1A to achieve a positive net present value (NPV)[12]. In other words, households in Funafuti need only value the additional water delivered by Portfolio 1A at $44/household/year for the portfolio to produce a net benefit to the community. By way of comparison, it is estimated that households in Funafuti will spend, on average, an estimated $200/household for the purchase of desalination water in a drought year and that water will cost the government an additional $450/household/year to produce.

Portfolio 1B (combining additional cisterns with implementation of the Water Act) has an estimated threshold value of $132/household/year, while Portfolio 1C (combining composting toilets with implementation of the Water Act) has an estimated threshold value of $162/household per year.

Portfolio 2A (combining Portfolio 1A with additional community cisterns) is likely to be the most cost effective pathway for achieving the critical target[13]. It is also likely to produce a net benefit overall to the community. A threshold value of $142/household/year is required for Portfolio 2A to achieve a positive NPV. This estimate assumes that all of the costs and benefits associated with the infill of borrow pits are attributed to the construction of cisterns in the borrow pits. Portfolio 2B (combining Portfolio 1A with a mix of additional cisterns, additional rainwater tanks and composting toilets) has an estimated threshold value of $240/household/year.

Portfolio 3B (combining Portfolio 2A with desalination water) is likely to be the most cost effective pathway for achieving the longer term target[14]. A threshold value of $307/household/year is required for Portfolio 3B to achieve a positive NPV. Portfolio 3A (combining Portfolio 2A with a mix of additional rainwater tanks and composting toilets) has an estimated threshold value of $556/household/year.

As with Portfolios 1C and 2B, the inclusion of composting toilets is a major factor driving up the cost of Portfolio 3A. At greater than $4000/unit, the upfront capital cost of composting toilets is the principal factor driving the high cost of this option.

5.3.2 Scenario and sensitivity analysis

Alternative rainfall scenarios

Scenario analysis of rainfall scenarios is set out in Table 12. The scenario analysis reveals that the rank ordering of options based on net present values does not change under any of the climate change scenarios. This result shows that the rankings are relatively robust to variations in underlying climate assumptions and their parameters.

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12 NPV is the Present Value (PV) of benefits delivered by an option or portfolio less the PV of costs incurred. An option or portfolio that has a positive NPV is likely to deliver overall economic or community benefits.

13 Critical target - sufficient clean and reliable potable water to meet all households' critical water needs for drinking, cooking and personal hygiene, including in the event of a worst case drought

14 Longer term target - sufficient clean and reliable potable water to meet all households' essential water needs for drinking, cooking, personal hygiene, other washing, clothes washing and water for animals.

Table 12: Rainfall scenario analysis, Funafuti portfolios ($A)

	Emergency Target Portfolios			Critical Target Portfolios		Long Term Target Portfolios	
	1A	1B	1C	2A	2B	3A	3B
Standard drought scenario							
NPV excluding value of water ($)	-548,141	-1,632,415	-1,993,821	-1,752,018	-2,961,007	-6,858,834	-3,784,896
Threshold value of water ($/household/year)	44.47	132.44	161.56	141.97	239.93	555.77	307.23
Worst case drought scenario							
NPV excluding value of water ($)	-548,141	-2,137,957	-3,432,437	-4,113,251	-9,827,716	-13,097,653	-7,581,610
Threshold value of water ($/household/year)	44.47	173.46	278.13	333.30	796.34	1,061.30	615.41
Change (%)	*0%*	*31%*	*72%*	*135%*	*232%*	*91%*	*100%*
Best case drought scenario							
NPV excluding value of water ($)	-548,141	-1,042,706	-1,282,836	-1,319,037	-1,506,523	-5,256,666	-3,135,714
Threshold value of water ($/household/year)	44.47	84.60	103.95	106.88	122.07	425.95	254.53
Change (%)	*0%*	*-36%*	*-36%*	*-25%*	*-49%*	*-23%*	*-17%*

Sensitivity analysis, key cost and benefit assumptions

Cisterns

As previously noted, Portfolio 2A is estimated to have a threshold value of $142/household/year. This estimate assumes that all of the costs and benefits associated with the infill of borrow pits are attributed to the construction of cisterns in the borrow pits. If instead, the costs and benefits associated with the infill of borrow pits are <u>not</u> attributed to the construction of cisterns or if land other than borrow pits land is used for the construction of the cisterns this changes the net cost of Portfolios that have cisterns (1B, 2A, 3A and 3B). For example, Portfolio 2A has a threshold value of $142/household/year when borrow pit costs and benefits are included compared with $101/household/year when they are not included (Table 13). That is, filling of borrow pits raises the threshold value by almost 30 percent. However, if a lower discount rate of 5% is used then the reverse is true, with borrow pit cisterns now having a threshold value of only $86 compared with $103 for the standard borrow pits. This outcome highlights the high sensitivity of borrow pit net costs and benefits assessment to the discount rate, reflecting the high upfront capital costs associated with filling in the borrow pits, contrasted with the health and land benefits which mainly accrue in the future. The outcome also highlights the value in undertaking further assessment of the potential costs and benefits of borrow pits.

However, the sensitivity analysis reveals that the rank ordering of cistern focussed portfolios, based on net present value, does not change if the attribution of costs and benefits of filling borrow pits to the cisterns is included or excluded. Portfolio 2A for example, will still be the most cost effective portfolio for achieving the critical target whether or not borrow pits are used for the cisterns.

Table 13: Sensitivity analysis of borrow pit cisterns ($A)

	Emergency Target Portfolios			Critical Target Portfolios		Long Term Target Portfolios	
	1A	1B	1C	2A	2B	3A	3B
Costs/Benefits of Borrow Pits are attributed to Cisterns							
NPV excluding value of water ($)	-548,141	-1,632,415	-1,993,821	-1,752,018	-2,961,007	-6,858,834	-3,784,896
Threshold value of water ($/household/year)	44.47	132.44	161.56	141.97	239.93	555.77	307.23
Costs/Benefits of Borrow Pits are not attributed to Cisterns							
NPV excluding value of water ($)	-548,141	-920,221	-1,993,821	-1,251,419	-2,961,007	-5,761,930	-3,289,653
Threshold value of water ($/household/year)	44.47	74.66	161.56	101.40	239.93	466.89	267.03
Change (%)	*0%*	*-44%*	*0%*	*-29%*	*0%*	*-16%*	*-13%*

Other costs and benefits

We have also undertaken sensitivity analysis of other options and portfolios examining the changes to:

- capital and operating costs (+/- 10%),
- the benefits associated with the options (+/- 10%); and
- the discount rate (5% and 10%).

We found that changes in these parameters do not affect the rank ordering of portfolios based on net present values.

5.4 Costs & benefits of options and portfolios, Vaitupu

5.4.1 Results

Results of the CBA of water security portfolios for Vaitupu are presented in Table 14 Table 11 for the standard drought scenario. Our analysis suggests that Portfolio 1A (combining a gutter maintenance program with additional cisterns and implementation of the Water Act) is likely to provide the most cost effective pathway for achieving the emergency target. A threshold value of $96/household/year is required for Portfolio 1A to achieve a positive NPV. In other words, households in Vaitupu need to value the additional water delivered by Portfolio 1A at $96/household/year for the portfolio to produce a net benefit overall to the community. This value is greater than for the corresponding Portfolio 1A in Funafuti which reflects the fact that to achieve the emergency target in Vaitupu requires the installation of additional cisterns as well as a gutter maintenance program and Water Act, whereas additional cisterns are not required to achieve the emergency target in Funafuti.

Portfolio 1B (combining a gutter maintenance program with additional cisterns, additional rainwater tanks and implementation of the Water Act) has an estimated threshold value of $124/household/year, while Portfolio 1C (combining additional cisterns with the Water Act) has an estimated threshold value of $112/ household per year.

Table 14: CBA of water security portfolios for Vaitupu, standard drought scenario ($A)

	Emergency Target Portfolios			Critical Target Portfolios		Long Term Target Portfolios	
Options	**1A**	**1B**	**1C**	**2A**	**2B**	**3A**	**3B**
Water Act							
Development Cost	-2,814	-2,814	-2,814	-2,814	-2,814	-2,814	-2,814
Ongoing Cost	-137,439	-137,439	-137,439	-137,439	-137,439	-137,439	-137,439
Gutter Maintenance							
Development Cost	-19,588	-19,588		-19,588	-19,588	-19,588	-19,588
Admin, Materials, Labour	-101,085	-101,085		-101,085	-101,085	-101,085	-101,167
Health Benefits	13,615	13,615		13,615	13,615	13,615	13,615
Cisterns							
Capital Expenditure	-176,943	-149,106	-298,057	-655,031	-392,843	-855,824	-655,031
Maintenance	-94,234	-79,002	-158,582	-347,658	-208,191	-455,147	-347,658
Water Collection	0	0	0	-273,196	-232,455	-774,849	-845,027
Land Opportunity Cost	-5,686	-4,767	-9,568	-20,976	-12,561	-27,461	-20,976
Health Benefit							
Additional RWTs							
Tank, Delivery, Labour		-181,875			-86,918	-869,176	
Land Opportunity Cost		-12,424			-6,002	-60,017	
Composting Toilets							
Construction Cost					-688,874	-286,133	
Maintenance					-237,165	-98,104	
Health Benefits							
Value of compost					43,448	17,972	
Groundwater (Motufoua to villages & school)							
Construction Cost							-408,012
Maintenance							-149,481
Land Opportunity Cost							-117,324
NPV excluding value of water ($)	**-524,174**	**-674,484**	**-606,460**	**-1,544,171**	**-2,068,871**	**-3,656,049**	**-2,790,901**
Threshold value of water ($/household/year)	**96.47**	**124.14**	**111.62**	**284.21**	**380.78**	**672.90**	**513.67**

Portfolio 2A (combining Portfolio 1A with additional community cisterns) is likely to produce the greatest net benefit/lowest net cost in achieving the critical target. A threshold value of $284/household/year is required for Portfolio 2A to achieve a positive NPV. Portfolio 2B (combining Portfolio 1A with a mix of additional cisterns, additional rainwater tanks and composting toilets) has an estimated threshold value of $381/household/year.

Portfolio 3B (combining Portfolio 2A with a piped groundwater scheme) is likely to produce the greatest net benefit/lowest net cost in achieving the longer term target. A threshold value of $514/household/year is required for Portfolio 3B to achieve a positive NPV. Portfolio 3A (combining Portfolio 2A with additional cisterns, additional rainwater tanks and composting toilets) has an estimated threshold value of $673/household/year.

Thus groundwater would appear to be a more cost effective option for achieving the longer term target in Vaitupu relative to other options (e.g. cisterns, rainwater tanks and composting toilets). A more detailed discussion of this option is contained in the appendices. As discussed in section 6.2 though, further work should be undertaken on the technical feasibility, sustainability and costs of this option before any decision is made to proceed with it.

5.4.2 Scenario and sensitivity analysis

Alternative rainfall scenarios

Scenario analysis of rainfall scenarios is set out in Table 15. The scenario analysis reveals that the rank ordering of options based on net present values does not greatly change under any of the climate change scenarios. As in Funafuti, this result shows that the rankings are relatively robust to variations in underlying climate assumptions and their parameters[15].

Table 15: Rainfall scenario analysis, Vaitupu portfolios ($A)

	Emergency Target Portfolios			Critical Target Portfolios		Long Term Target Portfolios	
	1A	1B	1C	2A	2B	3A	3B
Standard drought scenario							
NPV excluding value of water ($)	-524,174	-674,484	-606,460	-1,544,171	-2,068,871	-3,656,049	-2,790,901
Threshold value of water ($/household/year)	96.47	124.14	111.62	284.21	380.78	672.90	513.67
Worst case drought scenario							
NPV excluding value of water ($)	-733,649	-733,649	-921,102	-2,161,745	-3,421,392	-4,840,357	-3,952,283
Threshold value of water ($/household/year)	135.03	135.03	169.53	397.87	629.71	890.87	727.42
Change (%)	*40%*	*9%*	*52%*	*40%*	*65%*	*32%*	*42%*
Best case drought scenario							
NPV excluding value of water ($)	-440,380	-492,949	-550,009	-1,288,042	-1,959,982	-2,938,994	-2,394,046
Threshold value of water ($/household/year)	-81.05	-90.73	-101.23	-237.07	-360.74	-540.93	-440.63
Change (%)	*-16%*	*-27%*	*-9%*	*-17%*	*-5%*	*-20%*	*-14%*

Sensitivity analysis, key cost and benefit assumptions

We have also undertaken sensitivity analysis of other options and portfolios examining the changes to:

- capital and operating costs (+/- 10%),
- the benefits associated with the options (+/- 10%); and
- the discount rate (5% and 10%).

15 Note, Portfolio 1A and 1B have the same combinations of options. This is because the water supply-demand modelling reveals that the emergency target can only be met with additional cisterns. This is because of a large supply shortfall at the Motufoua School, which cannot be mitigated through household rainwater tanks or household composting toilets.

We found that changes in these parameters do not affect the rank ordering of portfolios based on net present values.

5.5 Distributional impacts

5.5.1 Overview

Before decisions are made on appropriate adaptation portfolios and pathways, attention should be given to identifying groups in the community who will benefit or benefit most from the decision and groups in the community who may be adversely impacted by the decision – usually referred to as ‘distributional impacts’. Consideration of distributional impacts is important for several reasons, including:

- First, the costs of options or portfolios on particular groups may affect their suitability. For example, ‘full (variable) cost pricing of desalination water’ is one option considered for a portfolio to meet the interim target in Funafuti; likely high impacts of this option on low income groups was an important consideration in leaving the option out of the relevant portfolio[16].
- Second, decision-makers may want to achieve or contribute to equity objectives through an option or portfolio. For example, the use of borrow pits for the construction of water cisterns in Funafuti have the potential to offer substantial equity benefits in that many of the communities who are most poorly serviced by existing supplies are ‘new’ communities living close to the borrow pits. On the other hand, filling in borrow pits is likely to require the relocation of tenants living adjacent to the borrow pits, potentially having adverse equity impacts unless this they are assisted with the relocation.
- Third, understanding of distributional impacts can be important for informing how best to share the costs of financing the portfolio or add to the case for financing the portfolio from potential funding sources (e.g. partner countries).

The process of assessing distributional impacts generally involves two main steps:

- mapping out the distribution of costs and benefits between stakeholders; and
- weighting the costs and benefits according to social priorities.

This process is detailed in the guide *Cost-Benefit Analysis for Natural Resource Management in the Pacific* (Step 6, Buncle et al. 2013). A comprehensive quantitative distributional analysis has not been undertaken as part of this CBA. However, the following general points can be made about the distributional impacts of some of the main options:

- Water Act and associated programs. The costs of this option are likely to be borne principally by the Tuvalu government, with benefits (mainly water security benefits) shared across the community.
- Gutter cleaning & maintenance program. The costs of this option are likely to be shared between the Government and householders, with benefits (mainly water security benefits) shared between households.

[16] Another factor influencing the decision to put this option aside was high uncertainty about whether the option would actually contribute to meeting the target. Nevertheless, further water strategy development in Tuvalu or other PICs should consider this option more closely.

- 'Standard' cisterns. The costs of this option are likely to be borne principally by the Tuvalu government or partner countries, with benefits (mainly water security benefits) going principally to communities in which the new cisterns are constructed.
- Rainwater tanks. The costs of this option are likely to be borne principally by the Tuvalu government or partner countries, with benefits (mainly water security benefits) going to individual households, principally smaller, less well-off households.
- Composting toilets. The costs of this option are likely to be borne principally by the Tuvalu government or partner countries. Water security benefits will go to individual households. Health benefits will be shared across the community.
- Desalination water. The costs of this option are likely to be shared between the Tuvalu government households (assuming desalination water remains subsidised). Water security benefits will go to individual households, principally wealthier households.

5.5.2 Further consideration of selected options in Funafuti and Vaitupu

Cisterns installed on reclaimed borrow pit land in Funafuti and a piped groundwater program in Vaitupu are two essentially new options. Without the operational experience of these options, their distributional impacts are therefore less clear than other options that have been in place for a long time in Funafuti and Vaitupu.

At a workshop, held in June 2014 with stakeholders from the Tuvalu government departments and regional organisations, the distributional impacts of these two options were discussed. Stakeholders were asked, in small groups, to identify the distributional impacts of the cisterns installed on reclaimed borrow pit land in Funafuti and a groundwater project in Vaitupu (Figure 16). The outcomes of their assessments are provided in distributional matrices (Table 16 and Table 17).

Figure 16: Discussion of distributional impacts, Funafuti, June 2014

Table 16: Distributional incidence matrix, cisterns constructed on reclaimed borrow pit land

Benefits and costs of option	Funafuti community	Landowners (borrow pit land)	Families living in area (not on pits)	Tenant families living in area (on pits)	Livestock owners	Kaupule	Tuvalu gov't	Donor partners
Benefits								
Water security benefits	✓✓		✓					
Health benefits	✓		✓✓			✓	✓	
Groundwater quality	✓	✓	✓✓					
Water accessibility			✓✓					
Reclaimed land	✓	✓✓	✓			✓		
Environment	✓	✓	✓✓			✓		
Costs								
Capital costs							X	XX
Operating costs						X	XX	
Water collection costs			X		XX			
Relocation costs				XX	XX			

Key: ✓✓= significant benefits, ✓= minor benefits; XX = significant costs, X = minor costs

What emerges from the distributional matrix above is that there are potentially significant distributional impacts associated with the installation of cisterns constructed on reclaimed borrow pit land in Funafuti. The most significant of these, from a policy implementation standpoint are:

- Significant costs that could be borne by tenant families who currently reside next to the borrow pits, but who will have to relocate if the borrow pits are filled in.
- Significant costs that could be borne by livestock owners who currently keep their stock next to the borrow pits, but who will have to relocate the stock if the borrow pits are filled in. There is a significant overlap between livestock owners and tenant families.

These impacts will need to be addressed in the implementation phase possibly through:

- Government and/or Kaupule and/or donor partner compensation and assistance to tenant families to assist with relocation; and /or
- Government and/or Kaupule and/or donor partner compensation and assistance to livestock owners to assist with relocation; and/or
- A land swap, with some of the land reclaimed through filling in of the borrow pits made available for relocation of the tenants and/or livestock; and/or
- Landowners waiving or deferring land-lease charges to tenants.

Table 17: Distributional matrix, piped groundwater project in Vaitupu

Benefits and costs of option	Vaitupu community	School	Wealthier households	Poorer households	Farmers	Kaupule	Tuvalu gov't	Donor partners
Benefits								
Water security benefits	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	
Health benefits	✓✓	✓✓	✓✓	✓✓	✓	✓	✓	
Water access	✓✓	✓✓	✓✓	✓	✓✓	✓		
Avoided water collection costs	✓✓	✓	✓	✓✓	✓✓	✓✓	✓	✓
Food security	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓	✓
Costs								
Capital costs							X	XX
Operating costs	X					XX	X	X
Loss of land	XX		X		XX			
Education & training	X					X	XX	

Key: ✓✓= significant benefits, ✓ = minor benefits; XX = significant costs, X = minor costs

What emerges from the distributional matrix above is that the benefits of a piped groundwater project are likely to be widely spread. For the CBA we have assumed that costs currently associated with collecting groundwater from across the island (vehicle and time costs) will be fully offset by the additional costs of collecting/distributing water from the central source (e.g. communal taps) located in the villages. It is possible however, that the net benefits of avoided water collection have been understated. On the other hand, costs of an education and training program to accompany the groundwater project (to ensure that the groundwater is properly managed) have not been factored into the CBA.

6. Conclusions and next steps

6.1 Conclusions

6.1.1 Water security in Tuvalu

Overview

Assessment of portfolios through the CBA and associated water supply-demand modelling suggests that there is ample scope to improve water security in Funafuti and Vaitupu in ways that will bring net benefits to the community overall. In particular it is likely that the emergency target can be achieved with a net benefit overall to the community in Funafuti ($44/household/year threshold value) given evidence that the community there values water at much greater than $44/household/year in drought situations. For example, household and government outlays for the production of desalination water in Funafuti are estimated to be about $420/household/year in a drought year. Achieving the emergency target in Vaitupu is likely to be more costly than in Funafuti ($96/household/year threshold value) but is still likely to produce a net benefit to the community given the high value the community places on the value of water in drought situations.

The critical target is likely also be achieved with net benefit overall in Funafuti ($101-142/household/year threshold value depending on whether borrow pits are used for cisterns), although the target will be significantly more costly in Vaitupu ($284/household/year threshold value). Again, given household and government outlays for the production of desalination water in a drought year in Funafuti, achieving the critical targets could be a reasonable objective in the short to medium term, producing net community benefits in both Funafuti and Vaitupu.

Achieving the longer term target will be more costly, in both Funafuti and Vaitupu ($307/household/year and $514/household/year threshold values respectively).

In summary, long term water security is a realistic and desirable objective for Tuvalu (Funafuti and Vaitupu). However, which of the targets the government chooses to meet (emergency, critical or long term) will require not only a judgement about the value of each target compared with the cost, but will also need to take into account broader considerations such as funding availability and the country's other expenditure priorities.

Water management

Tuvalu now has in place a *Sustainable and Integrated Water and Sanitation Policy 2013-2021* (Government of Tuvalu 2013) that includes a comprehensive suite of strategies relevant to improving water security. The Policy is underpinned by a Water Act. Based on discussions with government and non-government stakeholders however, it is apparent that aspects of the Act and Policy are not yet being implemented. Of particular importance are strategies aimed at improving the coordination of water management in Tuvalu between Government, non-government organisations (NGOs), Kaupule, communities and households.

Also important is improved coordination between donor countries in the delivery of water infrastructure and services, with a focus on ensuring that support provided meets the needs of Tuvaluan communities.

Water security options

Gutter cleaning & maintenance program

Water supply-demand modelling and economic modelling indicates that a gutter cleaning & maintenance program underpins all of the most cost effective portfolios for achieving the emergency, critical and longer term targets. In Funafuti, a gutter cleaning & maintenance program has the potential to deliver the emergency target by itself, provided it is well designed, funded and ongoing.

Cisterns

Cisterns are also important components of cost effective portfolios, especially for delivering the critical and longer term targets. A key barrier to the installation of more cisterns in Funafuti is availability of suitable land. A potential way around this barrier is to increase the capacity of existing cisterns. As previously noted, data for Funafuti and Vaitupu indicates that the roof area of many government and community buildings is great enough to allow for this option. As well, preliminary analysis suggests that filling in Funafuti's borrow pits has the potential to provide a relatively low cost means of overcoming these land constraints, as well as providing other community benefits (e.g. health benefits). Whether these additional benefits outweigh the additional costs of filling in the borrow pits however, depends on the weight given to future benefits, reflected in the choice of discount rate. Significant potential distributional impacts will also need to be addressed prior to implementing this option.

Groundwater

Groundwater has the potential to be an important component of a portfolio of options for achieving the longer term target in Vaitupu. Further assessment of this option is required though, to ensure that it is technically feasible and sustainable.

Rainwater tanks

Rainwater tanks are now the mainstay of household water supply in both Funafuti and Vaitupu and are likely to remain so for the foreseeable future. A small proportion of households (estimated to be approximately 5% in Funafuti – Government of Tuvalu & SPC 2014) do not currently have fully functioning rainwater tanks. It is important that all households in this situation be provided with at least one functioning 10,000 litre tank (or equivalent). It would also be desirable to ensure that all households have two 10,000 litre tanks in the longer term. Indeed, this is almost essential for Vaitupu households if groundwater is to become a key secondary source of water, since one tank will be required for rainwater storage and a second for groundwater storage.

Relying on an ever increasing number of household rainwater tanks to achieve the water security targets is subject to significant constraints however. Constraints include:

- lack of available land, especially in Funafuti;

- the high marginal cost of installing a third, fourth, fifth or even sixth tank in every household[17];
- the difficulty of controlling demand during emergency situations when water storage is highly decentralised.

Given these constraints, a gutter cleaning & maintenance program (discussed above) offers the best potential for improving the contribution of household rainwater tanks to water security.

Composting toilets

Notwithstanding the high cost of composting toilets compared with other options examined for this case study, the potential sanitation benefits of composting toilets means that they warrant more detailed consideration.

Data uncertainties

Data uncertainties place some limitations on the results of the analysis, although rainfall scenario analysis and sensitivity analysis of key costs and benefit assumptions indicate that results of analysis, in particular ranking of options, are quite robust to changes in assumptions.

Household water demand in Tuvalu in particular is uncertain. The water infrastructure stocktake funded by the Government of Australia and currently being undertaken by the Secretariat of the Pacific Community (SPC) will be a valuable exercise in addressing uncertainties with water storage data. Further survey based work on household water consumption in Tuvalu would be an important complement to the infrastructure stocktake.

6.1.2 Cost benefit analysis

Application to water security

The Funafuti and Vaitupu case studies indicate that a CBA of water security in Tuvalu is best undertaken in the context of developing an overall water/ drought management strategy for each island. On that point a key recommendation of the *Rapid Drought Assessment*, completed for Tuvalu in 2012 is supported, namely that a 'drought management plan/strategy should be developed at the island scale' (Sinclair et al., 2012, p.38).

This study sets out a framework through which those strategies can be developed, using CBA as part of an integrated decision-making process for achieving and sustaining water security under different climatic conditions. It is noted that outputs of the application of the framework to Funafuti and Vaitupu are preliminary and more work will be needed to achieve fully fledged strategies for those islands. Nevertheless, the framework presented here is robust, having been well tested in Australian contexts in the past, as well as different contexts in Funafuti and Vaitupu. The framework is likely therefore to be suitable for application to other islands in Tuvalu and potentially other PICs seeking to develop water security strategies.

It is important that the framework is applied in a way that reflects the specific circumstances of the location. In particular, island/region/country wide problem analysis is critical at an early stage in the process. The problem analysis should include analysis of water supply and demand

[17] Modelling for this study suggests that most households will require six tanks or more to tie them through a worst case drought.

under existing conditions and assessment of climate and non-climate water security risks. Application of the problem analysis to Funafuti and Vaitupu indicates that differences between the islands in terms of water supply and demand and water security risks significantly influences the design of option portfolios for meeting water security and hence the costs and benefits of options. Groundwater for example, is a viable longer term option for Vaitupu whereas it is not a viable option for Funafuti.

However, many aspects of framework application will be similar regardless of the context in which it is applied. For example:

- Application of the CBA should be consistent with the 'standard' CBA approach as set out in *Cost-Benefit Analysis for Natural Resource Management in the Pacific: A Guide* (Buncle et al. 2013).
- The CBA should be preceded by:
  - developing measurable water security objectives and targets, with intermediate targets (quantified levels of desired outcome) being used as the basis for sequencing actions over time (e.g. short, medium and long term); and
  - a holistic portfolio approach to options development.
- Cost effectiveness assessment (framed as 'levelised costing' ($ per kL) when applied to the assessment of water supply and demand options) can be useful for filtering and ranking options within a portfolio.
- Different techniques will be applied in the CBA to address different levels and types of data uncertainty. Examples include 'scenario analysis' (for climate change), 'sensitivity analysis' (for key costs and benefits) and 'threshold analysis' (for the value of water). More sophisticated uncertainty techniques such as 'Monte Carlo simulation' are unlikely to have wide application in water security planning by PICs. This is due to their complexity and the difficulty of developing probability distributions for key uncertain variables (e.g. average rainfall and rainfall variability).
- A well-developed (Excel based) water supply-demand model is an essential tool to inform the design and assessment of option portfolios and to understand the potential impacts of climate change on water security. The model needs to be structured so that different portfolios of options can be assessed, allowing for alternative combinations of options (e.g. water tanks, water cisterns, desalination, demand management etc.) and different sequences of options over time. The development of new models may be too complex or costly for some PICs or their individual communities. However, established models, such as the one developed for this project, could be tailored for local application by changing relevant assumptions and input (rainfall) data. Further work will be needed with potential users of the model however, to ensure that it is correctly applied.

Application to other issues

The framework also has potential application to the development of strategies for a range of other issues including:

- wastewater/ sanitation;
- solid waste management;

- coastal management; and
- energy security.

This is because the fundamental approach to strategy development involving problem analysis, objectives setting, development of portfolios of options for addressing the problems and assessment of those portfolios has been successfully applied to strategy development in Australia, the United Kingdom and elsewhere and could also be applied to strategy development on these issues in Tuvalu. Dealing with uncertainty, including climate change uncertainty, will also be important an important aspect of strategy development for these issues – notably coastal management and energy security – although the way in which this uncertainty is managed in the assessment will likely differ for these issues than it does for water security.

6.2 Next steps

6.2.1 Water security in Tuvalu

Water security/drought management

Steps to improve the management and coordination of water, especially in times of drought, will be important complements to additional water infrastructure and services. Following are some proposed steps towards improving water management.

1. A key recommendation of the Rapid Drought Assessment, completed for Tuvalu in 2012 is that a 'drought management plan/strategy should be developed at the island scale' (Sinclair et al., 2012, p.38). A *Sustainable and Integrated Water and Sanitation Policy 2012-2021* has now been developed for Tuvalu (Government of Tuvalu, 2013). However, there is scope for enhancing implementation of the water security aspects of the policy through developing an implementation plan for each island[18]. The plans would include:
    - Quantified water supply shortfalls under different population and climate scenarios, considering capacity and condition of existing water supplies.
    - Measurable water security objectives and targets.
    - Identified options and portfolios for meeting the targets and assessment of those options.
    - A schedule for implementing preferred options over time, considering objectives and current and potential future shortfalls in water availability.
    - Suitable financing/ funding mechanisms for implementing the preferred options, including funding to ensure that long term operating costs (where relevant) are met.
    - Allocation of responsibility within the Government and between the Government, Kaupule, communities, NGOs and householders for implementation of the options.
    - A monitoring and review schedule.

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18 Note, the sanitation aspects of the policy have not been examined in depth but would probably also benefit from an implementation plan.

2. Another recommendation of the Rapid Drought Assessment is that 'Linkages between the existing National Water and Sanitation Management Committee and the National Drought Management Committee should be improved to ensure that recommendations are included and coordinated with the longer-term water and sanitation strategies' (Sinclair et al. 2012, p.38). This recommendation is also supported.

   It is further recommended that linkages between all Government departments and agencies, non-government organisations, and communities involved in the management of water in Tuvalu[19] should be strengthened so as to achieve more effective co-ordination of water management. Improved co-ordination will require:

   - setting agreed priorities for water infrastructure, programs and services;
   - clearly defining the roles and responsibilities of departments, agencies, Kaupule, communities and households in delivering on priorities and in managing water more generally;
   - avoiding/removing duplication in management roles;
   - co-ordination of funding and program provision by donor countries to ensure that it is targeted at priority infrastructure, programs and services and at priority locations;
   - improved management of water resources at the community level (see recommendation 6).

3. Additional survey-based research on the levels and patterns of household, government and business water consumption in each of the islands in Tuvalu would be a valuable input to water security strategy development, complementing the water infrastructure stocktake that has already been completed by the SPC. This is because better understanding of water consumption can ensure investments are targeted and resources not wasted where they are not required.

4. Significant work has been undertaken through this study to provide a basis for water security strategies in Funafuti and Vaitupu. However, additional work is needed to ensure a fully-fledged strategy is completed for those islands, including:

   - Further assessment of the potential health, environmental and food security benefits of composting toilets, noting that the benefits of avoided contamination of lagoon waters and fish stocks were not assessed for this study.
   - Further analysis of the viability of groundwater as a long term water resource in Vaitupu.
   - Detailed specification of a desalination training and maintenance program to ensure that desalination can be a reliable source of water for meeting the longer term target.
   - The implementation stage of the strategy – covering the last four dot points of recommendation 1.

[19] These include the Disaster Coordinator, Office of the Prime Minister, Public Works Department, Department of Environment, Ministry of Health, Kaupule, the National Adaptation Plan of Action (NAPA), the Pacific Adaptation to Climate Change (PACC) project, Red Cross and Tuvalu Association of Non-Government Organisations (TANGO).

Implementation of options and portfolios

Notwithstanding the need for further water security strategy development in Funafuti and Vaitupu, assessment for this study suggests that some options and portfolios are likely to warrant implementation as soon as is practically feasible. Steps towards implementing two of these options are detailed further below.

5. ***Gutter cleaning & maintenance program***. Given the low net cost of a gutter maintenance program and the significant water security benefits that it could deliver, it should be a foundation of any portfolio, regardless of the target. Thus this option should be pursued as a priority in Funafuti and Vaitupu and probably other islands as well.

   Drawing on feedback from Tuvalu Government departments and agencies at a workshop held in Funafuti in August 2014, it is recommended that the gutter cleaning & maintenance program should include the following elements:

   - The program needs to be ongoing.
   - Involvement of householders and communities (through Kaupule) will be crucial to the program's success. Their involvement could be facilitated through:
     - gutter cleaning & maintenance education (e.g. held at program commencement with communities/ villages, in schools and through radio and other media to increase awareness of the importance of keeping gutters and roofs clean and well maintained);
     - involvement of Kaupule in the implementation of the program at the community/ village level including to coordinate maintenance of gutters on community buildings;
     - involvement of NGOs (e.g. Red Cross) especially on education and awareness;
     - households to be responsible for cleaning their own gutters;
     - households to pay at least some of the repair costs for their own gutters (e.g. labour costs); and
     - incentives (e.g. awards) and possibly disincentives to encourage householders to keep their gutters clean and well maintained.
   - Funding and technical support from a partner country or organisation (e.g. NAPA, PACC) should be sought to help establish the program.
   - The Government of Tuvalu should be responsible for ongoing program costs with at least partial cost recovery from households (see earlier point). Ongoing costs will include central co-ordination and administration of the program, a gutter maintenance and repair budget and ongoing monitoring of the condition of gutters.
   - The program is probably best co-ordinated through the Water & Sewage section of the Public Works Department.
   - A register of suppliers/ contractors to tender to undertake major guttering works should be established.
   - There should be an annual review of the program, with a more comprehensive evaluation of the program after 2-3 years of implementation to review its effectiveness. The evaluation will draw on monitoring information, feedback from

Kaupule and data compiled through the SPC stocktake (Government of Tuvalu & SPC 2014).

- The program should be revised if necessary drawing on results of the evaluation.

6. ***Water Act and associated measures.*** Options aimed at improving water security will be more effective if they are underpinned by complete implementation of the Water Act and associated measures, such as improved management of community water resources. Effective management arrangements for community water resources will entail ongoing monitoring of community water supplies (generally cisterns) by relevant local communities and effective day to day management of the resources especially during dry periods. Management arrangements developed for the Lofeagai community cistern (SPREP 2014) provide a possible model for management of community cisterns in other communities in Tuvalu.

   It is important to note that The Water Act and associated measures will not necessarily deliver additional water by themselves but are likely to improve effectiveness and efficiency of other options.

7. ***Borrow pit cisterns***. As noted earlier, cisterns are likely to be important components of portfolios for delivering the critical and longer term targets in Funafuti. Preliminary analysis suggests that filling in Funafuti's borrow pits has the potential to provide a relatively low cost means of providing the land required for the cisterns, as well as producing other community benefits (e.g. health benefits). Further research into the extent of the benefits created by the borrow pits may be useful. The significant potential distributional impacts of this option will also need to be addressed.

6.2.2 Integrating CBA into government decision making

A number of steps are proposed for integrating CBA into decision making by the Tuvalu Government and agencies more broadly. Following are recommendations for achieving this.

8. The Tuvalu Government, through the Office of the Prime Minister and Department of Planning and Budget, should seek to integrate CBA into its decision making on all major investments, policies and programs. This will help to increase confidence within government, the community and partner countries that decisions are being made in the best, long term interests of the community.

   Drawing on feedback from Tuvalu Government departments and agencies at a workshop held in Funafuti in August 2014, the following measures are proposed as ways to help achieve that integration:

   - Existing decision making processes of the Tuvalu Government (e.g. Departmental Co-ordinating Committee [DCC] papers, proposal papers) should include specific reference to whether a CBA has been or should be completed as part of the decision making process.

   - Similarly, departmental and inter-departmental manuals and procedures relating to strategy and project development and assessment should include specific reference to the importance of determining whether a CBA is required before decisions are made by Government to proceed with a project.

- A hard copy of the SPREP and SPC CBA guide (Buncle et al. 2013) should be kept in all Government departments. Electronic copies should be sent to all senior government staff likely to have a role in decision making.
- New staff joining the Government of Tuvalu should be provided with high level training on CBA and decision making processes more broadly as a part of their induction process.
- Additional, more comprehensive CBA training should be completed in Tuvalu by selected departmental and agency staff. The training should be of sufficient depth to enable those staff to undertake or oversee CBAs at the strategy and project level in the future. The P-CBA programme provides a potential avenue for that training.

9. Where possible, CBAs should be undertaken at the strategy/planning level. This will help to ensure that investment decision making is strategically focussed considering short, medium and longer term outcomes. It will also help to ensure that CBAs are integrated into the strategy development process and not undertaken merely as an afterthought.
10. Strategy/ planning CBAs will be complemented by project level CBAs where needed or where strategic level analysis is not possible.
11. The broad framework applied to this water security case is likely to be suitable for strategy development for a range of other issues, including potentially wastewater/ sanitation, solid waste management, coastal management, and energy security. However, specific application of the framework will differ according to the issue to which it is applied.
12. Nevertheless, the way in which the framework is structured and applied to assessing costs and benefits of investments is likely to have common elements regardless of the issue to which it is applied. Those common elements include:
    - Application of the CBA should be consistent with the ‘standard’ CBA framework as set out in *Cost-Benefit Analysis for Natural Resource Management in the Pacific: A Guide* (Buncle et al. 2013).
    - It is desirable (and should be feasible) to develop a new cost benefit model for each new application rather than attempt to use a standard template.
    - The CBA should generally be preceded by:
        - problem analysis including assessment of climate and non-climate risks;
        - development of measurable objectives and targets; and
        - a holistic portfolio approach to options development.
    - Different techniques will need to be applied in the CBA to addressing different levels and types of data uncertainty.
    - It is important to ground truth assumptions (preferably from multiple sources), when there is a lack of documented evidence for key water supply and demand assumptions or cost and benefit assumptions.
    - A monitoring and review stage will need to be developed and implemented to ensure that:

- the portfolio(s) implemented actually achieve their intended objectives/ targets; and
- portfolios are adjusted in light of monitoring outcomes or in response to new information (e.g. on climate change or the costs and benefits of options).

Glossary

Word / abbreviation	Description
Cost benefit analysis (CBA)	A method that compares the benefits and costs associated with alternative options quantified in monetary ($) terms. The scope of CBA is on economic (community wide) costs and benefits as opposed to the private benefits and costs assessed in a financial analysis.
Cost effectiveness assessment (CEA)	An alternative to CBA that considers only the costs attributable to meeting a specified objective. CEA can be used when individual options are likely to deliver similar benefits.
Discount rate	The rate at which future values of benefits or costs are adjusted to express them in present day values.
Distributional impact	The distribution of costs and benefits across different sectors, groups or regions. These may or may not constitute broader economic costs.
Economic benefits and costs	Community wide benefits and costs. These include market and non-market benefits and costs.
Levelised cost	A cost effectiveness assessment technique applied to water supply and demand options. It is calculated as the present value cost of the water source divided by the present value of water that will be supplied by that water source.
Multi criteria analysis (MCA)	A method that allows for comparison of options considering several criteria. Often used as an alternative to CBA when costs and benefits of alternative options are difficult to quantify in monetary ($) terms.
Net present value (NPV)	Sum of the discounted stream of costs and benefits over time.
PACC	Pacific Adaptation to Climate Change Programme. Coordinated by the Secretariat of the Pacific Regional Environment Programme (SPREP).
PIC	Pacific Island Country.
Portfolio	A group of complimentary options.
Risk assessment	A process of appraising risks by evaluating the likelihood (probability) of a hazard occurring and the consequences of that hazard for infrastructure, people, services or the natural environment.
Scenario analysis	The process of constructing plausible future states of the world, factoring in how all of the important uncertain variables in the analysis could change.
Sensitivity analysis	The process of measuring how results of an assessment (of options) changes when an underlying variable (or uncertain variable) in the assessment changes.
SPC	Secretariat of the Pacific Community.
Threshold analysis	Used in a CBA to define the point at which an option or portfolio will or will not produce a net community benefit. In a water security CBA the threshold value of water could be expressed in $/kilolitre or $/household.

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Appendices

Appendix A: Water security CBA workshops

Overview

A series of water security - CBA training workshops was held in Funafuti as part of this project. Three two-day workshops were held:

- Workshop 1, 18-19 March 2014;
- Workshop 2, 6 & 9 June 2014; and
- Workshop 3, 8 & 11 August, 2014.

The primary purpose of the workshops was to provide training to participants on CBA in the context of a broader decision making process. The water security case study discussed in this report was used as the focus for that training.

The workshops consisted of presentations by project team members from Marsden Jacob, DAI and Gilbert & Sutherland on different aspects of CBA and decision making of water security, a series of facilitated exercises and group feedback and discussion following each exercise. The exercises were undertaken in small groups by workshop participants. The exercises were designed to take participants step-by-step through the CBA decision making process as set out in Figure 3. In effect therefore, participants were taken through many aspects of the process that the project team went through in undertaking the analysis for this project.

It is important to note however, that the workshop presentations and exercises were set at a high level on the understanding that participants would not gain sufficient understanding of CBA through the workshops to undertake CBA's themselves. Rather, they would have a good general understanding of some of the key principles and concepts of CBA and have improved understanding of the role of CBA in decisions by their departments and agencies in the future.

A secondary purpose of the workshop was to use some of the exercises to generate information that could help inform project analysis. To that end, information generated through the exercises was recorded on templates and on butcher's paper.

Workshop participants

The workshops were held with representatives of Tuvalu Government departments and agencies and regional non-government organisations. Table A1 (over page) provides a list people who participated in one or more of the three workshops.

Workshop 1

At the workshop project team members provided background information on the water security project and then discussed the concept of CBA, its purpose and usefulness and then described the broader decision making process under which CBA can be taken (see Figure 3). Five exercises were then undertaken in small groups, with the groups split so that the exercises could be applied separately by two groups each to the Funafuti and Vaitupu case studies. The exercises covered the early stages of the decision making process and included exercises on:

- (water security) problem identification and risk assessment;

- objective setting;
- options identification;
- combining options into portfolios; and
- identifying types and of costs and benefits associated with different options.

After each exercise there was a report back session by each of the groups and a whole group discussion.

Table A1. Participants in the water security - CBA training workshops

Name	Department/Organisation
Simalua Enele	Ministry of Public Works and Utilities
Lita Molu	Planning & Budget Department
Tusipese Morikao	Planning & Budget Department
Loisi Seluka	Planning & Budget Department
	Planning & Budget Department
	Planning & Budget Department
	Department of Environment
	Department of Environment
	Department of Environment
	Department of Environment
Gunter Koepke	Public Works Department
	Public Works Department
	Tuvalu Electricity Corporation
	Tuvalu Electricity Corporation
	Tuvalu Electricity Corporation
Meelina Ailesi	Tuvalu Met Office
	Tuvalu Met Office
Taiane Amasone	SPREP, PACC Project
Loia Molipi	SPREP, PACC Project
Pisi Selegana	IWRM project
Petesa Finikaso	NAPA Tuvalu
Teu Manuella	USP, EU Global Climate Change Alliance Project (GCCA)
Phil Pickering	Marsden Jacob Associates
Peter Kinrade	Marsden Jacob Associates
Nadja Arold	Marsden Jacob Associates
Eric Rooke	Gilbert & Sutherland
Joey Manfredo	DAI
Dominic Ransan-Cooper	Australian Government, Department of the Environment

Workshop 2

The focus of Workshop 2 was on assessing costs and benefits, with a particular focus on non-market costs and benefits and on how to deal with uncertainty in a CBA. Four exercises were undertaken in small groups, with the groups split again to cover the Funafuti and Vaitupu case studies. The exercises covered:

- understanding and valuing the benefits of water and water security;
- valuing the cost of land and cost of time;
- distributional impacts – who benefits and who pays for options; and
- dealing with climate change uncertainty – scenario analysis.

As in Workshop 1, there was a report back session by each of the groups and a whole group discussion after each exercise.

Workshop 3

The focus of Workshop 3 was on implementation of preferred options and integrating CBA into decision making. Three exercises were undertaken in small groups, with the groups this time split according to department/ organisation that participants were from. The exercises covered:

- reviewing results of the CBA undertaken for the water security case studies – this process was used to help familiarise participants with CBA Excel spreadsheets;
- implementing preferred options – drafting a high level implementation plan; and
- integrating CBA into decision making.

As in Workshops 1 and 2, there was a report back session by each of the groups and a whole group discussion after each exercise.

Workshop 3 concluded with a conclusions and feedback session.

Appendix B: Water supply-demand model

An Excel-based water supply-demand model was developed specifically for this study to reflect conditions in Tuvalu and other Pacific Island Countries. The model was used to assess shortfalls in water supply in Funafuti and Vaitupu relative to the emergency, critical and longer term drought targets, under the standard, worst case and best case drought scenarios. The model could be described as a strategic model in that it was designed to examine short and longer term water security at a country, island or village level rather than at the level of an individual household or government or community building. As such, it was set up to integrate water supply from a range of sources including household rainwater tanks, government and community cisterns, desalination and groundwater.

At the outset, the model was calibrated to reflect current conditions in Funafuti and Vaitupu, taking into account the number of households, house sizes, household demand, household rainwater tank capacity, capacity of existing cisterns and rationing rules. In particular, the model was set up to replicate the water supply-demand imbalance experienced during the 2010-11 drought and was calibrated by comparing model results with known information about what happened 'on the ground' during the drought.

The model then steps through all available supply sources to determine the overall shortfall for the respective islands:

- household rainwater tanks;
- Motufuoa school storages (in the case of Vaitupu);
- community and government cisterns; and
- desalination (Funafuti); or
- groundwater (Vaitupu).

However, desalination and groundwater supplies are assumed to be available only for the longer term drought target.

Sections 3.2.2 and 3.2.3 detail the water supply and demand assumptions applied in the model for Funafuti and Vaitupu respectively. The following sections outline the calculations of the model.

Rainwater Tanks

The model utilises historical rainfall data to calculate on a monthly basis:

- *water collected*, i.e. water that is harvested off roofs every month, calculated as monthly rainfall times roof size times run-off coefficient;
- *household demand*, i.e. the volume of water that households need and/or want to use each months, calculated by multiplying daily household water demand with the number of days per month;
- *water used*, i.e. the actual water available for household use in a particular month as opposed to the household demand. Water used is the lower value of *household demand* or

the sum of *volume in tank* from the previous month plus *water collected.* This value has a lower bound of zero and an upper bound equal to the monthly *household demand*;

- *volume in tank*, i.e. the surplus water stored in the tank at the end of the month, calculated as *volume in tank* from previous month plus *water collected* less *water used*. This value has a lower bound of zero and an upper bound equal to the total storage capacity;
- when *water used* is smaller than *household demand*, the model calculates the *shortfall* both in volume (litres) and days. The shortfall in days is based on the shortfall in litres divided by daily household demand.

These calculations are undertaken for average, small and large houses separately. In the case of Vaitupu, monthly supply-demand balance of the Motufoua School is calculated in the same way.

When additional rainwater tanks are added to the small or large houses under different portfolios, the model increases the storage capacity accordingly. The calculations described above remain unchanged.

Community and Government cisterns

The model assumes that there are three sizes of cisterns in Funafuti, and two sizes in Vaitupu.

- *Large* – 750 kL with a collection roof of 550 sqm;
- *Medium (Funafuti)* – 250 kL with a collection roof of 400 sqm;
- *Medium (Vaitupu)* – 150 kL with a collection roof of 350 sqm; and
- *Small* – 60 kL with a collection roof of 250 sqm.

The size of both the cisterns and the roof area can be adjusted.

Additional cisterns that are added as part of the portfolios are included in the model as a separate group: *Additional cisterns.*

When household rainwater tanks run dry and are not able to supply the full monthly household demand, some (if possible, all) of the shortfall will be supplied from community cisterns. However, the model assumes that there is a rationing system in place similar to the rationing rules applied during the 2010-11 drought in Funafuti and Vaitupu. That is, households are restricted in the volume they can source from cisterns. This *allowance* increases with the critical and longer term water supply targets.

The model also assumes a *constant use* of water from the cisterns for community gatherings and other purposes. However, this amount is negligible.

The model calculates the water supply-demand balance for each group (small, medium, large) separately to account for the differences in roof-to-storage ratios. The medium size cisterns have a larger roof-to-storage ratio (400/250 = 1.60) compared to the large cisterns (550/750 = 0.73). This means that medium size cisterns fill up quicker because the relative catchment area (in relation to storage size) is larger.

The model apportions household demand for cistern water (i.e. the shortfall in rainwater tank supplies), the rationed allowance (i.e. how much water households are allowed to take from cisterns per month), as well as the constant demand to the cisterns using the ratio of volume stored in the respective size group to the total volume available across all cisterns at the end of the previous month. The model allows for different ways of apportioning the water demands to the cisterns, including based on cistern capacity and catchment size.

The model then uses calculations similar to those used for household rainwater tanks to determine the monthly supply demand balance for each group of cisterns:

- *water collected*, i.e. water that is harvested off roofs every month, calculated as monthly rainfall times roof size times run-off coefficient;
- *constant usage*, i.e. the volume assumed for constant usages times the ratio of *volume in cistern* (large, medium, small **or** additional) to *volume in all cisterns;*
- *allowance*, i.e. the volume of water under rationing rules that household are allowed to source from government or community cisterns times the ratio of *volume in cistern* (large, medium, small **or** additional) to *volume in all cisterns*
- *household shortfall*, i.e. total shortfall across all households for the particular month, calculated by multiplying the small house shortfall time the number small houses plus the large house shortfall times the number of large houses;
- *water used*, i.e. the actual water available for use by households and for community gatherings (*constant usage*) in a particular month. Water used is lower value of *allowance* plus *constant usage*, *household shortfall* plus *constant usage* or *volume in tank* from the previous month plus *water collected*;
- *volume in cisterns*, i.e. the surplus water stored in the cisterns at the end of the month, calculated as *volume in tank* from previous month plus *water collected* less *water used*. This value has a lower bound of zero and an upper bound equal to the storage capacity of the respective cistern group;
- when *water used* is smaller than the *allowance*, the model calculates the *shortfall* in days. The shortfall in days is based on the shortfall in litres divided by the number of households (i.e. converted to a per household shortfall) and then divided by the daily household allowance (i.e. ration or target per household per day).

Desalination (Funafuti)

The model assumes that desalination supplies are available to household in Funafuti under the longer term target. The desalination plant is assumed to have a daily capacity of 130 kL, allowing for downtime to conduct regular maintenance works.

When the desalination plant is in use, the model assumes that the desalination plant will be accessed before the cisterns to supply households. That is, household shortfalls will first be covered by desalination water. Once the desalination plant has reached capacity, cistern water will be used to cover the remaining shortfall of supply, if any.

The following calculations are used to determine the monthly supply demand:

- *desal capacity*, i.e. the total monthly volume the desalination plant can produce, calculated as daily capacity times the number of days per month;
- *household shortfall*, i.e. total shortfall across all households for the particular month, calculated by multiplying the small house shortfall time the number small houses plus the large house shortfall times the number of large houses;

- *desal water used*, i.e. the volume of desalination water used by households in a particular month. Water used is the lower value of *household shortfall* or *desal capacity*;

If the desalination water produced in any given month is not sufficient to cover the household shortfall, the cisterns will be accessed, with the calculations being the same as above.

Groundwater (Vaitupu)

The model assumes that groundwater is utilised for non-potable uses only. That is, only the difference between the critical and longer term target for Vaitupu (i.e. 143 litres per household per day) would be supplied by groundwater.

The model assumes that up to 181 kL per day of groundwater can be supplied to households and the school in Vaitupu.

The monthly supply demand balance for groundwater is calculated as follows:

- *groundwater capacity*, i.e. the average monthly sustainable yield of groundwater, calculated as daily yield times the number of days per month;
- *household (non-potable) shortfall*, i.e. total shortfall across all households for the particular month, calculated by multiplying the small house shortfall times the number small houses plus the large house shortfall times the number of large houses;
- *groundwater used*, i.e. the volume of groundwater water used by households for non-potable uses in a particular month. Water used is the lower value of *household (non-potable) shortfall* or *groundwater capacity*;

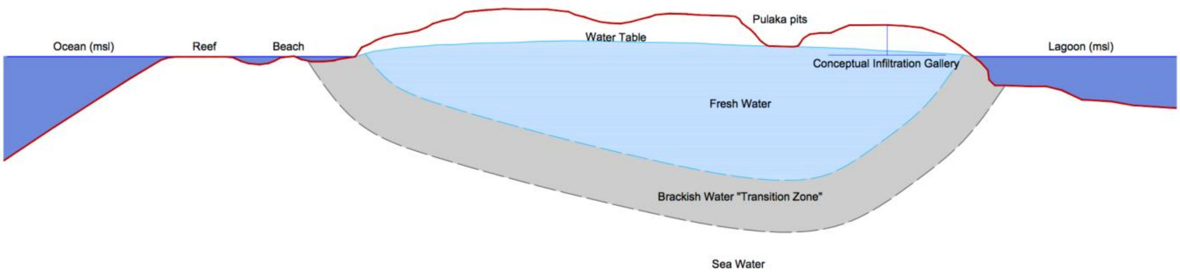
If the groundwater yield is not sufficient to cover the household shortfall, the cisterns will be accessed, with the calculations being the same as above.

Appendix C: Groundwater in Vaitupu

Occurrence

Atoll and reef islands greater than about 1.5 hectares (ha) in size contain a permanent lens of freshwater surrounded by saltwater. A conceptual representation is depicted in Figure C1 below.

Figure C1: General conceptualisation of the groundwater system of a low-lying coral island, showing an infiltration gallery for groundwater abstraction



The volume of the lens is roughly proportional to the surface area of the islet or island (NATA-I, 2013). The amount of freshwater in the lens is a balance between what is added by rainfall recharge[20] and what is lost through discharge or tidally driven vertical mixing and what is taken from wells (Falkland, 1991). The water table of such an islet is invariably shallow (sometimes 1 m or less below ground level depending on ground elevation above mean sea level, AMSL). The thickest part of the freshwater lens tends to be distorted towards the lagoon side of such islands. This is due to lower permeability (finer grain size) characteristic of the sediment found on the lagoon side.

Tuvalu consists of low elevation (maximum of 4 - 5 m AMSL and usually much less) atoll and reef islands that are made up of coarse textured, highly permeable soils, calcareous sand and porous coral rocks, which results in rapid infiltration and negligible surface runoff (except on hardstand[21]). On each islet a freshwater lens has developed of variable surface area and geometry that generally mimics the land area ('landmass') and shape of the islet.

Use

Groundwater abstraction for human consumption/use and for subsistence farming (food crops and pig rearing) varies between islands and no accurate figures are available. Groundwater is

20 And leakage and seepage from septic tank overflow and pipes on developed islands.

21 Where surface water will pond adjacent to hardstand and eventually drain to the lens.

used as a non-potable secondary source for livestock, washing clothes and bathing (GEF, 2007). Historically, groundwater has been used where salinity levels are brackish or fresh[22]. In times of prolonged drought it has been used as an emergency source for drinking water on some islands (NWSC, undated).

The majority of islands have wells. Some wells are just holes dug down to the water table, and are not protected from contamination and pollution. Within villages, most wells are physically protected by coral stonewalls, capped and provided with hand pumps (diaphragm type) with latrines often adjacent. Water quality is often poor and nowadays, well water is seldom used for drinking. It has been observed that during periods of low rainfall, groundwater quality can deteriorate, and become more saline.

The potential variability in groundwater quality must be recognised and contrasted with the consistency of water quality associated with rainwater. Compared to groundwater, the capture and storage of rainwater from roofs is less variable in terms of quality and less susceptible to contamination[23] than groundwater.

The groundwater that is available supports the natural vegetation and crops grown in pulaka[24] pits and plantations (NWSC, undated). Rainfall deficits are more likely on the northern islands, and result in a reduction in the fresh/ brackish groundwater lens with consequent effects for pulaka pits (GEF, 2007). An immediate indicator of slightly brackish to fresh groundwater resources is the presence of existing wells and pulaka pits. Conversely, abandoned wells and pulaka pits are a strong indicator of natural salinity or manmade salinisation of the freshwater lens.

A rapid survey of the water resources of outlying island including Vaitupu was undertaken in response to the drought declaration of October 2011 (Sinclair, 2012). One of the key findings was that communities and households had increased the use of brackish well water, for bathing, washing clothes and flushing toilets to cope with the reduced access to rainwater – their primary water source. An average of 61 % of the households relied upon groundwater to help meet their needs for non-potable water. In most cases this meant utilising brackish water that ordinarily would be considered ‘marginal’ for use.

Sinclair (2012) stated that access to groundwater for communal non-potable water supplies should be improved. He argued that this would lessen the difficulties associated with reduced access to water, including the time and cost required to access water for non-potable needs.

Toilet (WC) flushing into septic tanks typically uses 6 - 10 L[25] per flush, and represents more than 30 % of household water use in Tuvalu. During the 2011 drought, flushing toilets were a significant contributor to drawing down water reserves (GEF, 2013). The water demand

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22 Brackish water is defined as having total dissolved salts (TDS) between ~5,000 and 30,000 ppm; however in this context, for domestic use it is defined as ~1,500 mg/L to 5,000 mg/L TDS and freshwater is defined as below 1,500 mg/L TDS (Note that for drinking water purposes, the WHO guideline value is 1,000 mg/L TDS).

23 Subject to appropriate design and achieving compliance with best practice plumbing, maintenance and management requirements.

24 ‘Swamp taro’.

25 Average use about 20 L of water for flushing per person day = ~ 140 L for flushing per household per day (Gerber, 2011).

calculations used herein for Vaitupu are based on an estimate of current and future water use, including toilet flushing. Composting toilets, designed to be dry systems that minimise or prevent deep percolation into the water table, deliver environmental benefits, water savings and improve water quality and security. Should Vaitupu adopt the use of composting toilets (made as part of the recommendations herein), and then the assumed water demand used in this study would be lower.

Resource estimates

In most of the outer islands the available groundwater and its quality is largely unknown. Although comprehensive groundwater assessments have not been undertaken, earlier rapid, hydrogeological and geophysical surveys (van Putten, 1988, and Salzmann-Wade and Hallett, 1992) found fresh groundwater on many outer islands of Tuvalu (GEF, 2007).[26]

Significant groundwater occurs on the atolls of Nanumea, Nanumaga, Niutao, Vaitupu and Nukufetau. It was estimated that the thicknesses of freshwater lenses ranged from 3.2 to 7.9 m. Taking a conservative freshwater thickness of 2 m and assuming that 10 % of this can be sustainably abstracted; there is potentially about 1,000 ML of groundwater of variable quality available for extraction (White, 2005 reported in GEF, 2007).

Contamination

Seawater intrusion

During dry periods, recharge to the water-table decreases and the remaining fresh water mixes with saline water and becomes brackish. A further pressure on fresh groundwater lenses is rising sea level (Titus, 1990 reported in GEF, 2007). High tides and/or sea storm surges can produce similar effects with a reduction in groundwater quality associated with an increase in salinity (GEF, 2007) and this has implications for any consideration of groundwater security. Coastal erosion is more severe on the ocean side coastlines, than the lagoon side coastlines. For most of the islands that comprise Tuvalu, the western side constitutes the ocean side. The severity of coastal erosion depends on the frequency of cyclone-driven surges and coastal currents (UNDPGEF, 2007).

Latrines and septic tanks

On many of the islands groundwater is available under the villages, which is probably why the villages were originally settled in their locations. However, because of the extensive use of pit latrines and septic tanks, the water is now contaminated (GEF, 2007). Latrines and septic tanks dispose wastewater on site into the permeable, shallow water table aquifers thereby compromising the existing water wells, or discouraging the construction of new wells, for safe potable use. This is further constrained by the small landmass and property ownership rights that often result in juxtaposition of wells and latrines/septic tank systems.

26 The current study has been unsuccessful in accessing these references.

Latrines and septic tank systems require a finite unsaturated zone[27] through which pathogens can be attenuated before reaching the water table. Insufficient soil profiles (i.e. lacking organic and fine material), insufficient depth to groundwater and limited area for effluent 'irrigation' mean that septic tanks cannot function as designed (Saloa 2005 reported in NATA-I, 2013). A national septic tank audit (AusAID, 2001 reported in NWSC, undated) identified that 96 % of septic tanks were inadequately designed to operate as required to treat household inputs, and to prevent groundwater contamination.

Contaminant transport within an aquifer depends on the aquifer matrix[28] and the velocity of groundwater movement. Atoll and reef island aquifers are made of variably cemented, karst limestone and sand deposits with heterogeneous hydraulic properties. These typically result in preferential groundwater flow paths that can rapidly transport contaminants over long distances. This rapid transport may be exacerbated by preferential capture by the drawdown cone surrounding water supply wells.

Groundwater contamination by pathogens has been recorded more than 1 km from latrines and septic tank systems. A fifty-day residence time in the subsurface is needed to provide effective pathogen die-off for drinking water. Different guidelines have been applied in different jurisdictions ranging from 30 m to over 200 m separation between domestic septic tanks and water supply wells. The horizontal and vertical separation distance should always be the subject of detailed study to ensure they are appropriate to the setting.

Sewage from pigs also contributes to the contamination of groundwater in the lagoon on Funafuti and, to a lesser degree, in the populated outer islands of the rest of Tuvalu (NWSC, undated).

Solids, including sewage sludge and chemical (or 'landfill') wastes

There is no functioning sludge management in Tuvalu, which means that most septic tanks are currently full and the only method of emptying them is by disposal of raw sludge in a hole dug beside the tank. This practice is a major health and environmental hazard (AusAID, 2001 reported in NWSC, undated).

Compared with sewage sludge, it is unlikely that household chemicals, batteries and waste oils contaminants are a significant concern in the outer islands. There is no data available on the use of synthetic fertilisers or pesticides. However, Atrazine and Simazine are common pesticides that may be in use on agricultural plots, plantations and sport fields.

Natural hazards

Tuvalu is susceptible to storm surges from cyclones and king tides. These increase the frequency and duration of inundation, causing fresh groundwater lenses to become salinised as well as the loss of landmass.

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27 This is the biologically active zone, die-off rates are considered to be greater than in groundwater and therefore increasing the residence time of pathogens in the unsaturated zone is a valuable groundwater protection strategy.

28 The material(s) present in the aquifer that are the water-bearing unit.

Return to ambient conditions may be prolonged via a process of 'natural flushing' of saltwater from freshwater lenses, and consequent restoration of wells to a potable condition. For example, following Cyclone Percy in 2005, salinity measurements from monitoring boreholes indicated that recovery occurred over 12 months as the more dense saline water moved downward through the freshwater lens (Terry and Falkland, 2010 reported in Falkland, 2011).

Groundwater protection

There is no existing land use policy with special emphasis on water resources, wastewater management and water source protection (GEF, 2007).

High density domestic, government and commercial occupation have impacted on groundwater generally. In Funafuti, these impacts mean that groundwater is no longer fit for human use, even as a brackish secondary source. Increasingly, threats to groundwater quality are affecting other islands.

Most house owners maintain their own septic tanks. A draft National Building Code has been produced that includes specifications for the proper construction of septic systems, the required fittings, and the minimum distance from buildings and groundwater wells (GEF, 2007).

If groundwater is to be used as a primary source of water or as a source for conjunctive use with rainwater, or to provide an emergency supply for the population in times of drought, care will have to be taken to ensure that the water is not polluted or over-extracted. Over-extraction during a drought (late 1990s and 2000) on the outer islands resulted in a drop in the water table and the groundwater became brackish and salty, with serious consequences for the vegetation (GEF, 2007).

To prevent such possibilities, control can be exerted by licensing abstraction in the same way that the Constitution provides for rainwater supply to be controlled and rationed during times of drought (GEF, 2007).

Climate change impacts

The following climate change synopsis for Tuvalu (BoM & CSIRO, 2011) to Year 2030[29] is summarised as Table C1 together with comment on potential impacts to the groundwater resources.

29 See also http://www.bom.gov.au/cosppac/countries/Tuvalu/

Table C1. Hazard – risk table of projected climate change impacts to groundwater, Tuvalu

Parameter / hazard	Climate change prediction	Confidence level	Risk to groundwater	Notes
Annual mean rainfall	Small increase	High	Little impact	~ 1 - 3 % increase = ~ 100-118 mm pa
Mean dry season rainfall	Small to large increase	High	Should reduce vulnerability	
Mean wet season rainfall	Small to moderate increase	High	Should reduce vulnerability	
Mean monthly rainfall intensity	Increases in either all or most months	High	Should enhance groundwater recharge to freshwater lenses[30]. May exacerbate pollution from septic tanks overflows	Intensity & frequency of extreme rainfall days projected to increase
Days of extreme heat	Mean monthly temperature increases	Very high	Assuming linear increase from present to 2090, the increase in potential evaporation is likely to be ~ 25 to 50 mm/yr – may counteract any gains in recharge from above scenarios through increased evapotranspiration. Impact of temperature rise on *water demand* would be insignificant	0.6ºC to 1.1ºC increase. Intensity and frequency
Drought	Incidence is projected to decrease	Moderate	Should reduce vulnerability	
Mean sea-level	Rise projected to continue.	Very high	Increased vulnerability via reduction in landmass & resultant reduction in freshwater lens. E.g. groundwater-modelling has shown that a loss of land width by 20 % would lead to ~ 30 % loss in groundwater storage (Falkland, 2011). Hence a decline in landmass would have a disproportionate impact on volume of the lens	Increase range 0.7 - 4.1 mm/yr. Tuvalu might lose up to 1 m of coastline area per year (Bardsley & Vavae (2009)[31]

In general, the highest risks to groundwater security in order of perceived risk (UNDPGEF, 2007, adapted herein) are:

- Population increase leading to;
  - increasing water demand
  - increase in pollution (exacerbated by water logging mobilising sewage from septic systems).
- Salt water intrusion salinising freshwater lenses from increases in;

[30] Note that climate variability studies indicate that Tuvalu may experience three or less months with small monthly *reductions* (arbitrarily taken as 5 mm) in rainfall (Falkland, 2011).

[31] Webb and Kench (2010), reported in Falkland (2011), indicated that many reef islands have remained largely stable or increased in size over the past 20-60 years. These results are contrary to the widespread perceptions that all atoll/reef islands are eroding in response to recent sea level rise.

  - more intense storm surges driven by increased intensity and frequency of tropical cyclones
  - sea level rise.
- Saltwater intrusion and groundwater flooding[32] salinising and water logging soils, respectively leading to decreased food crop productivity.
- Rainfall variability increase (rather than gradual changes in mean annual rainfall) possibly leading to more incidences of water scarcity due to prolonged drought.
- Decreased landmass by increased severity of coastal erosion leading to reduction in volume of freshwater lenses.

[32] …from more intense rainfall events resulting in higher groundwater tables. The Falekaupule (island elders) reported that there is an increasing percentage of land flooded due to inundation, something that had never occurred in the past (UNDPGEF, 2007). They also reported 'upwelling' of saltwater resulting in a thinning of the groundwater table, and over-extraction of groundwater at Motufoua Secondary School (Poni Faavae Adaptation Experience in Tuvalu http://www.env.
go.jp/en/earth/ap-net/documents/seminar/11th/31_Faavae1.pdf).

Vaitupu

Population and Physiography

Vaitupu is the second-most populous island, being home to 16.6 % of the total population of Tuvalu (GEF, 2007). A rapid census conducted in October 2011 gave a population of 1,600 in 260 households (source: Government of Tuvalu/ Kaupule reported in Sinclair, 2012). An estimated population growth rate of 1 % to year 2030 would yield a population of 1,914 and a 2 % growth would see the population rise to 2,285.

Vaitupu is 'tear-drop' (elliptical) shaped (see attached Figure 2) with an area of 5.63 km^2 – the largest land area of the nine island groups. Geologically it is classified as a 'composite island' as it has characteristics of both atolls and table reef islands. There may be a substrate of lower permeability Holocene Epoch sediments (of thickness about 20 m) underlain by a high permeability Pleistocene limestone platform. It has two virtually landlocked lagoons connected to the sea by narrow channels. The reef flat includes an area of lagoon of approximately 109 ha. The soils are highly permeable above the hardpan of the reef flat, due to the porosity of the sands and gravels. Excess rainfall drains to the water table where a lens of fresh to brackish water is formed and floats on the saline marine water[33].

Existing domestic water use and supporting supply infrastructure

Despite a number of surveys/censuses, there appears to have been no actual water use figures calculated. The 2011 rapid drought census recorded 1,100 people (presumably mostly in the two neighbouring villages of Asau and Tumaseu) and 485 students and teachers at Motufoua School (Sinclair, 2012). Of approximately 200 survey respondents, 5 families relied on wells as their primary source for drinking water, 139 as their secondary source and 121 for 'other household use' (washing and bathing). Regarding wastewater production, 109 households had water seal toilets, 77 flush toilets (WCs) and 11 used pit latrines or the bush.

Table C2 summarises the volume of water storage that was available for use in Vaitupu at October 2011.

Table C2. Summary of water storage tanks

	Household	Communal
Total Storage (kL)	4,458	1,006
No. of tanks	391	11
Max. size of tank (kL)	61.7	209.6
Av. Size tank (kL)	11.4	91.5
Median Size Tank (kL)	7.81	82.6

Note: No. of houses surveyed =294. (Adapted from Table 6, Sinclair, 2012)

General water rationing rules enforced on communal tanks by the kaupule was 3 buckets (15 L) per household 4 times a week. The ration rules in force at the time of the 2011 drought

33A phenomenon known as the Ghyben-Herzberg principle.

(Sinclair, 2012) was 25 L per household per day from communal water supplies; viz. 5 L/p/d (based on a family of 5).

Table C3 summarises the volume of rainwater that was available for use in Vaitupu at October 2011.

Table C3. Summary of available water (communal water supplies as of October 2011)

Vol. of available rainwater in tanks (kL)	1,706
Available rainwater against total rainwater storage (%)	24 %
Volume in storage (kL)	317; (248 school)
Supply at ration of 15 L/p/d (No. of days)	19 (33 school)

Note: No. of measurements taken = 485 from 23 to 25/10/11.

Motufoua secondary boarding school was to install 40 tanks of 10 kL capacity each (totaling 400 kL) (Sinclair, 2012).

Sinclair (2012) assessed the groundwater resource to be mostly brackish and anticipated that it would continue to be used for non-potable uses or as feed water for the desalination plant(s).

Water wells

Most of the existing wells are located outside the main villages (GEF, 2007). Community wells provide backup supply in times of low rainfall. Small solar-powered pumps lift water from a depth of about one metre into a storage/ header tank from which people fill their water containers. Sinclair (2012) considered that providing greater access to community wells would promote the use of groundwater as an alternative to relying on rainwater for non-potable needs such as washing, bathing and toilet flushing, and reduce the costs of accessing this water, making it more available to the community.

Asau and Tumaseu villages

Sinclair (2012) described one main communal well 'located on the east coast, more than 3 km from the village'. It was equipped with a solar pump. This well provided water with a salinity, represented by electrical conductivity (EC), of 2,000–3,000 µS/cm. The community accessed this water directly at the wellhead or by water carting to houses at a cost of $5/load of 500 L. Bathing as well as water collection could be undertaken at the wellhead. The following site-specific recommendations were made:

- Provision of spare parts for the well pump and a cut-off float switch on the tank.
- Improved access to and maintenance of the site with regard to drainage around designated collection points and showering/bathing facilities to allow privacy.
- Construct a header tank and pipeline to bring the water closer to the village with distribution at strategic locations.

Motufoua School

Sinclair (2012) reported that Motufoua School used brackish groundwater (4,500 – 13,000 µS/cm) for non-potable purposes (washing, bathing and toilet flushing) and as feed water for a 8 kL capacity desalination unit (now decommissioned). The salinity of the feed water from the well supplying this desalination unit was reported to be brackish (10,000 µS/cm). Abstraction was taking place from unlined wells, which had silt-laden bottoms. Anecdotally, the well pumps had a shortened operational life (about a year) due to sediment pumping and corrosion by the brackish water. The following site-specific recommendations were made:

- Short term:
  - two replacement pressure pumps be provided to allow communal access for non-potable needs
  - line all wells with geo-fabric to reduce sediment impacts on pumps.
- Long term:
  - investigate the construction of an infiltration gallery at or near the playing field to be used for abstraction of all groundwater needs for Motufoua
  - provision of a similar sized desalination unit as a permanent replacement
  - line the well that provided water to the desalination unit to maintain efficiency.

Water Demand

As noted above, there are a number of risk factors capable of impacting upon the ongoing quality of Vaitupu's groundwater resources. Drought, sea level rise and storm surges can each affect groundwater quality, particularly salinity as represented by electrical conductivity. For this reason, it is prudent to ensure that any groundwater supply scheme is undertaken in parallel with other measures to capture and store rainwater. Wherever practicable, rainwater should be reserved for potable use whilst groundwater use should be for non-potable purposes.

Domestic consumption

For the purposes of this report a normal household water use of 300 to 600 L /household/day has been applied in calculations of sustainable yield. Assuming an average of 5 persons per household, then the per capita water demand is approximately 60 to 120 L/person/day. During drought it is assumed that the demand would be reduced to some 15 L/person/day (rather than the 5 L allowed per person during the 2011 drought emergency).

Table C4 summarises predicted water demands that would need to be served by any groundwater supply scheme.

Table C4. Summary of water demand (used for sustainable yield calculations) from a groundwater supply scheme for Vaitupu

Scenario			Domestic demand		
Population	**Climate conditions**	**Per capita demand (L/p/d)**	**Average daily (kL/d)**	**Maximum daily (peak factor of 2.5)**	
				(kL/d)	**(L/s)**
Current 1,600	Normal	120	192	480	5.56
		60	96	240	2.78
	Drought	15	24	60	0.69
1% growth 1,914	Normal	120	230	574	6.65
		60	115	287	3.32
	Drought	15	29	72	0.83
2% growth 2,285	Normal	120	274	686	7.93
		60	137	343	3.97
	Drought	15	34	86	0.99

Whilst it is realised that buffering storage (header water tank(s)) will be commissioned in any water supply scheme planning, the maximum daily demand is taken for purposes of groundwater sustainable yield calculations. This is a conservative approach that also accounts for any additional water use including garden water use and system leakage.

Agricultural water consumption

NAPA-I (2013) indicated at least 100 kL fresh water supply and water storage systems capacity was required to support agriculture in each of at least four atolls including Vaitupu. From an inspection of satellite imagery, assuming not more than 2 % of Vaitupu is given over to crops; then an area of some 1,000 ha requires 450 ML/year of 'consumptive use' from groundwater [34]. This has not been factored into the demand calculation under the assumption that the water table will support plant growth directly.

Rainfall

As stated above, rainfall represents a water supply that should be intercepted and stored in tanks for potable use. Rainfall that is not intercepted and directed to storages will recharge groundwater (as shown in the conceptual schematics in Appendix C1).

Tuvalu's climate is characterised by two distinct seasons: a wet season from November to April and a dry season from May to October. High inter-annual variability in rainfall is

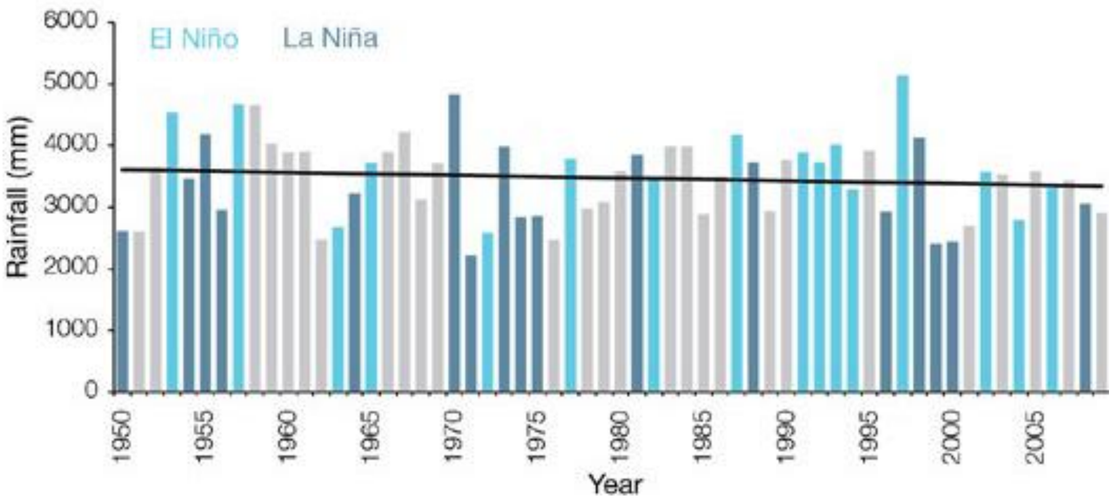
34 assuming a water use of taro of 450 kL/ha/day (i.e. application depth of ~ 45 mm) http://www.ctahr.hawaii.edu/oc/freepubs/pdf/RES-140-29.pdf

observed in Tuvalu. Annual and seasonal rainfall trends for Funafuti and Nanumea for the period 1950–2009 are not statistically significant (BoM & CSIRO, 2011).

Tuvalu has four synoptic stations[35], situated on Funafuti (Fongafale islet), Nui, Nanumea and Niulakita that record rainfall, barometric pressure, humidity, wind speed and wind direction.

Funafuti has the longest duration of record of rainfall data (available from 1927 to date). Mean annual rainfall in Funafuti is 3,500 mm (Figure 3) with 42 % mean rainfall falling in the dry season and 58 % falling in the wet season. In the wettest years Funafuti receives about twice as much rainfall as in the driest years[36]. Rainfall averages more than 200 mm each month of the year.

Figure C3. Annual rainfall for Funafuti. (Light blue, dark blue and grey bars denote El Niño, La Niña and neutral years respectively). (Source: BoM & CSIRO, 2011)



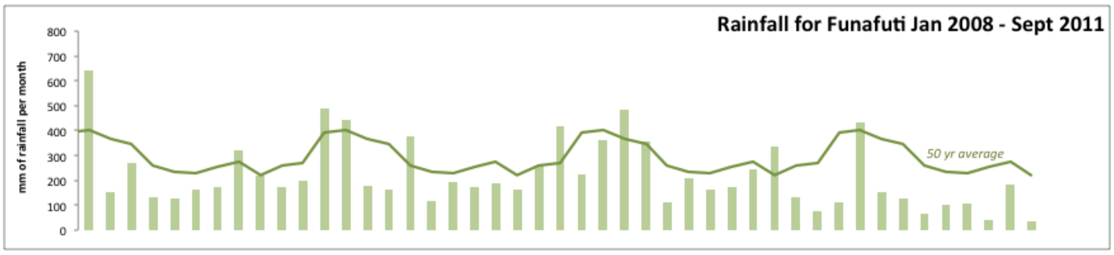
There is single observation daily-read rainfall station at Vaitupu. Based on 37 years of data (1948-84), Vaitupu has a mean annual rainfall of 3,117 mm. Typically, the annual wet season occurs from December to March whilst the annual dry season occurs from April to November, during which dry periods of about three months can occur. Rainfall is generally sufficient so that soil moisture deficits are infrequent (Falkland, 2011).

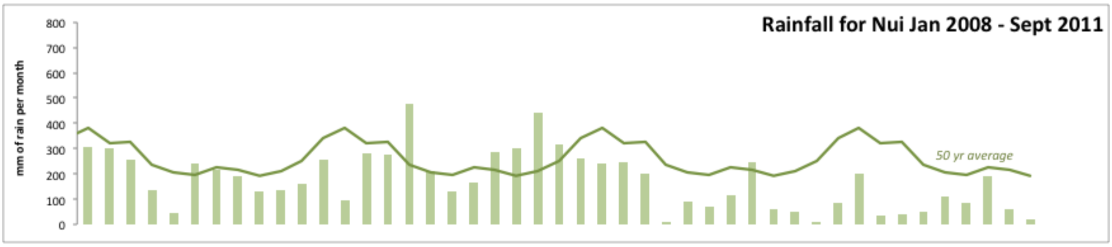
35 Multiple observations within a 24-hour period.

36 coefficient of variation of 0.20 giving a range of rainfall from 2,400 to 4,000 mm per annum.

Figure C4 presents rainfall for the closest synoptic stations to Vaitupu, namely, Funafuti to the south and Nui to the west.

Figure C4. Monthly rainfall for Funafuti and Nui for period January 2008 to September 2011. (Source: Sinclair, 2012)





Rainfall recorded over the final three years of the Sinclair 2012 dataset from the four stations showed alarmingly low monthly totals relative to averages in the previous 12 months.

On average, Funafuti experiences eight tropical cyclones per decade, with most occurring between November and April with a high inter-annual variability in numbers (BoM& CSIRO, 2011).

Evaporation and evapotranspiration

The current range of potential evaporation within Tuvalu is in the order of 1,500 to 1,800 mm/year (Falkland, 2011).

Transpiration from trees was recorded as 70-130 litres/day suggesting a total transpiration rate of 400-740 mm/year per tree planted at 8 m centres with 100 % tree cover (Falkland and Brunel 1989, reported in Falkland, 2011).

Simple water balance

A water balance for a typical island in Tuvalu can be denoted as follows:

- P = Et + R

  or, expressed in terms of groundwater recharge, as:

- R = P – Et

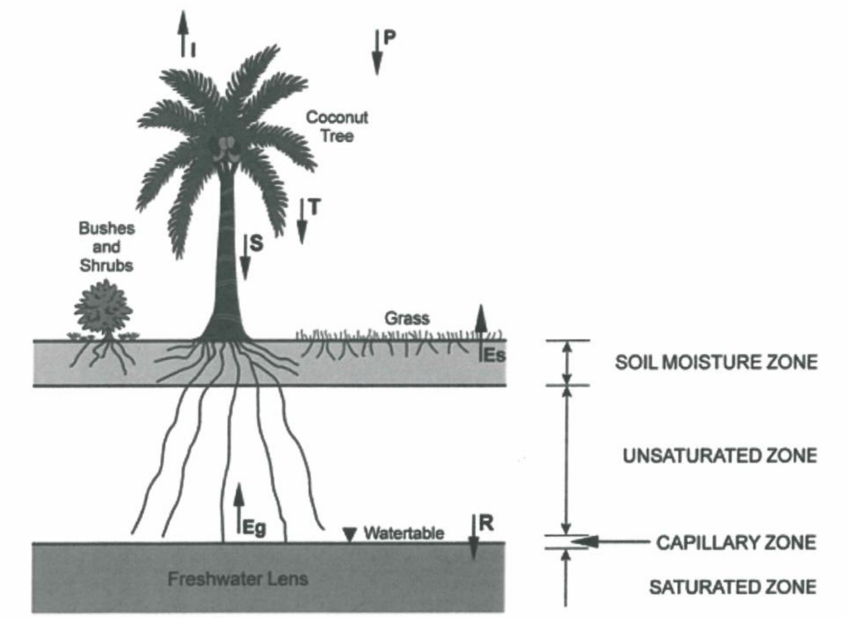
  where
  R = recharge to the water-table;
  P = rainfall;
  Et = evapotranspiration.

Et can be broken down into terms;

- interception (I);
- evaporation and transpiration from the soil zone (ES);
- transpiration of deep-rooted vegetation directly from groundwater (Eg).

Figure C5 illustrates the water balance model to estimate the recharge.

Figure C5. Water balance model to estimate groundwater recharge for a low-lying coral reef or atoll island



Actual evapotranspiration is a major component of the water balance and can range from about 50 % to more than 70 % of rainfall in some small islands (Falkland, 2011)[37].

Calculation of Et is fraught with difficulties and complexity and is beyond this scope. Standard procedure uses the Penman-Monteith method.[38] From experience in this environment it is likely to range from 3 mm/day (in the wet season) to 5.5 mm/day (in the dry season). A soil moisture – recharge account needs to be done on a monthly basis to estimate monthly recharge to the groundwater lens. An example done for Tarawa (Rooke, unpub.), indicated 3 months with nil recharge in the dry season and up to approximately 440 mm recharge in wet season months (example cited was for January 1977).

The groundwater balance *for* the lens can be expressed in terms of groundwater recharge as:

$R = GF + D + Q + \Delta S$

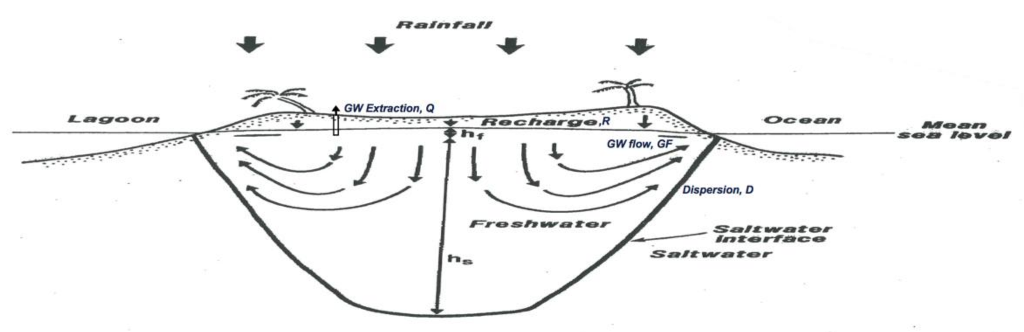
37 A water balance for Bonriki Is., Tarawa atoll, Kiribati (White et al, 2002; 2007a reported in Falkland, 2011) reported actual evaporation and recharge components estimates of approximately 50% of rainfall based on rainfall, climate, coconut palms sap flow, estimated palm densities, soil moisture and groundwater measurements.

38 Refer http://www.fao.org/docrep/x0490e/x0490e06.htm for explanation.

where
R is groundwater recharge
GF is groundwater flow to the sea
D is dispersion at the freshwater/seawater interface
Q is groundwater extraction and
ΔS is change in fresh groundwater storage.

Figure C6 shows a typical groundwater balance for a freshwater lens on a small coral island.

Figure C6. Groundwater balance for a freshwater lens for a low-lying coral reef or atoll island



Recharge estimates (analytical calculations using groundwater hydraulics) as percentage of rainfall ranged from approximately 9 % o 40 % for Tongatapu, Tonga (Rooke, unpub.).

Applying 9 % (i.e. the most conservative value) to the mean annual rainfall of Vaitupu (3,117 mm) = 280 mm/year reports as recharge to the groundwater table.

Groundwater dependent vegetation

Mangroves

The mangroves of Tuvalu were listed as a threatened ecosystem (Dahl, 1986 reported in NAPA-I, 2013).

There are two small brackish tidal lagoons on Vaitupu, connected to the sea by narrow channels. Mangroves occur on the shores of both lagoons, and are almost entirely cut off from the sea. These mangroves reach about 6 m in height and cover about 6 ha (Woodroffe, 1987 reported in NAPA-I, 2013).

Mangroves thrive in brackish water of salinity 50 % seawater / 50 % freshwater. Hence, mangroves are dependent on the brackish water found in the lagoons, where most of the freshwater component is supplied by freshwater and/or brackish water discharge to the coastline (http://www.mangrovewatch.org.au).

Pulaka (swamp taro)

Taro and pulaka are both grown in pits at about groundwater level. Pulaka plants require a long time to mature. A survey of Vaitupu farmers' crops had plants up to 12 years old although 80 % were less than 6 years old. Thus, it is important that there are no substantial changes in the average water table level or groundwater quality. Production within the pits is dependent on the creation of a humus-rich soil, availability of relatively fresh groundwater and suitable cultivation.

Problems have arisen from changes in groundwater and increased salinity giving rise to damaged crops and abandonment in the worst cases (GEF, 2007). Since pulaka grows best close to the water table, the direct impact of saltwater intrusion due to sea level rise on groundwater could result in total loss of pulaka productivity. More than 60% of pulaka pit plantations have been devastated by saltwater intrusion (UNDPGEF, 2007). Former research (Mourits 1996, reported in Sinclair, 2012 and confirmed by a 2006 survey conducted by SOPAC (Webb, 2007)), indicated that salinities above about 3,300 - 5,000 µS/cm resulted in reduced yield, potential crop failure and pit inactivity and abandonment. Whilst the 2011 rapid drought survey supported this trend, the 2011 data appeared to show that plant stress occurred at salinity levels greater than 11,000 µS/cm, indicating a greater tolerance to salinity and/or adaptation to exploit 'intermittent rainfall 'than previously observed.

Coconut, breadfruit, pandanus and other trees grow on the raised banks of the pits. Sweet potatoes occupy 4.2-5.0 ha of Vaitupu, although the area allocated for the crop varies (Webb, 2007).

Figure 7 (attached) maps the pulaka pit salinity results of the 2006 survey (Webb, 2007). Figure 7 takes the suite of data and reports them as a single average salinity value for each of a number of pits centered about a locale as identified under a pulaka pit name. Salinity results from the 2011 drought survey are also plotted on Figure 7. Together, these data sets have enabled a basic understanding of where freshwater is available, and more importantly have identified areas of brackish groundwater that should be avoided in terms of any potential for groundwater development.

Table C5 summarises the average salinities for two salinity survey data sets, with measurements taken in the pulaka pits, only.

Table C5. Mean salinities (EC) of pulaka pits, Vaitupu (adapted from Webb, 2007 and Sinclair, 2012)

Date of survey	No. of pulaka pits	Pulaka pit mean salinity (EC) (μS/cm)
Oct. 2011	95	8,596
Jan. 2006	32	1,132

It is unclear whether some of the readings were replicated in the same pits and at the same depths within the pits. Nevertheless, it is apparent that the drought did impact groundwater salinity with a resultant salinisation probably through lack of flushing of the water table by rainfall recharge.

Safe yield for water supply

Over-extraction in 1999 and 2000 resulted in groundwater becoming brackish/salty and the water level dropped with serious consequences for the vegetation as witnessed in Vaitupu (GEF, 2013). Whilst this reported incident is not conclusive, it represents a warning as to the vulnerability of Tuvalu's groundwater resources in times of stress.

Ambient conditions

Volume of fresh groundwater in storage and from recharge to the water table

Figure 2 (attached) shows the locations and nominal extents of two separate fresh groundwater lenses that have been interpreted using a combination of viewing the landmass shape from satellite imagery and maps. Figure 7 combines two separate studies of groundwater salinity (specifically January 2006 after Webb, 2007 and October 2011 after Sinclair, 2012). These two groundwater resources are named Te Pela (after a pulaka pit surveyed in the general area) and Motufoua (after the School located immediately to the east).

The estimated volume of water available in storage for these two freshwater lenses is given as Table C6.

Table C6. Volume of freshwater lenses, Vaitupu (desktop 'first pass' estimate only)

Given name of groundwater resource	Length long-axis (m)	Length short-axis (m)	Surface area of lens (m2)	Thickness of freshwater (m)	Aquifer freshwater matrix volume (m3)	Specific yield	Total available freshwater in aquifer (kL)
Te Pela	400	200	251,327	3.2	804,248	0.15	120,637
Motufua	300	250	235,619	3.2	753,982	0.15	113,097

These estimates are high order and err on the side of conservatism. They are constrained by the following broad-based assumptions:

- There are two separate fresh groundwater lenses that are separated by the 'neck' of land situated between the lagoon and Tumaseu and Asau Villages.
- The areas of these two lenses have the shape of ellipses with their long-axis parallel to the lagoon and ocean sides of the island. The conservatism of the current approach is highlighted by comparing the areas calculated in Table 5 with those calculated by Table 4, Taulima (2002), reported in GEF (2007) that reports a groundwater area of 0.94 km^2 for 'Northern' and 0.34 km^2 for 'Motufoua' (cf ~ 0.25 km2 for Te Pela, assumed to be roughly in the same location as 'Northern', and ~ 0.24 km^2 for Motufua).
- The ground elevation at each location averages approximately 1.2 m AMSL (refer Figure 2 – inset Vaitupu elevation section).
- The water table lies at an elevation of 0. 2 m AMSL; that is 1 metre below ground level.

- The relationship of the Ghyben-Herzberg principle is modified and taken as z=15h[39] where h = thickness of the freshwater zone above sea level and z represents that below sea level. This principle has been modified to account for dynamic tidal loading of the freshwater lenses that essentially mixes the overlying freshwater with the underlying seawater giving a zone of brackish water known as the transition zone. This results in only a thin zone of some 3.2 m thickness of freshwater.
- The specific yield, Sy is a hydrogeological term that, essentially, describes the drainable volume of the aquifer.[40] A value of 0.15 (15%) has been applied to the aquifer matrix volume which is typical of a well sorted, calcareous sand or porous limestone.

Tables C6a and C6b translate this availability of fresh groundwater into an equivalent number of days supply under the different demand scenarios, based on the lenses being mined and the accession to the water table by an annual recharge of 280 mm, respectively.

Whilst this is an overly simplistic analysis, and is a non-sustainable approach to a highly dynamic groundwater hydrological situation, it does give an indication that a groundwater supply is a feasible solution to meet all the water use demands of Vaitupu.

With the groundwater-mining scenario (Table C6a), even under the worse case scenario at Motufoua, theoretically, there is some 165 days (viz. over 5 months) of continuous supply before the fresh groundwater would be exhausted in the aquifer. Again, examining the Motufoua fresh groundwater resource, given the current population, and the largest demand scenario, there would be 236 days (i.e. some 7 ½ months) of continuous supply prior to exhaustion of the resource. Likewise Te Pela has 176 (nearly 6 months) and 251 days (over 8 months), respectively. Within this time the rainfall record indicates that there should be multiple episodes of recharge to the aquifer that would replenish the freshwater lens.

Table C6a. Theoretical duration of supply from extractable freshwater lenses, Vaitupu (assumes groundwater mining)

			Available fresh groundwater stored in aquifer (kL)	
			Motufoua 113,097	Te Pela 120,637
Population	Climate condition	Maximum daily demand (kL/d)	Equivalent supply duration (No. of days)	
Current 1,600	Normal	480	236	251
		240	471	503
	Drought	60	1885	2011
1% growth 1,914	Normal	574	197	210
		287	394	420
	Drought	72	1576	1681
2% growth 2,285	Normal	686	165	176
		343	330	352
	Drought	86	1320	1408

39 Normally z = 40h (as the relative density of seawater is 1.025).

40 An analogy might be visualised as a wet bath sponge; not all of the water is released by the sponge under gravity (atmospheric pressure) despite being very porous.

Table C6b. Theoretical duration of supply from extractable freshwater lenses, Vaitupu (assumes recharge – using a recharge factor of 9 % applied to Vaitupu's average annual rainfall of 3,117 mm)

			Annual volume of fresh groundwater acceded to water table by recharge (kL)	
			Motufoua 65,973	Te Pela 70,372
Population	Climate condition	Maximum daily demand (kL/d)	Equivalent supply duration (No. of days)	
Current 1,600	Normal	480	137	147
		240	275	293
	Drought	60	1,100	1,173
1% growth 1,914	Normal	574	115	123
		287	230	245
	Drought	72	916	977
2% growth 2,285	Normal	686	96	103
		343	192	205
	Drought	86	767	818

Note: that for purposes of this exercise, in Tables 6a and 6b 'climate condition' refers to the demand figures as presented in Table 4 and reproduced herewith.

With the contribution to the water table by the recharge scenario (Table 6b), even under the worse case scenario at Motufoua, theoretically, there is the equivalent reserve of some 96 days (viz. ~ 3 months) of continuous supply. Again, examining the Motufoua fresh groundwater resource, given the current population, and the largest demand scenario, there would be the equivalent of 137 days (i.e. some 4 ½ months) of continuous supply.

Likewise Te Pela has 103 (over 3 months) and 147 days (over 4 ½ months), respectively.

Volume of fresh groundwater from recharge to the water table under abnormally dry conditions

This analysis examines a 'worst case' dry year record that results in a reduced recharge, hence a lower volume of water percolating to the water table.

For the purposes of this analysis, daily rainfall data was taken for Vaitupu and summed into annual totals after filtering out years with incomplete records. The period assessed was 1960 to 1997, inclusive. The annual totals were then ranked and the lowest annual rainfall was extracted and its value then reduced by 10 %. The 9 % recharge factor was then applied per Table 6b. The minimum annual rainfall was 1,532 mm (recorded for the year, 1975).

Table C6c. Theoretical duration of supply from extractable freshwater lenses, Vaitupu (assumes recharge – using a recharge factor of 9 % applied to Vaitupu's minimum recorded annual rainfall of 1,532 mm minus 10 %)

			Annual volume of fresh groundwater acceded to water table by recharge (kL)	
			Motufoua 29,217	Te Pela 31,165
Population	**Climate condition**	**Maximum daily demand (kL/d)**	**Equivalent supply duration (No. of days)**	
Current 1,600	Normal	480	61	65
		240	122	130
	Drought	60	487	519
1% growth 1,914	Normal	574	51	54
		287	102	109
	Drought	72	406	433
2% growth 2,285	Normal	686	43	45
		343	85	91
	Drought	86	340	362

With the contribution to the water table by the reduced recharge scenario (Table C6c), under the worse case scenario at Motufoua, theoretically, there is the equivalent reserve of some 43 days of continuous supply. Again, examining the Motufoua fresh groundwater resource, given the current population, and the largest demand scenario, there would be the equivalent of 61 days (i.e. 2 months) of continuous supply.

Likewise Te Pela has 45 days and 65 days (~ 2 months), respectively.

This assessment indicates that even in experiencing an abnormally dry year, continuity of supply could be anticipated, although the interception and taking of recharged water might need to be complemented by some mining from the groundwater lenses. This would be especially anticipated under the 2 % population growth scenario, particularly if the abnormally dry year were followed by another dry year.

Under climate change scenarios

The reduction in water resources availability due to mean sea level rise is difficult to quantify accurately. If the assumption made for Tarawa of a 20% reduction in groundwater sustainable yield is applied to other similar small islands, the impact of this projected climate change is significant, but is relatively minor compared to the influence on demand for water due to population increase (Falkland, 2011).

A number of impact studies for freshwater lenses on atoll islands (viz. Enjebi Island, Enewetak, RMI (Oberdorfer and Buddemeier, 1988) and Bonriki island, Tarawa, Kiribati (Alam and Falkland 1997 and World Bank 2000 reported in Falkland, 2011) have been modelled for a range of projected mean sea level rises and rainfall changes. Significant results for Falkland (2012):

- A MSL rise of 0.2 m (similar to the upper range projection from PCCSP of 0.17 m) and similar rainfall to the present would cause virtually no change to the freshwater lens. Although it might cause long-term inundation and loss of land, and hence consequent loss of fresh groundwater.
- A MSL rise of 0.4 m (more than double the upper range projection) and similar rainfall to the present would cause a slight increase in thickness. This is due to the fact that the average level of the freshwater lens, which is influenced by MSL, would rise slightly into less permeable Holocene sediments than the highly permeable underlying Pleistocene limestone.

If land were lost at the edges of the island due to inundation from rising sea level and/or erosion from storms, this would have a significant effect on the freshwater lens. The analysis assumed a loss of about 20 % in width of the island due to inundation, which led to a 29% reduction in freshwater lens thickness (and volume) for a 0.4 m MSL rise and current rainfall.

In respect of low-lying landforms of the sort that are found in the Tuvalu archipelago, evidence of landform transition and change due to sea level rise is inconclusive as there are a number of variables that may affect erosion, accretion, shoal establishment and movement, lagoon and littoral zone behaviour over time. Whilst some studies identify sea level rise as a major threat, others indicate a landform response to the influence of sea level rise resulting in new or different landform, groundwater and recharge relationships. Accordingly, case studies or individual study area scenarios will be more useful than general trend analysis. In any event, with respect to the groundwater resources, the relative influence of the climate change scenarios in the Tuvalu setting is less important than the more influential factors of population growth and urban planning and hence have not been modelled herein.

Water supply site investigations, conceptual design and associated cost estimates

Groundwater studies and investigations

Prior to any engineering design studies proceeding for a groundwater supply scheme to serve Vaitupu, a comprehensive, staged suite of groundwater investigations is required. These may be summarised as follows:

Stage 1 – Preliminary island-wide groundwater survey

- Review Salzmann-Wade, B. and Hallett, V. (1992), and Van Putten, F. (1988) to ascertain if any groundwater investigations were completed specifically on Vaitupu as part of these two studies. Pertinent results and recommendations may be used to inform the following field investigations.
- Carry out salinity measurements to complement, compare and update the salinity data taken in 2006 and 2011 reported in Woodroffe (2007) and Falkland (2012), respectively. Salinity measurements should be taken in all accessible wells, pulaka pits and any other depressions, pits or trenches that are open to the water table. Where possible, salinity profiles should be taken by measurements at progressively deeper depths from the water table.
- Depths to water table below ground level should be recorded and the total depths of all wells and pits.
- A topographic survey of the whole of Vaitupu is required to an accuracy of +- 5 cm. The top of and ground levels of all wells and pits to be surveyed (coordinated and height).
- Record of any wells being pumped with estimated discharge rates at time of sampling and duration of pumping prior to sampling.
- Using the above data, produce a plan(s) and section elevations of Vaitupu showing the water table in relation to ground surface. If sufficient distributed data points are verified, produce water table level contour map and selected sections from depth to water readings. If sufficient distributed data points are verified, produce groundwater salinity contour map and salinity profile elevations.
- Using all the above, produce a conceptual plan and sections showing the theoretical freshwater – seawater interface by applying the Ghyben-Herzberg principle for Vaitupu.
- Perform analytical calculations (spreadsheet-based) of potential recharge to the water table. Create a preliminary water balance to assess groundwater pumping sustainable yields.
- Identify potential site-specific investigation areas (e.g. Te Pela and Motufoua) where groundwater has the lowest salinity values and the freshwater lens is adjudged to be at its thickest.

- Produce report with recommendations to progress to Stage 2.

Decision point – to proceed to targeted field investigations including exploratory geophysical survey, construct test wells/trenches and test pumping.

Stage 2 – Targeted field investigations (preferably 2 sites)

- Select one or more investigation area(s) and demarcate in the field.
- Carry out field audit of infrastructure within the investigation areas particularly accounting for any latrines and septic tanks to avoid these areas (minimum buffer distance of 50 m) and operating wells that may be impacted by testing and consult with owners.
- Carry out surface geophysical surveys using resistivity soundings and electromagnetic induction (‘TEM’). Probably 3 lines in each investigation area (2 long lines parallel to coastline and one short transverse line).
- Geoelectric and hydrologic surveys need to be timed to account for the influence of tides.[41]
- Interpret results in field to guide construction of test wells/trenches to target freshest groundwater.
- Dig and construct test wells or trenches; two (2) in each investigation area.
- Take salinity profiles.
- Test pump for minimum 48 hours proceeded by 24 hours of recovery readings, under standard specifications; record pumping rate, drawdown and salinity. Use the non-pumping well/trench for observation readings. Pumped water to be discharged a minimum distance of 250 m from the pumping source.
- Reverse the order of testing – i.e. test pump the well /trench previously not pumped at each investigation area.
- Take water samples for laboratory analysis (initially TDS, major and minor ions and nutrients (BOD and nitrate).
- Analyse tests using standard groundwater hydraulic procedures to inform safe pumping yields that will preclude/minimise saline intrusion. Assess hydrochemistry and water quality.
- Produce report with recommendations to progress to Stage 3.

Decision point – to proceed to pilot-scale groundwater infiltration gallery trial by constructing (temporary) long-trench (up to 200 m long). Probably select one site only, guided by the groundwater resource and engineering supply economics.

[41] Large changes in bulk resistivity and the electrical conductivity of groundwater from wells indicate that periodic salinization in phase with the semidiurnal tides occurs, especially in areas at lower elevation than the high-tide level.

Stage 3 – Infiltration gallery pilot trial (preferably 1 site only)

- From Stage 2 results, select the hydrogeologically more suitable site (cognisant of the engineering water supply infrastructure placement economics).
- Test pump for 30 days with commensurate recordings of pumping discharge, drawdown and salinity. Pumped water to be discharged a minimum distance of 500 m from the pumping source.
- Take water samples for laboratory analysis (initially TDS, major and minor ions and nutrients (BOD and nitrate).
- Analyse tests using standard groundwater hydraulic procedures to inform safe pumping yields that will preclude/ minimise saline intrusion. Assess hydrochemistry and water quality.
- Produce report with recommendations to progress to Stage 4.

Decision point – to proceed to engineering concept design. Probably select one site only guided by the groundwater resource and engineering supply economics.

Stage 4 – Engineering concept design of groundwater infiltration gallery(ies) with capital, and operational and maintenance cost estimates

- Produce conceptual engineering design including preliminary engineering drawings, a process flow diagram, and associated process and instrument drawings.
- Produce high level cost estimates based on the drawings and bills of quantities.
- Report with recommendations based on detailed benefit cost analysis to progress to Stage 5.

Decision point – to proceed to detailed engineering design and construction. Probably select one site only guided by the groundwater resource and engineering supply economics.

Stage 5 – Detailed engineering design and construction of a groundwater infiltration gallery(ies)

- Specify and let tender(s) for detailed engineering design
- Assess and award contract
- Detailed engineering design received
- Specify and let tender(s) for construction
- Assess and award contract
- Supervise and build
- Test and commission.

Groundwater studies and investigations – cost estimate

Table C7 presents a high level, 'first pass' cost estimate to inform the investigation of two (2) sites on Vaitupu with a view to carrying out a pilot trial at the preferred site. If preliminary results and scheme economics are favourable, proceed to engineering design and construction of a groundwater infiltration gallery-sourced water supply scheme.

Table C7. Cost estimate for investigations to proceed to the design and construction of a groundwater infiltration gallery scheme as a water supply source for Vaitupu

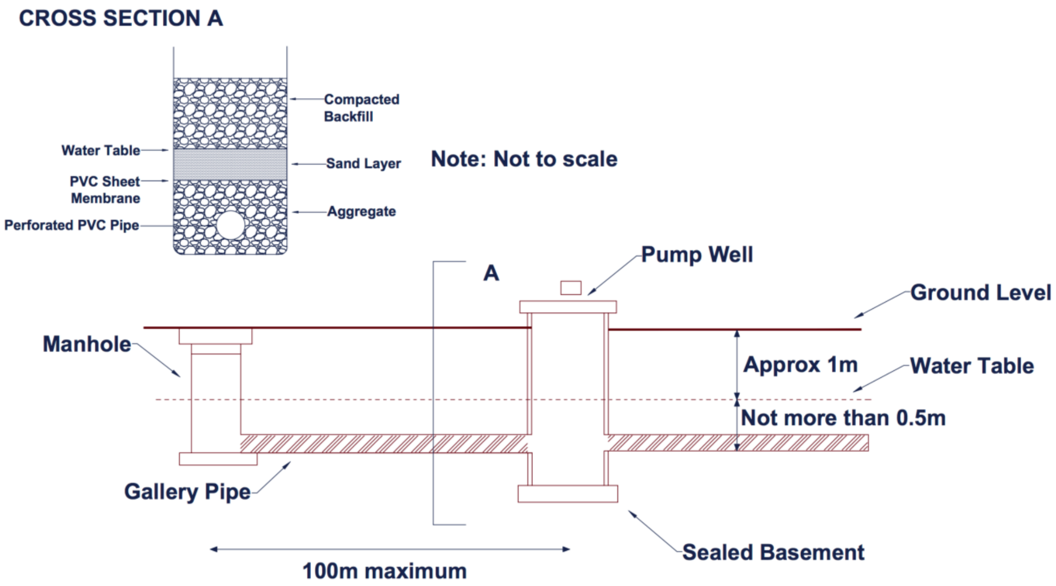
Stage / Task	Description	Estimated cost (AUD, mid-2014)
1	**Preliminary island-wide groundwater survey**	
1.1	Desktop review	5000
1.2	Field survey (GW depth and salinity measurements)	25000
1.3	Topographic survey - ground level and all wells & pits	30000
1.4	Pumped well inventory and records	see 1.2
1.5	Produce water-table and salinity contour plan(s).	2500
1.6	Conceptual groundwater map and sections	3000
1.7	Calculate recharge & water balance re. groundwater sustainable yield	2000
1.8	Identify site investigation areas	1000
1.9	Report	9000
		$ 77,500
2	**Targeted field investigations (2 sites)**	
2.10	Select investigation areas & demarcate	5000
2.20	Field audit of infrastructure	see 2.1
2.30	Surface geophysical survey	50000
2.40	Interpret results in field	see 2.4
2.50	Dig & construct test wells/trenches; 2 in 2 investigation areas	10000
2.60	Take salinity profiles	2000
2.70	Test pump (48 hours + 24 hours recovery)	25000
2.80	Reverse order of testing	see 2.7
2.90	Lab. water samples	7000
2.10	Analyse tests & assess water quality	10000
2.11	Report	12000
		$ 121,000
3	**Infiltration gallery pilot trial (1 site)**	
3.1	Specific site selection	5000
3.2	Test pump for 30 days	45000
3.3	Lab. water samples	14000
3.4	Analyse tests & asses water quality	10000
3.5	Report	12000
		$ 86,000
4	**Engineering concept design & costings**	
4.1	Conceptual engineering design (prelim eng dwgs, PFD & P&IDs	50000
4.2	High level cost estimates	20000
4.3	Report incl BCA	15000
		$ 85,000
5	**Detailed engineering design & construction contracts**	
5.1	Specify & let tender - engineering design	20000
5.2	Assess & award contract - engineering design	12000
5.3	Receive engineering design - review	8000
5.4	Specify & let tender - construction	15000
5.5	Assess & award contract - construction	12000
5.6	Supervise & build	see separate cost estimate table
5.7	Test & commission	40000
		$ 107,000
	TOTAL	**$ 476,500**
	Add 20% contingency	**$ 571,800**

Groundwater infiltration galleries

Where extraction rates are small, dug wells are appropriate. However, moderate to high pumping from wells or boreholes can lead to up coning of brackish water, causing the pumped water to become saline. The reason for this is that the impact of the pumping is localised near the point of extraction. A more appropriate method of groundwater pumping from freshwater lenses on small coral islands is to pump from infiltration galleries (also called "horizontal wells" or "skimming wells").

Infiltration galleries (depicted conceptually in Figure C8 below) avoid the problems of saline intrusion because they spread the impact of pumping over a wider area of the freshwater lens.

Figure C8. Cross section through a typical infiltration gallery or skimming well [source: Falkland, 2011)



Infiltration galleries generally consist of buried horizontal conduits, which are permeable to water, for example PVC slotted pipes, which are laid in trenches dug at or close to mean sea level. Once the pipes are laid and connected to one or more sealed pump wells, the area is backfilled.

As reported by Falkland, 2011, infiltration galleries have been reported to be successfully operating in Tarawa and Kiritimati, Kiribati (Falkland and Woodroffe, 1997; White and Falkland, 2010), Kwajalein in the Marshall Islands (Hunt, 1996) and Lifuka, Tonga (TWB, 2000). On Lifuka, where groundwater pumped to the residents from a combination of wells and later shallow boreholes had traditionally been quite saline, improvements using infiltration galleries in the late 1990s significantly lowered the salinity of the water supply and has remained low.

Use of pipe materials that allow for effective and fewer joints should be encouraged. An example is the use of polythene pipes with mechanical compression joints rather than PVC pipes with solvent-welded (glued) joints. The former is available in long coils for diameters less than 100 mm leading to fewer joints (and less leakage).

Preliminary concept design calculation of an infiltration gallery

The key issues in developing a groundwater supply scheme are:

- Determination and optimisation of the achievable production rates at the source; basically, the sustainable inflow rates into either wells or trenches.
- Estimation of a "sustainable yield" from the groundwater system, which in this case is related to the volume of the freshwater lens(es) that maybe exploited without irreversible salinisation of the lens(es) that in turn is dependent on replenishment of the lens(es) by rainfall recharge versus the rate of groundwater inflow to the system. (This can only be assessed after the recommended whole of island and site-specific hydrogeological investigations recommended herein).

Dealing with the first dot-point, taking the two potential areas identified for groundwater development, with reference to the calculation outlined in Appendix C2, the following conclusions can be made:

- After 2 days of continuous pumping[42]) a yield of 92 kL/day could be achieved with a radius (line) of drawdown influence of 17 m.
- After 5 days of continuous pumping the yield would have declined to some 62 kL/day with a radius (line) of drawdown influence of 27 m.

Apart from the analytical assumptions given in Appendix C2, the following practical assumptions for the infiltration gallery are listed below:

- A total length of infiltration pipe of 200 m (i.e. 100 m either side of the collection well or 'sump') per infiltration gallery.
- The hydraulic properties and parameters of the aquifer (freshwater lenses) are the same at both the Te Pela and Motufoua sites.
- A trench ('effective' pipe) width of 1 m.
- A water-table level of 1 m below ground; with the infiltration pipe set at 0.5 m below the water table (approximately 0.3 m below MSL).
- The impacts of long-term continuous pumping rates are not examined; as such scenarios are operationally impractical. It is most likely that the extraction pump will be switched on and off (and, ideally, should have a flow switch to avoid drawdown of more than say 0.5 m maximum to ensure saline groundwater is not drawn in, that will inevitably lead to 'staccato pumping'.

By comparing these two short-term pumping scenarios with the demand figures (Table C4), the following supply infrastructure matrix is arrived at (see Table C8).

[42] *De facto* interception and capture of the groundwater by drainage.

Table C8. Number of groundwater infiltration galleries required to satisfy different demand scenarios from either the Te Pela site or the Motufoua site (assuming 2 days and 5 days pumping periods from each gallery)

			2-days continuous pumping (Yield 92 kL/d)	5-days continuous pumping (Yield 62 kL/d)
Population	**Climate condition**	**Average daily demand (kL/d)**	**No. of infiltration galleries each of 200 m length required to meet demand**	
Current 1,600	Normal	192	3	4
		96	1	2
	Drought	24	1	1
1% growth 1,914	Normal	230	3	4
		115	2	2
	Drought	29	1	1
2% growth 2,285	Normal	274	3	5
		137	2	3
	Drought	34	1	1

Note: *the number of galleries has been rounded up to provide whole numbers – in reality, with detailed engineering design, the infiltration pipe lengths could be adjusted accordingly.*

It is emphasised that this methodology is conservative in that it does not consider recharge (nor any delayed yield / vertical leakage induced by pumping drawdown) and it assumes that the thickness of the aquifer is equivalent to the depth of the trench (gallery). The application of these factors would act to increase long-term sustainable inflow rates, though the short-term rates would be largely unaffected.

From Table C8 it is apparent that from a groundwater supply infrastructure perspective most, if not all, demand scenarios could be satisfied. Table 9 follows from Table 8 in terms of physical separation of the infiltration galleries to preclude mutual interference and to ascertain whether or not they would fit physically into the freshwater lens' footprints per Table 5 and Figure 2 for Te Pela and Motufoua, respectively. It is important that no part of the infiltration collection zone extends beyond the theoretically designated groundwater source areas as this could lead to saline intrusion.

In preparing Table C9 the following assumptions are made:

- For Te Pela and Motufoua, the spacing between each infiltration gallery should be not less than 54 m (i.e. twice the maximum predicted radius (line) of pumping drawdown influence of the 5-days continuous pumping scenario).
- Each infiltration gallery would be aligned sympathetically to the long-axis of the ellipse shaped groundwater resource area.
- The distance between the end gallery and the edge of the groundwater resource area should be not less than 27 m.

Table C9. Spacing of groundwater infiltration galleries required to satisfy different demand scenarios from either the Te Pela site or the Motufoua site (assuming a 5-days pumping period from each gallery)

Population	Climate condition	Given name of groundwater resource	Total length short-axis (m)	No and width of footprint (m) of galleries to meet different scenarios	
Current 1,600	Normal	Te Pela	200	4	N (216)
				2	Y (108)
	Drought			1	Y (54)
1% growth 1,914	Normal			4	N (216)
				2	Y (108)
	Drought			1	Y (54)
2% growth 2,285	Normal			5	N (270)
				3	Y (162)
	Drought			1	Y (54)
Current 1,600	Normal	Motufoua	250	4	Y (216)
				2	Y (108
	Drought			1	Y (54)
1% growth 1,914	Normal			4	Y (216)
				2	Y (108)
	Drought			1	Y (54)
2% growth 2,285	Normal			5	N (270)
				3	Y (162)
	Drought			1	Y (54)

Note: *N = No – the scheme cannot meet the demand without causing drawdown impacts beyond the designated groundwater resource area.*

Y = Yes – the scheme can meet the demand with drawdown constrained within the designated groundwater resource area

In interpreting Table 9, the following conclusions can be made concerning the suitability of exploiting the groundwater use by means of infiltration galleries:

- Drought declaration (reduced water demand of 15 L/p/d) can be met for the present and future projected populations.
- All normal low-end (i.e. 60 L/p/d) demand can be met for the present and future projected populations.
- Normal high-end (i.e. 120 L/p/d) demand can be met by using the Motufoua groundwater resource, except for the 2 % population growth scenario.
- Normal high-end (i.e. 120 L/p/d) demand *cannot* be met by using the Te Pela groundwater resource for the present and future projected populations.

Groundwater infiltration gallery – establishment costs (estimates)

Tables C10 to C15 below present a summary of cost estimates based on two variants of three scenarios, as follows:

- Scenario 1 is to construct an infiltration gallery at Te Pela and connect it by buried pipeline (50 or 75mm dia HDPE) to Tumaseu and Asau.
- Scenario 2 is to construct an infiltration gallery at Motufoua and connect it by buried pipeline (50 or 75mm dia HDPE) to Tumaseu and Asau.

- Scenario 3 is to construct an infiltration gallery at Motufoua and connect it by buried pipeline (50 or 75mm dia HDPE) to Motufoua School.
- Scenario 4 is to construct an infiltration gallery at Te Pela and cart water to Tumaseu and Asau.
- Scenario 5 is to construct an infiltration gallery at Motufoua and cart water to Tumaseu and Asau.
- Scenario 6 is to construct an infiltration gallery at Motufoua and cart water to Motufoua School.

Table C10. Te Pela to village - Infiltration gallery with pipeline

Infiltration gallery	Amount ($)
Materials	50,100
Construction	11,400
Header tanks	30,000
Pipeline	
Materials	65,300
Construction	148,200
Transport	
Transport from Brisbane to Vaitupu	16,000
Sub Total	321,000
GST Component	32,100
Total Amount	$353,100
Total Amount including 20% contingency	**$423,720**

Notes: Pricing is for the installation of a single infiltration gallery system; Estimated pipeline distance of 2,600m

Table C11. Motufoua to village - Infiltration gallery with pipeline

Infiltration gallery	Amount ($)
Materials	50,100
Construction	11,400
Header tanks	30,000
Pipeline	
Materials	25,800
Construction	57,000
Transport	
Transport from Brisbane to Vaitupu	16,000
Sub Total	190,300
GST Component	19,030
Total Amount	$209,330
Total Amount including 20% contingency	**$251,196**

Notes: Pricing is for the installation of a single infiltration gallery system; Estimated pipeline distance of 1,000m

Table C12. Motufoua to school - Infiltration gallery with pipeline

Infiltration gallery	Amount ($)
Materials	50,100
Construction	11,400
Pipeline	
Materials	11,600
Construction	29,700
Transport	
Transport from Brisbane to Vaitupu	16,000
Sub Total	118,800
GST Component	11,880
Total Amount	$130,680
Total Amount including 20% contingency	**$156,816**

Notes: Pricing is for the installation of a single infiltration gallery system; Estimated pipeline distance of 1,000m; Existing header tanks presumed to be at the school

Table C13. TePela to village - Infiltration gallery with water truck

Infiltration gallery	Amount ($)
Materials	50,100
Construction	11,400
Header tanks	30,000
Water truck	
Water truck 10,000L capacity	211,000
Transport	
Transport from Brisbane to Vaitupu	30,000
Sub Total	332,500
GST Component	33,250
Total Amount	$365,750
Total Amount including 20% contingency	**$438,900**

Notes: Pricing is for the installation of a single infiltration gallery system; Truck driver and running costs included in the above price were calculated for one year; Estimated distance between TePela to village 2,600m

Table C14. Motufoua to village - Infiltration gallery with water truck

Infiltration gallery	Amount ($)
Materials	50,100
Construction	11,400
Header tanks	30,000
Water truck	
Water truck 10,000L capacity	207,000
Transport	
Transport from Brisbane to Vaitupu	30,000
Sub Total	328,500
GST Component	32,850
Total Amount	$361,350
Total Amount including 20% contingency	**$433,620**

Notes: Pricing is for the installation of a single infiltration gallery system; Truck driver and running costs included in the above price were calculated for one year; Estimated distance between Motufoua to village 1,000m

Table C15. Motufoua to school - Infiltration gallery with water truck

Infiltration gallery	Amount ($)
Materials	50,100
Construction	11,400
Water truck	
Water truck 10,000L capacity	205,000
Transport	
Transport from Brisbane to Vaitupu	30,000
Sub Total	285,100
GST Component	28,510
Total Amount	$313,610
Total Amount	**$376,332**

Notes: Pricing is for the installation of a single infiltration gallery system; Truck driver and running costs included in the above price were calculated for one year; Estimated distance between Motufoua to village 500m

Review of Tables C10 to C15 indicates that the most influential cost factor for the pipeline scenarios is associated with the length of pipeline to be installed, whilst the carting scenarios are all influenced by the capital cost of acquiring a truck. However it must be stressed that costs of running a water carting business are unknown and will themselves be influenced by other factors such as whether other water carting clients may be in the market, fuel prices and/or the ongoing staffing, insurance and vehicle maintenance typically associated with such operations.

Conclusions

- A significant and easily accessible resource ('lens') of brackish to fresh groundwater occurs in a shallow water table aquifer floating on seawater on Vaitupu.
- This groundwater system is highly dynamic and vulnerable to external stressors, especially growth in water demand, periodic dry periods and open to natural contamination from the sea and land-based contamination from inappropriate land use planning, particularly with regard to sanitation systems and practices.
- During dry periods, recharge to the water-table decreases and the freshwater mixes with saline water and becomes brackish.
- Historically, over-extraction during droughts has resulted in temporary drops in the water table and resultant groundwater salinisation. This has not only impacted humans but has seriously stressed groundwater dependent vegetation.
- Existing dug wells act as point sources for water supply and are located close to the two neighbouring villages of Asau and Tumaseu, and Motufoua School. Salinity levels of water taken from these wells has been recorded between 2,000 and 13,000 µS/cm (i.e. mildly brackish to brackish).
- Groundwater is used as a non-potable secondary source for livestock, washing clothes, flushing toilets and bathing. In times of drought it use may increase to cope with reduced access to rainwater – the primary water source, and it has been used as an emergency source for drinking water.
- Toilet flushing s (WCs) constitutes a significant percentage of water use.
- Composting toilets deliver environmental benefits, water savings and improve water quality and security.
- Groundwater contamination from latrines and septic tank systems by pathogens is a real threat. A fifty-day residence time in the subsurface is needed to provide effective pathogen die-off for drinking water. Different guidelines have been applied in different jurisdictions ranging from 30 m to over 200 m separation between domestic septic tanks and water supply wells.
- In general, this study has identified that the highest risk to groundwater security is from population growth leading to increasing water demand and increase in pollution. With respect to groundwater resources, the relative influence of climate change is less important than the more influential factors of population growth and urban planning and has not been modelled herein.
- For the purposes of this report a normal per capita water demand of approximately 60 (low level use) and 120 L/person/day (affluent or high level use) has been taken for sustainable use estimates. During drought it has been assumed that the demand would be reduced to some 15 L/person/day. A water supply peaking factor of 2.5 for maximum daily demand has been applied.

- For purpose of sustainable yield calculations a recharge factor of 9 % of annual average rainfall for Vaitupu (3,117 mm), viz. 280 mm/year has been used.
- Using results from two historical salinity surveys of pulaka pits and one survey of well salinities, two areas for potential investigation for fresh groundwater resources have been identified. For the purposes of this study, these two groundwater resources have been named as ‘Te Pela’ (after a pulaka pit surveyed in the general area) and ‘Motufoua’ (after the School located immediately to the east).
- Based on a number of assumptions (necessary because of the lack of hydrogeological data), the Te Pela lens is calculated to contain some 120,000 kL of potentially exploitable fresh groundwater, whilst the Motufoua lens is calculated to contain some 113,000 kL of potentially exploitable fresh groundwater.
- These two potential groundwater resources could be developed subject to further detailed island wide and site-specific investigations (see next dot-point).
- Prior to any engineering design studies proceeding for a groundwater supply scheme to serve Vaitupu, a comprehensive, staged suite of groundwater investigations is required. Such investigations have been described and costed.
- In the absence of detailed studies, a high order/first-pass simple assessment has been undertaken that arrives at an equivalent number of days supply that might be available under the different demand scenarios, based on the lenses being mined and the accession to the water table by an annual recharge of 280 mm, respectively.
- Under a groundwater-mining scenario under the worse case scenario at Motufoua, there is over 5 months of continuous supply and at Te Pela there is nearly 6 months of continuous supply before the fresh groundwater would be exhausted in the aquifer.
- Under a water take of the estimated annual average recharge scenario under the worse case scenario at Motufoua, there is a reserve of some 3 months of continuous supply and at Te Pela there is a reserve of over 3 months of continuous supply.
- Groundwater infiltration galleries avoid the problems of saline intrusion because they spread the impact of pumping over a wider area of the freshwater lens. They have been reported to be successfully operating several similar Pacific nations.
- A groundwater flow analytical calculation has been used as a basis to determine the number of groundwater infiltration galleries required to satisfy the different demand scenarios from either use of the Te Pela site or the Motufoua site.
- It is apparent that from a groundwater supply source perspective, employing such infiltration galleries could satisfy most, if not all, demand scenarios. Some demand scenarios would require only one gallery per site whilst other demand scenarios require more than one (up to 4 galleries that, theoretically should not cause excessive drawdown that might allow saline water to be intercepted and drawn in).
- A series of tables are presented that summarise cost estimates for the construction of a groundwater infiltration gallery scheme based on two variants of three scenarios, as follows:

- Scenario 1 is to construct an infiltration gallery at Te Pela and connect it by buried pipeline (50 or 75mm dia HDPE) to Tumaseu and Asau.
- Scenario 2 is to construct an infiltration gallery at Motufoua and connect it by buried pipeline (50 or 75mm dia HDPE) to Tumaseu and Asau.
- Scenario 3 is to construct an infiltration gallery at Motufoua and connect it by buried pipeline (50 or 75mm dia HDPE) to Motufoua School.
- Scenario 4 is to construct an infiltration gallery at Te Pela and cart water to Tumaseu and Asau.
- Scenario 5 is to construct an infiltration gallery at Motufoua and cart water to Tumaseu and Asau.
- Scenario 6 is to construct an infiltration gallery at Motufoua and cart water to Motufoua School.

- It should be noted that the price estimate presented in each table is for the installation of a single infiltration gallery system, only.

Recommendations

Management – Tuvalu

- Provide clear and accessible public information on the linkage between sanitation and groundwater contamination.
- Enact the Water Resources Act and support for the relevant conditions of the Tuvalu National Building Code, which provides regulations and guidelines for design of roof catchments, rain storages, and sanitation systems (NWSC, undated).
- Establish centralised water supply systems remote from any existing sanitation systems.
- Train construction workers and plumbers for the design and construction of groundwater supply infrastructure.
- Train stakeholders in groundwater resources assessment, development and management, monitoring and analysis, including establishing a baseline survey of groundwater table levels and groundwater quality data.
- Carry out a baseline data survey on nutrient and pathogen levels in the groundwater in the planned wellfield development area.
- Establish monitoring procedures for nutrients and pathogens and in drinking water supplies, develop a contingency plan for occasions when water does not meet the required quality e.g. disinfection of water supply wells.
- Record water consumption to ascertain if the design supply criteria are being met.
- Wellhead protection areas – regulate land use planning and management by declaring wellhead protection areas[43] for the exclusion of certain activities designed to protect groundwater sources (wells and/or galleries) from contamination. Specify well-head protection zones (minimum separation distances for contaminant sources).
- Land tenure arrangements (traditional, historical and current) need to be addressed to balance the rights of stakeholders with the community's need for access to undeveloped and uncontaminated groundwater resources for the public good.

Management – Vaitupu

- Pollutant point sources and contaminating land uses need to be examined and, where practicable, prohibited, regulated and/or otherwise managed within designated groundwater source areas. Measure may include auditing leaking septic tanks, declaring exclusion areas where no new tanks/septics may be used, auditing/continually improving the environmental performance of piggeries, cemeteries, and solid waste operations, etc.
- Wellhead protection areas are particularly relevant to Vaitupu as a groundwater development scheme is being encouraged. Such areas would provide for the exclusion of certain activities designed to protect groundwater sources (wells and/or galleries) from contamination.

43 WHPAs; also known as Wellhead Protection Zones (WPZs).

- Comprehensive stakeholder and community consultation is required to support and encourage acceptance and participation in declaring, observing and policing wellhead protection areas.

Technical – Vaitupu

- A comprehensive groundwater assessment investigation is required. This groundwater survey should include baseline groundwater monitoring, a topographic survey of sufficient resolution (+- 5 cm) to accurately assess the study area, a geophysical survey, the construction of shallow test wells/trenches, test pumping, etc.
- Subject to confirmation of the presented assumptions in respect of two possible sites (namely “Te Pela” and “Motufoua”), and the costs of investigation and development of a groundwater supply scheme, a groundwater infiltration gallery pilot trial is warranted.
- The pilot trial and any subsequent installation of a groundwater supply scheme should employ infiltration galleries for interception and collection of groundwater.
- Composting toilets are recommended to replace existing sanitation systems as they pose less risk to groundwater contamination given that the existing land quality and size is not sufficient to allow correct management of sewage and sludge.
- Solar photovoltaic has been used successfully in Tuvalu for electricity generation and should be considered as a power source for groundwater pumping.
- The conjunctive use of water (rainwater and groundwater) is recommended. Rainwater should be reserved for potable purposes with groundwater being used for non-potable purposes.

Appendix C1 – Detailed and conceptual drawings

Figure C9 – Impact of tidal loading on the freshwater-saltwater interface that together with dispersion creates a zone of mixing of brackish water – the 'transition zone'.

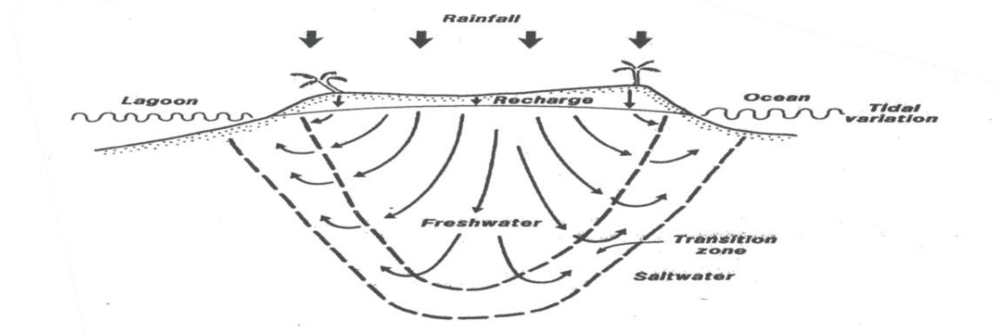


Figure C10 – Detail of groundwater hydrology at island edge showing the relationship between the shoreline, water table, freshwater discharge zone and the transition zone.

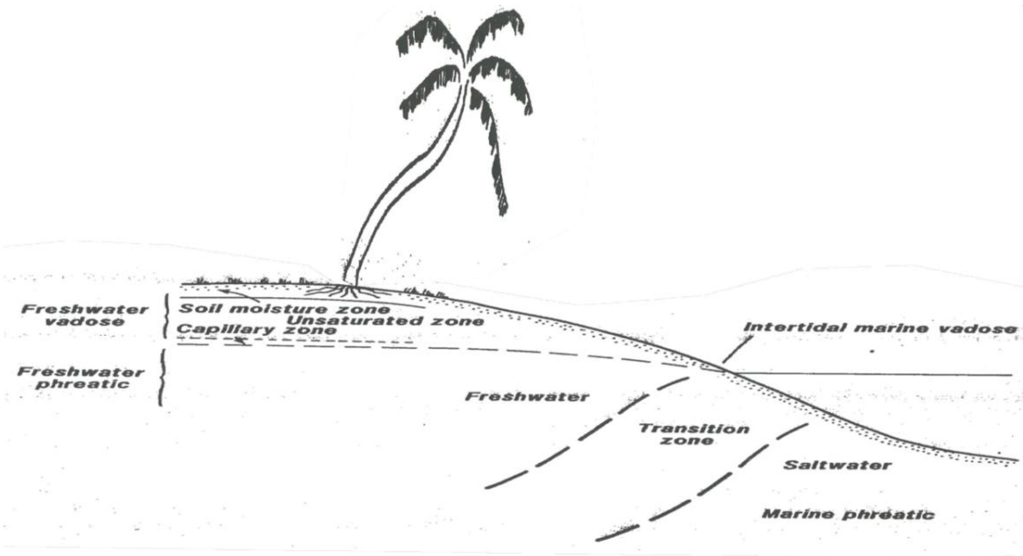
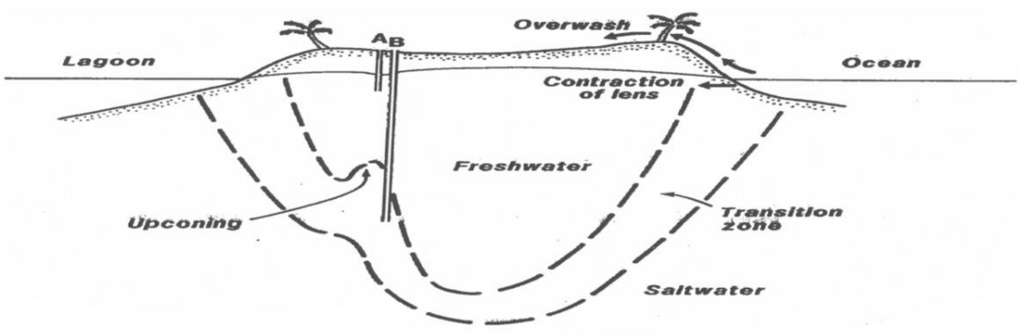


Figure C11 – (1) Effect of saline up-coning (intrusion) into the freshwater lens as a result of extraction from an overly deep well completed at the base of the freshwater lens vs. a shallow well (or gallery pipe) completed immediately below the water table. (2) Impact of storm surge causing over-wash that results in overland flow of saline water. Net impacts are diminution of freshwater lens.



Appendix C2 – Calculation of trench (infiltration gallery) performance

Trench performance in an unconfined (water table) aquifer can be estimated using the modification of the Dupuit-Forchheimer Equation presented in Hazel, (2009).

$$Q = \frac{\pi K(H^2 - h^2)}{2.3\log(r_0 / r_w)} + 2\frac{(x+y)K(H^2 - h^2)}{2L_0}$$

Where

Q= Flow rate into pit

K = Permeability

H = Static Water Level

h = pumping water level

r_0 = radius of influence (1.5 $\sqrt{}$K.d.t/S_y)

r_w = effective radius of pit corners (use 1m)

x = pit length

y = pit width

$L_0 = r_0$

d = pit depth

t = duration of pumping

S_y = Specific Yield

… and the following assumptions:

- An infiltration gallery can be considered as a ‘trench’ for the purposes of this analysis
- Hydraulic conductivity (permeability), K of the aquifer = 20 m/day (typical of a coarse sand)
- The specific yield, Sy of the aquifer = 0.15
- D is the pumping drawdown (H-h) = 0.5 m maximum, and is equivalent to the depth to the base of the infiltration gallery’s horizontal pipe.
- The thickness of the aquifer is equivalent to the depth of the trench
- Recharge and vertical leakage are nil (i.e. not accounted for)

Unconfined flow															Scenario	Unconfined flow		
Qr	Ql	Qt	S	r0	L0	t	K	b	H	hw	h	rw	x	y		Vt	C Vt	A Vt
Radial flow rate	Linear flow rate	total flow rate	Specific Yeild	radius of influence	length of influence	duration of pumping	Hydraulic Conductivity	thickness	Initial Head	Pumping Head	head at dist R	effective radius	width	length		Volume pumped	Cumulative volume pumped	Average flow rate (m3/day)
11.6	259.5	271.1	0.15	4	4	0.1	20	0.5	0.5	0		0.5	1	200	High Yield K = 20, S = 0.15, D = 0.5	27	27	271
7.3	116.0	123.3	0.15	9	9	0.5	20	0.5	0.5	0		0.5	1	200		49	76	153
6.3	82.1	88.3	0.15	12	12	1	20	0.5	0.5	0		0.5	1	200		44	121	121
5.5	58.0	63.5	0.15	17	17	2	20	0.5	0.5	0		0.5	1	200		64	184	92
4.8	36.7	41.4	0.15	27	27	5	20	0.5	0.5	0		0.5	1	200		124	308	62
4.3	25.9	30.3	0.15	39	39	10	20	0.5	0.5	0		0.5	1	200		151	460	46
4.1	21.2	25.3	0.15	47	47	15	20	0.5	0.5	0		0.5	1	200		126	586	39
3.9	18.3	22.3	0.15	55	55	20	20	0.5	0.5	0		0.5	1	200		111	697	35
3.3	8.2	11.5	0.15	122	122	100	20	0.5	0.5	0		0.5	1	200		918	1616	16