Secretariat of the Pacific Community (SPC)

Household Survey to Assess Vulnerabilities to Water Resources and Coastal Erosion and Inundation

Lifuka, Ha'apai, Tonga

On the brink: A Lifuka home

Peter Sinclair, Amit Singh, Anja Grujovic, Jens Kruger,
Zulfikar Begg, Paula Holland, and Brigitte Leduc

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SPC SOPAC DIVISION TECHNICAL REPORT

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ABBREVIATIONS AND SYMBOLS

AusAID	Australian Agency for International Development (the government overseas aid program)
CBN	Census block number
DCCEE	Australia's Department of Climate Change and Energy Efficiency
E. coli	*Escherichia coli*
EC units	Electrical conductivity units
FAC	Free available chlorine
GDP	Gross domestic product
GPS	Global positioning system
HDP	SPC's Human Development Programme
ICCAI	International Climate Change Adaptation Initiative
ID	Identification
LIF	Lifuka salinity monitoring bore
MECC	Ministry of Environment and Climate Change
MLSNR	Ministry of Land, Survey and Natural Resources
NEOC	National Emergency Operations Committee
NGO	Non-governmental organisation
OCHA	Office for the Coordination of Humanitarian Affairs
PASAP	Pacific Adaptation Strategy Assistance Program
PDN	Pacific Disaster Net
PVC	Polyvinyl chloride
RWH	Rainwater harvesting
SOPAC	SPC Applied Geoscience and Technology Division
SPC	Secretariat of the Pacific Community
TC	Tropical cyclone
TCDT	Tonga Community Development Trust
TOP	Tongan Paʻanga
TWB	Tonga Water Board
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization

Measurements

KL/day	Kilo litres per day
L	Litres
L/min	Litres per minute
L/p/d	Litres per person per day
L/sec	Litres per second
m^3	Cubic metres
ML/day	Mega litres per day
µS /cm	Microsiemens per centimetre
mS/cm	Millisiemens per centimetre

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HOUSEHOLD SURVEY: KEY FINDINGS

- Nearly all of Lifuka's people (98%) perceived that the island's beaches were eroding.
- All households were aware of sea-level rise, and many feared its impact.
- Households generally didn't link beach mining for domestic purposes with coastal erosion.
- Of all homes within 120 m of the coast, 29% had been flooded.
- The village of Pangai had the highest rate of flooding, the greatest beach loss and also the highest rate of beach mining.
- Groundwater was at very high risk of faecal contamination.
- Most families did not treat their drinking water.

HOUSEHOLD SURVEY: KEY RECOMMENDATIONS

We strongly recommend that the **people of Lifuka be made aware of the widespread bacteriological contamination of groundwater**, and that they be advised that groundwater for drinking must be treated by either boiling or chlorination. They should also take care to avoid ingesting untreated groundwater while using it for other purposes.

Consideration should be given to an **awareness-raising programme providing householders with incentives to maintain an efficient and safe rainwater harvesting system**. An effective way forward might be a community-based approach to water safety planning, with the clear message that householders are responsible for maintaining an efficient and safe drinking-water supply.

The management of coastal mining around Lifuka should be revisited. Given that households need a regular supply of aggregate, and that it is inappropriate to mine vulnerable beaches, **more appropriate locations for aggregate mining should be sought.**

Encouraging community engagement is suggested as a way to **raise awareness about sea-level rise** and what it means for lives and livelihoods.

Alternative options for sewage disposal should be developed, such as properly installed and maintained composting toilets and better enforcement of building codes for on-site wastewater systems. Without improved on-site wastewater disposal, the risk of water-borne diseases will remain high.

1. BACKGROUND

1.1 PASAP project

As part of the International Climate Change Adaptation Initiative (ICCAI), the Pacific Adaptation Strategy Assistance Program aims to facilitate the development of evidence-based adaptation strategies in partner countries. The programme is implemented by Australia's Department of Climate Change and Energy Efficiency (DCCEE), with the primary objective of enhancing the capacity of partner countries to assess key vulnerabilities and risks, formulate adaptation strategies and plans, and mainstream adaptation into decision-making.

The project was conceived by the Government of Tonga's Ministry of Environment and Climate Change (MECC) in consultation with DCCEE. It responds to coastal erosion issues that accelerated immediately following the May 2006 earthquake in the Ha'apai island group, which resulted in subsidence along the island chain. There is some suggestion of coastal erosion occurring prior to the earthquake (Cummins et al. 2006).

DCCEE and MECC approached the Secretariat of the Pacific Community (SPC) to assist in the development of a project to investigate the causes of coastal erosion and the impacts of sudden sea-level rise on the coast and the communities of Lifuka. The project was nested within a community-focused framework to promote the selection of suitable mitigation and adaptation strategies in a context of adaptation to expected future impacts of climate change.

SPC's Human Development Programme (HDP) and Applied Geoscience and Technology Division (SOPAC) developed a proposal that identified climate-change adaptation strategies appropriate to Lifuka with application to other parts of Tonga and the Pacific. The project is formally referred to as Island Vulnerability and Adaptation to Sea-Level Rise project on Lifuka Island and is intended to develop an evidence-based strategy for adapting to sea-level rise while supporting the capacity of the Government of Tonga and relevant NGOs to conduct similar assessments of coastal and social vulnerability and adaptation to sea-level rise in the future. The overall project design is based on an earlier draft proposal developed by DCCEE, MECC and Melbourne University.

The project consisted of a sequence of activities which included a scientific analysis of coastal process dynamics and inundation modelling, topographic and groundwater resource mapping, analysis of community social and environmental values and analysis of community exposure to risk. Outputs from the project consist of reports from each of the project steps that will serve as primary inputs into the project's final report. The final report will draw important conclusions across related pieces of work and will capture lessons learned from the various processes.

One of the project activities was the household survey carried out on Lifuka between 17 March and 3 April 2012. The household survey captures information on changes to the shoreline, the state of infrastructure, freshwater resources and society's perceptions related to subsidence from the 2006 earthquake. Additional information on primary and secondary water sources was collected.

This document outlines the methods used in implementing the household survey and reports on the preliminary findings. The outcomes of this survey will serve as inputs into parallel analyses which form part of this project.

1.2 National context

Tonga is an archipelago of approximately 170 islands, with a population of 102,000 inhabiting 36 of the islands. The total land area is 650 km^2 (see Figure 1 for a map of Tonga). The main island of Tongatapu is home to 71% of the population and has the highest population density – 277 people/km^2. The population of the Ha'apai Group, the region of focus for this project, is 7,570 people at a density of 69 people/km2. Tonga is highly dependent on the transfer of remittances from abroad, which account for close to 40% of gross national product (GNP). Tourism and aid both account for approximately 15% of GNP, and agriculture and fisheries are also significant sources of revenue. In recent years, annual GDP growth has fluctuated significantly, ranging from 3.6% in 1998 and 1999 to -3.6% in 2004–2005. The linear trend of GDP growth between 1993 and 2008 is 1.8% per annum, according to the 2006 Census.

Crops are grown to feed families, for sale at local markets, and, increasingly, for export. Successful export crops include squash pumpkin sold to Japan and vanilla sent to France, Japan and the United States. Agricultural exports, including fish, make up 73% of exports, but are vulnerable due to fluctuations in commodity prices, high transportation costs and the effects of natural disasters such as cyclones. Traditional root crops and vegetables such as taro, kumara, cassava, watermelon and yams are also exported to the large Tongan communities living in New Zealand, the United States and Australia.

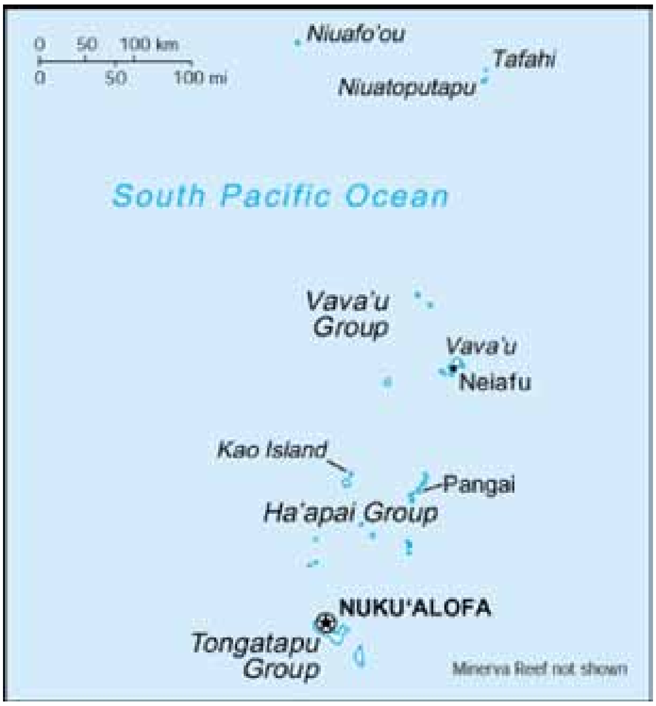


Figure 1. Map of Tonga (Source: CIA, 2012)

Urban drift to the capital of Nuku'alofa is a feature of life in Tonga. Between 2001 and 2006, Tongatapu's population grew by 1200 people, whereas it declined in Vava'u, Ha'apai and the Niuas. Youth unemployment on Tongatapu is high, with unemployment among those aged 15 to 19 approximately 40%, according to 2006 census figures. In 2006, the overall rate of unemployment was 34%, a figure that includes subsistence farmers, with 1000 to 1200 school-leavers competing for a limited number of formal jobs each year. Tonga ranked 99 out of 182 in the UN Human Development Index for 2007. Based on an analysis of Tonga's 2001 Household Income and Expenditure Survey, about 23% of households were estimated to be living below the basic-needs poverty line of TOP 28.18 per day. This does not necessarily mean the poor in Tonga don't have enough to eat, but rather that some households do not have enough income for a basic diet plus the costs of other essential items.

The majority of Tongans are Christians; the main churches are the Free Wesleyan Church (37%), the Church of Latter Day Saints (Mormon) (17%), the Catholic Church (16%) and the Free Church of Tonga (11%). The churches collect regular contributions from their congregations in the form of food and cash, which is used mainly toward spiritual aims, building infrastructure and running church schools; churches are key education providers.

1.3 Haʻapai group

The Haʻapai group of islands consists of 60 small, low-lying islands. These are grouped into six administrative districts. The region's administrative centre is the town of Pangai, on the island of Lifuka. Lifuka is home to 2,967 people – about 40% of the population of the Haʻapai group. Lifuka houses the region's airport and main harbour.

All the islands have primary schools, often with fewer than 20 students, catering for children up to class 6. Families raise funds to send their children to high school and college in Pangai or Nukuʻalofa. The isolation of the Haʻapai islands constrains the delivery of core services and access to markets.

High migration rates from the Haʻapai group have resulted in negative population growth. There has been an overall population decrease of 7% within a decade. While the population of the urban district has not decreased, the four remote districts have experienced population decreases of between 14% and 20% (PASAP 2011). Villages and towns report that up to 30% of homes are uninhabited, as people have moved to Tongatapu or overseas.

Most of the houses on each island have individual household rainwater tanks and most islands have groundwater, which is used for non-drinking purposes, although some islands are fully reliant on rain for their fresh water. The majority of households also have access to pit or flush toilets and most have access to electricity, either through diesel-generated power or solar power. However, the cost of diesel energy can limit usage (Tonga 2006 Census).

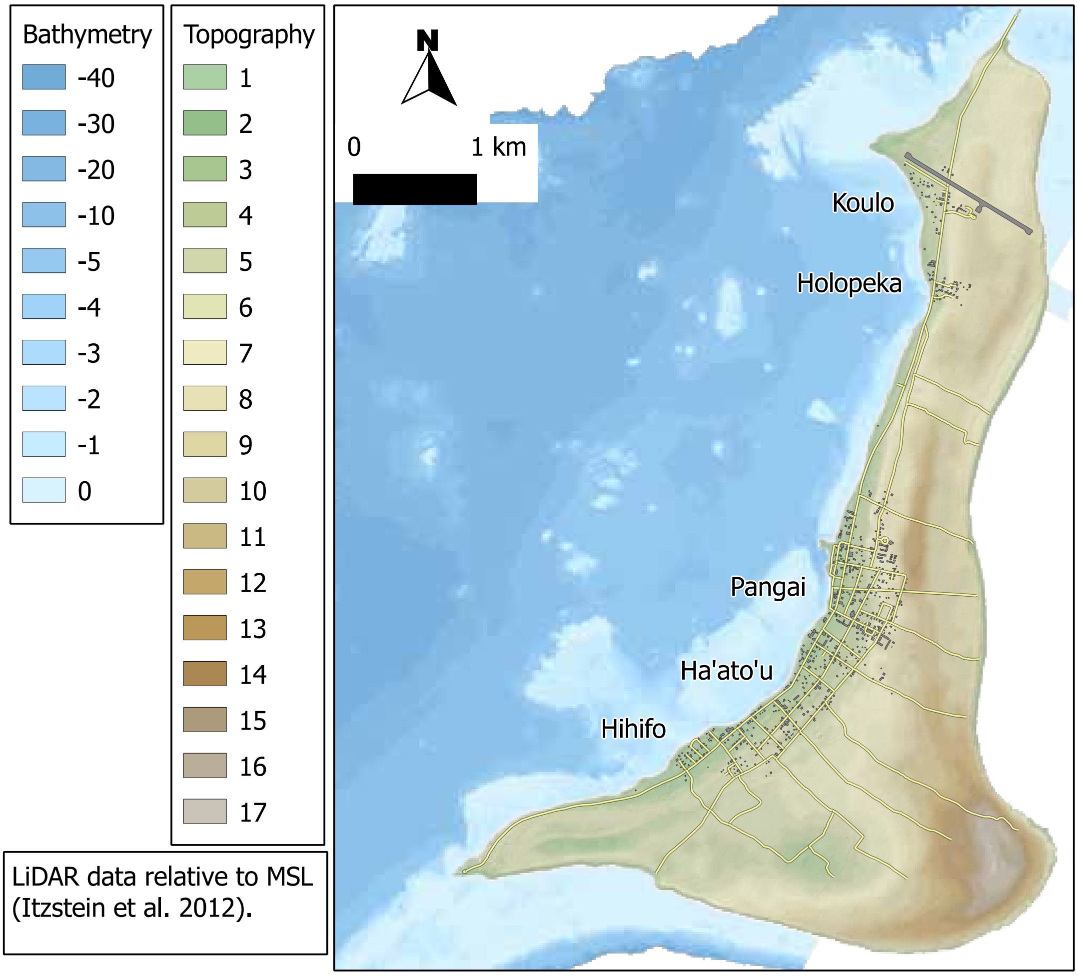


Figure 2. Map of Lifuka

Families rely on subsistence agriculture (root crops, fruits and greens), fishing, pigs and some goats; there is limited production of fresh vegetables. Some of the small islands have very little fertile soil for agriculture. A few villages have horses for transportation. Gender roles are quite defined, with men exclusively doing fishing, ploughing, planting and harvesting of crops, and preparation of *umu* (cooking pits). Women undertake day-to-day food preparation, treating pandanus and weaving.

Income on the outer islands is derived almost exclusively from fishing and weaving (including the sale of pandanus), with September's annual sea cucumber harvest bringing substantial revenue. While fishing is a vital source of income, most islands do not have refrigeration or ice-block machines to store fish before sale.

1.4 Coastal erosion on Lifuka

The Ha'apai group experienced an earthquake on 3 May 2006 that measured approximately 7.9 on the Richter scale and resulted in subsidence of 23 cm on the western side of Lifuka Island, the coast on which Pangai is located (Cummins et al. 2006). In recent years, the island has experienced significant coastal erosion, impacting infrastructure over a 3 km section of the coastline. The infrastructure affected includes the harbour, housing, a broadcasting tower, a church and Lifuka hospital.

Rising sea levels over the next few decades and the resulting wave impact, particularly at high tide, will further erode the coastline in Pangai, leading to increasing inundation of and damage to infrastructure along the shoreline. There are related impacts on groundwater, health, and food production, and it is notable that some septic systems are below mean high-tide levels. Historically, rainwater has been the main source of water for Ha'apai, with some piped groundwater available from wells provided by the Tonga Water Board to Pangai and Hihifo. Construction of galleries for groundwater collection in 1999 and 2000 saw improvements to the quality of the piped water supply to Hihifo and Pangai. Operation and status of the groundwater system, where there are concerns over deteriorating water quality, have not been assessed since before the subsidence of 2006.

Figure 3. Erosion on the Lifuka coast, southern end of Lifuka, after Cyclone Cyril, February 2012

1.5 Lifuka component of the PASAP project

Coastal erosion on Lifuka Island has been identified as a major concern and has therefore become an adaptation priority (MLSNRE 2009). However, there is a lack of expertise and resources within the Government of Tonga to undertake an impact assessment on Lifuka Island. The existing research base, positive feedback from officials in Nukuʻalofa and Pangai, and awareness-raising about climate change already undertaken in communities of Lifuka Island made the activity a suitable choice for the PASAP project. The goal of the PASAP project was to develop an evidence-based strategy for adapting to sea-level rise on Lifuka, which can be used as a case study to be applied in other parts of Tonga and the Pacific.

The objectives of the Lifuka component of PASAP project are:

- To assess the impacts of seismic subsidence on the coastal zone and on the people of Lifuka;
- To analyse the vulnerability of the coastal zone and of people of Lifuka to future rises in sea level;
- To propose and assess a range of adaptation strategies for adapting to sea-level rise on Lifuka;
- To support the capacity of the Government of Tonga and relevant NGOs to conduct assessments of coastal and social vulnerability and adaptation to sea-level rise in the future;
- To design a system to monitor ongoing changes in natural and social systems on Lifuka.

The results will provide an informed basis for selecting an appropriate adaptation response to future sea-level rise and storm surges in the western coastal zone of Lifuka.

Enhanced community understanding of climate-change impacts and increased capacity to adapt to impacts of climate change on coastal zones will be an overarching outcome of the project. The PASAP project on Lifuka adopts an integrated approach to analysing adaptation to sea-level rise. Adaptation is a complex process of matching communities' social and environmental values and expectations with a physical setting undergoing change. The combined approach used by this project includes a physical assessment of Lifuka's environment to better understand the issues and impacts, coupled with a survey of the communities' values and expectations. This method better facilitates discussion to inform decisions about adaptation so that potential risks and trade-offs can be identified and, where possible, managed.

Figure 4. Coastal erosion in front of the Lifuka Royal Palace

Furthermore, this project stresses an ongoing community focus, noting the need for the community to be engaged so people feel they have a stake in decision-making processes.

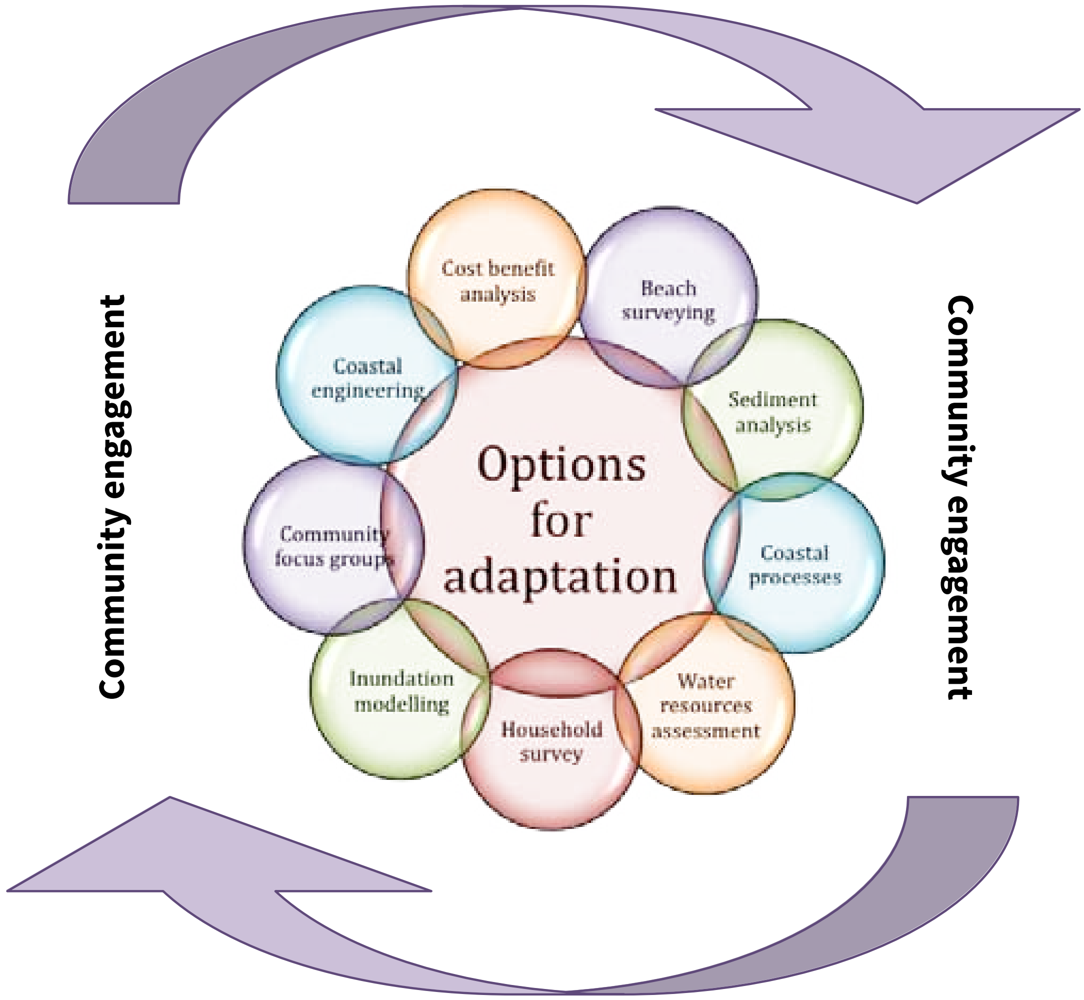


Figure 5. Schematic of physical assessment components of project supported by community engagement to facilitate community-developed adaptation options and strategies

By synthesising the information generated through different activities, the project will help ensure communities and decision-makers are well placed to develop adaptation strategies.

2. OBJECTIVES OF THE HOUSEHOLD SURVEY

The household survey captures social and physical information from 464 households on Lifuka to:

1) Assess the physical condition of rainwater catchment and domestic well assets, and assess water quality on Lifuka;
2) Capture specific information from households on social and economic impacts associated with coastal inundation, coastal erosion, beach aggregate mining, water-use practices and sources of supply on Lifuka.

The household questionnaire served as a platform for the households to share their views on what should be done regarding water supply, costal inundation and coastal erosion, and it collected household-specific information.

The household questionnaire was designed and implemented with the guidance of the Government of Tonga, led and managed by the MECC, with external technical expertise and management support provided by SPC. Considerable effort was undertaken to involve the Tonga Department of Statistics staff in this work and link it to previous population censuses to ensure continuity.

The aims of the survey are to:

- Generate baseline information on the water resources and coastal processes and threats;
- Support the capacity of the Government of Tonga and relevant NGOs to conduct similar assessments of coastal and social vulnerability in regard to sea-level rise;
- Support inter-agency planning in Tonga and provide comparable information as a basis for decision-making in other areas at both national and regional levels;
- Benefit other regional organisations that can draw from the project's methods and outcomes to inform parallel responses;
- Benefit the Tonga Statistic Office by generating additional data on social and economic aspects of households and their livelihoods;
- Benefit the community of Lifuka, offering people an opportunity to comment on the issues of water, coastal inundation and erosion;
- Benefit the Australian Government and other donor partners; and
- Provide an approach to better understand and engage with communities such as Lifuka as they consider climate-change issues and adaptation and mitigation options.

The following sections of the report are based on four thematic components of the survey: water resources, coastal inundation and erosion, aggregate mining, and social indicators.

3. METHODOLOGY

3.1 Census data sets

The household survey is comprised of physical measurements and a household questionnaire. The survey was carried out concurrently by trained teams of enumerators and technicians.

The survey was carried out in close collaboration with the Tonga Department of Statistics and Tongan field officers. All efforts were made to link this household survey with the previous national censuses of 2006 and 2011.

The Tonga Department of Statistics provided a complete household listing for Lifuka as used in the 2006 census, which included census blocks, household numbers, and names of heads of households (Table 1). However, no exact household location details existed. A door-to-door approach was adopted to identify as many households, wells and rainwater tanks as possible. Where possible, identification numbering and household name as used by the Tonga Department of Statistics were retained.

Table 1. Example of census block listing with 2006 census data

Census Block Number:	**3010**				
Village Name:	**HOLOPEKA**				
District:	**PANGAI**				
Division:	**HA'APAI**				
H/hold no.	**Name of head of household**	**Status**	**Verified and marked on map**	**New name of head of household (if changed)**	**Comment**
1	SIPE LEAMEIVAKA TAPU	Occupied			
2	SEINI TAPU	Occupied			
3	PENI KIOLE	Occupied			
4	LOPETI TAUFA KAILOMANI	Occupied			
5	MIKIMASI FOTU	Occupied			
6	RESIDENT	Vacant			
7	MELIELI PULU	Occupied			
8	SAIMONE MANU	Occupied			
9	RESIDENT	Vacant			
10	PO'ULIA KIOLE	Occupied			
If household is not on the list above, add it below with a new number (Team name+number) e.g. A1					

To orient the teams and ensure optimum coverage of households, a set of 31 overlapping field maps at a 1:2,000 scale were produced by splitting a WorldView-2 satellite image of Lifuka taken on 6 June 2011. Each map was numbered and had census block areas transcribed onto it, using the boundaries provided by the Department of Statistics. Since the census block boundaries and census block listings originated from the 2006 national census, using this technique allowed consistency to be maintained.

During the survey, teams moved from house to house and interviewees were asked the name of the head of the household. Once a household was identified on the household list, the household number was marked on the roof of the house on the map. Where a household name match was not possible, the house was given a new household number and this number was noted on the map. Unfortunately, in those cases where the name of the head of the household was not found on the census listing, the link to previous census data was lost.

When marking the map, different symbols were used to denote house condition. If a house had been destroyed, its location was marked by an X. If the householders were away or unable to be interviewed, an O was used, and a vacant house was marked by a V. It was important to keep track of these conditions so that a precise count of the Lifuka population and a calculation of the survey's coverage rate could be made. The physical survey of ground and rainwater could be undertaken regardless of the house condition, and any time a well was located its position was marked on the map and a GPS coordinates of the location were recorded.

Figure 6. Example of a marked field map

Houses in each census block number (CBN) were allocated a unique identification number corresponding to the map number, CBN number and house number. For example, a house situated on map number 13 in CBN area 1040 and whose head-of-household name corresponded to household number 38, would be allocated the unique ID of 13104038. All data collected as part of household interviews and rainwater and groundwater surveys were tracked using this unique ID.

For mapping purposes, GPS coordinates of each house and well were taken, along with photographs. All data collected were linked back to the corresponding house using its unique ID and uploaded into a geographic information system to assist with future analysis and assessments.

3.2 Survey forms and questionnaire design

Three separate forms were designed to record the data: the household survey questionnaire, rainwater harvesting survey form and physical groundwater survey form.

Household survey questionnaire: A set of 51 questions that were asked by the enumerators directly to a member of a household. Most of the questions on this form were closed multiple choice questions, though some allowed open responses. The household survey questionnaire was divided into 12 distinct topics: drinking-water sources and treatment, domestic water use, well water use, sanitation, rainwater harvesting, water purchase, household tenure, coastal inundation, TC Rene damage, TC Rene other effects, coastal erosion, and beach mining. Results are discussed in sections 5 to 8.

Rainwater harvesting survey form: Used to record data on rainwater tanks and general characteristics of buildings. The rainwater harvesting survey form was divided into five parts: location, storage, roof, guttering, and risk.

Physical groundwater survey form: Used to record data on household wells. The groundwater survey was divided into five parts: well location, well characteristics, well water quality, well water sampling, and risk of contamination.

Both survey sheets and the questionnaire were designed by SPC staff in consultation with the Tonga Department of Statistics. Both the survey forms and the household questionnaire underwent field testing prior to their use in the project. Copies of the survey forms and the household questionnaire are in Annexes 1 and 2.

4. SURVEY IMPLEMENTATION

4.1 Training

Two days of training for enumerators and physical assessment teams on Lifuka preceded the survey. Day one concentrated on the purpose of the survey, the schedule and an introduction to the technique of interviewing households. Part of the training was run by the Tonga Department of Statistics in Tongan, and its technical expertise in surveys proved to be invaluable. The group also studied the survey forms and household questionnaires to ensure a common understanding. A number of minor amendments were subsequently made.

Participants were split according to their function into enumerators and water technician teams, and contained a mix of skills and both men and women. Team composition is outlined in Annex 3.

The enumerators continued to review and refine the questions to ensure consistency of explanation in Tongan, while the water technicians received training in operation of the GPS receivers, salinity conductivity metres and water-level measuring instruments as well as procedures for bacteriological sampling and observational recording (Annex 4).

Figure 7. Training of enumerators and physical surveyors

The groups conducted a field test in Koulo on the second day of their training. Initially, six teams were established, each consisting of one enumerator and two physical surveyors, and a buddy-system approach was used, whereby two teams combined to undertake the survey for training purposes. This approach proved to be valuable in ensuring consistency throughout the survey.

During the field test, it became evident that the physical surveys were considerably quicker to complete than the household interviews. Subsequently, four teams were established, each team consisting of two enumerators who conducted household survey questionnaires separately, supported by two physical surveyors shared between the two enumerators.

Figure 8. Transporting teams into the field, Lifuka

4.2 Field

The four teams of four people executed the survey across Lifuka over a period of six days. Every day, each team was given a specific area to cover. The teams would then move from house to house within their field maps, interviewing every household as they went and carrying out the physical measurements and sampling of each rainwater tank and well. Rain tanks and wells were referenced to the owner of the household. In the event that no one was present at a house, it was marked as 'away' and a second attempt to undertake the household questionnaire was made later on. Houses that had been unoccupied for some time were marked as vacant.

Figure 9. Interviewing a householder with the questionnaire

All interviews were carried out in Tongan. Different teams worked at varying rates, but in general, a household questionnaire was completed in 30 minutes, about the same amount of time it took to undertake the physical survey of two households. The household survey was apparently well received: of the 392 households covered, none refused to participate.

Figure 10. Measuring rain-tank dimensions during the physical survey

4.3 Issues and difficulties

The survey progressed relatively smoothly, but two issues were noted. First, in a number of cases, households were marked in one census block, but the name of the corresponding head of the household was found on a different census block. This was resolved through thorough note-taking and determining that the census block numbering as found on the maps – that is, the physical location of a house within the census block bounds – would be used. The problem probably arose due to an outdated census block listing.

Secondly, upon finishing the survey, a total of only 70% of households appeared to have been covered, based on the 2006 census block listing. However, when the preliminary 2011 census data were used, the coverage rate was considerably higher, at 84.4%. The 2006 census block listing seems to overestimate the current population of Lifuka.

The implementation of the survey coincided with the death of His Royal Highness King George Tupou V as well members of the community on Lifuka. Out of respect for the royal family, the Tongan nation and other families, the field-work timetable was adjusted.

4.4 Sample size

A total of 392 households were interviewed, and 439 households were physically surveyed for rainwater catchment (Table 2). To calculate the coverage rate of the household survey, these numbers were compared to the preliminary report of the 2011 national census (Table 2). Overall, the coverage rate for interviews was 84%, and for the physical survey it was 95%. The difference in coverage rates between the household interview and household physical surveys is due to some members of some households being away or unreachable.

Table 2. Overview of household interview and physical survey coverage compared with 2011 preliminary census data, by village

	Census 2011* households	Households interviewed	Households physical survey	Percentage of households interviewed**	Percentage of households physically surveyed**
Hihifo	166	146	166	88%	100%
Holopeka	27	24	29	89%	107%
Koulo	37	32	36	86%	97%
Pangai	234	190	208	81%	89%
Total	**464**	**392**	**439**	**84%**	**95%**

* Source: Tonga Department of Statistics 2012

** With respect to 2011 census data

5. HOUSEHOLD QUESTIONNAIRE – WATER RESOURCES ASSESSMENT

5.1 Overview

According to the household questionnaire, 92% of all households on Lifuka use rainwater as their primary source of drinking water (Figure 11).

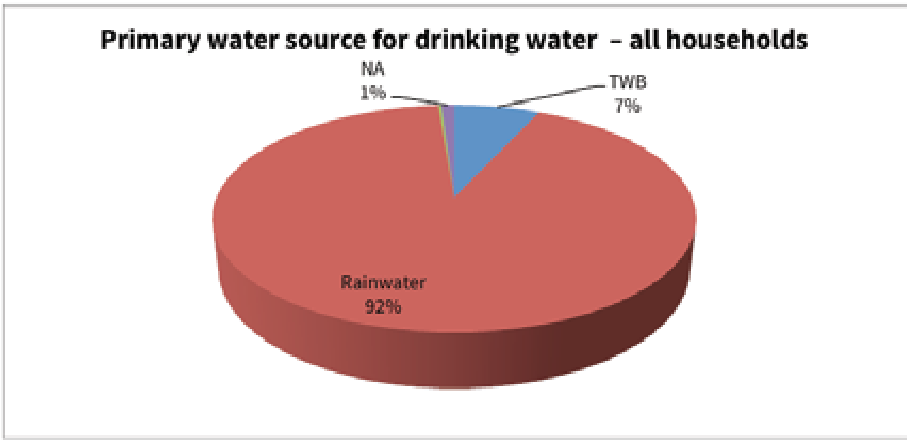


Figure 11. Primary potable water source for all households on Lifuka, Ha'apai, Tonga

Households were asked to identify where they would get drinking water if, for some reason, they were unable to use their usual primary source of drinking water (Figure 12). A total 17% of households indicated they would use TWB water (13%) and private wells (4%).

This leaves 83% that didn't respond, suggesting that they didn't have another source, or that any alternative source, such as private wells, would not be used. It's not clear why the majority of households didn't nominate an alternative drinking-water source. It's possible that they haven't been in a position where rainwater was not available, either due to household prioritisation and rationing of rainwater or because neighbours and/or family had rainwater they could use.

It is clear, however, that for drinking water needs, groundwater from either private wells or TWB pipes, even during times of rainwater shortage, was generally not relied upon as a secondary source of drinking water. Both water quality and community perception are probably determining factors.

However, groundwater still provided a significant portion of the total water used in households by volume, according to TWB usage figures from July 2011 to August 2012 (See Annex 5). However, TWB water was used for personal bathing and gardening as well as other tasks for which non-potable water was appropriate. The availability of TWB water is probably a source of reassurance during times of water shortage.

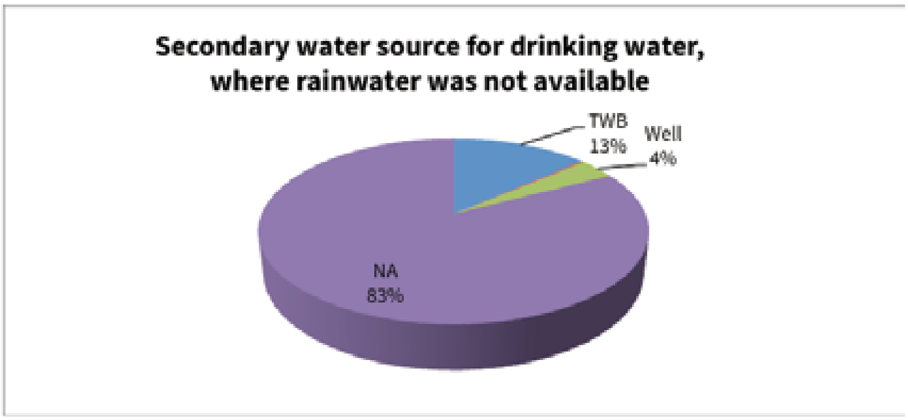


Figure 12. Secondary potable water source for all households on Lifuka, Ha'apai, Tonga

Households identified the type and frequency of treatment they employed to safeguard the quality of their drinking water. The majority of households (79%) said that they never or rarely treated their drinking water. Of those that did, most opted to boil water. However, treatment was fairly haphazard, with just 5% of households saying they always or mostly treated their drinking water (Figure 13).

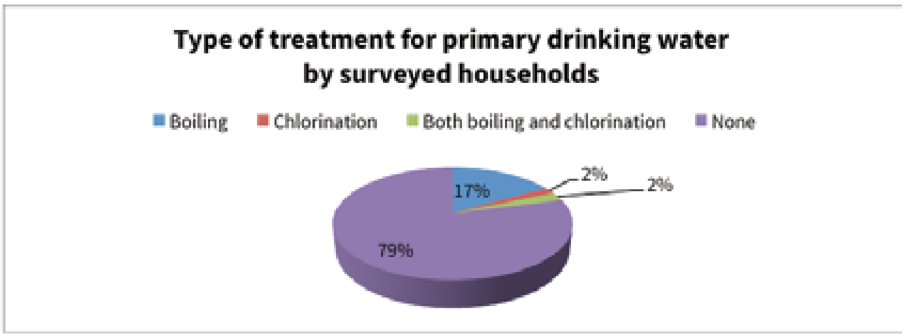


Figure 13. Type of treatment for primary drinking water by surveyed households on Lifuka, Ha'apai, Tonga

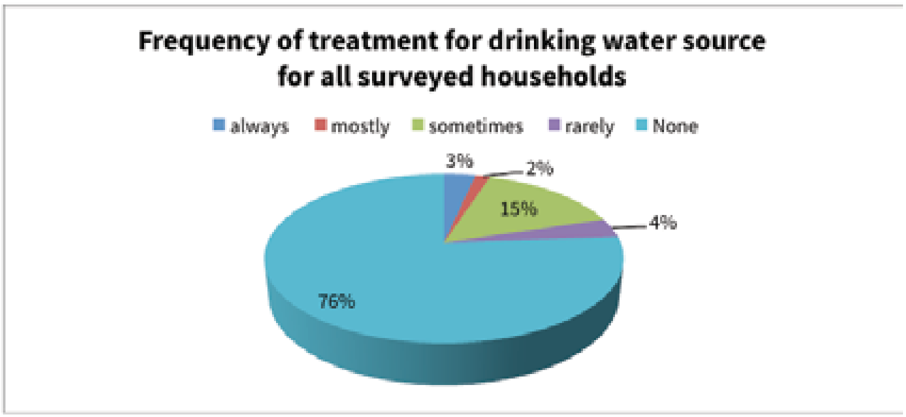


Figure 14. Frequency of treatment for drinking-water source for all surveyed households on Lifuka, Ha'apai, Tonga

In those households treating water, just over half (54%) said responsibility for the task fell on both men and women. A total of 34% of the households indicated that this task was undertaken only by women, and 12% of the households said the task was carried out only by men.

5.2 Frequency of water shortage for primary drinking-water sources

Generally, security of drinking-water supply from rain tanks was considered quite good: 60% of households said they rarely or never ran out of drinking water (Figure 15).

On average, some 32% of the population indicated that they faced water shortages regularly. This is interpreted to mean that water from the primary drinking-water supply (rainwater) was in short supply for 32% of the population approximately once every six months. Table 3 identifies the frequency of shortage as a percentage for each village. Whilst it was not clear how long these shortages lasted, it was assumed that outside of protracted dry conditions, the water shortages would persist until the next adequate rainfall (>20 mm), when tanks would start to fill. Possible explanations for shortages could include:

- limited collection from inadequate guttering;
- excessive use;
- inadequate storage for family size;
- leaking storage.

Table 3. Shortages in access to primary drinking-water supplies as a percentage for each village

Village	Monthly	3-monthly	6-monthly	Yearly	Rarely	Never
Hihifo	12%	8%	11%	10%	29%	30%
Holopeka	4%	16%	8%	4%	48%	20%
Koulo	16%	13%	13%	6%	19%	34%
Pangai	16%	5%	10%	8%	29%	32%

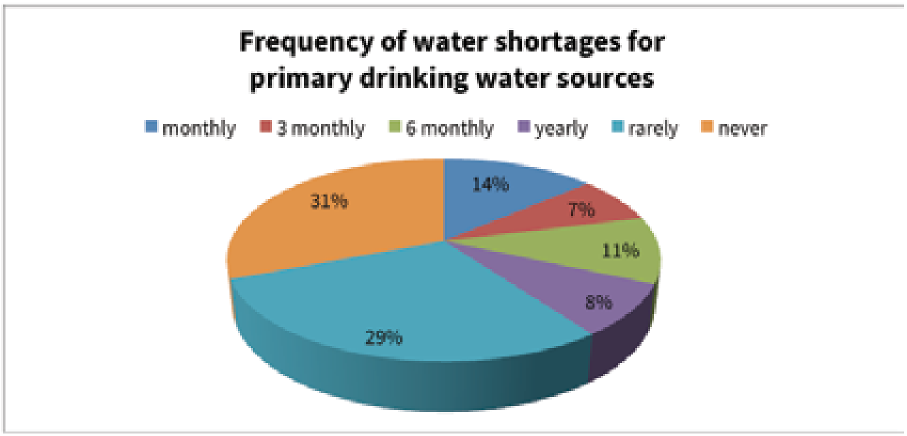
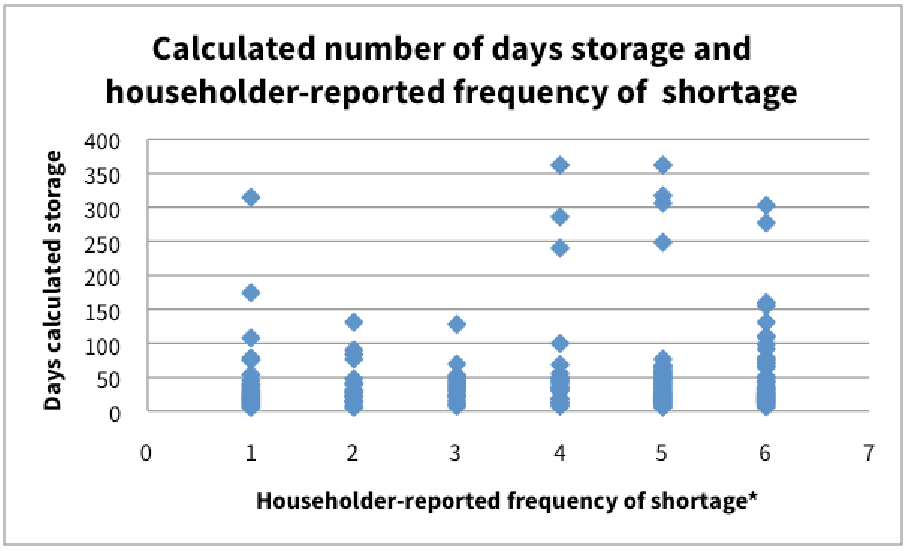


Figure 15. Frequency of water shortages for primary drinking-water sources.

An analysis was made of the number of respondents who reported primary drinking-water shortages against their calculated number of days of storage, based on tank size. The analysis revealed that no correlation could be determined between these two parameters, suggesting that tank size was not a dominant factor in respondents reporting an increased frequency of water shortages (Figure 16).



Householder-reported frequency of shortage*					
1	**2**	**3**	**4**	**5**	**6**
Monthly	**Once every 3 months**	**Once every 6 months**	**Once every year**	**Rarely**	**Never**

Figure 16. Calculated number of days of storage and householder-reported frequency of shortage

A total of 96% of all households took their drinking water from an external tap connected to a rainwater collection tank. Refer to Figure 17.

Figure 17. External tap on a plastic tank

Analysis shows men and women played an equal role in collecting primary drinking water for the household from the external tap. However, adults were more than twice as likely to collect household water as young people.

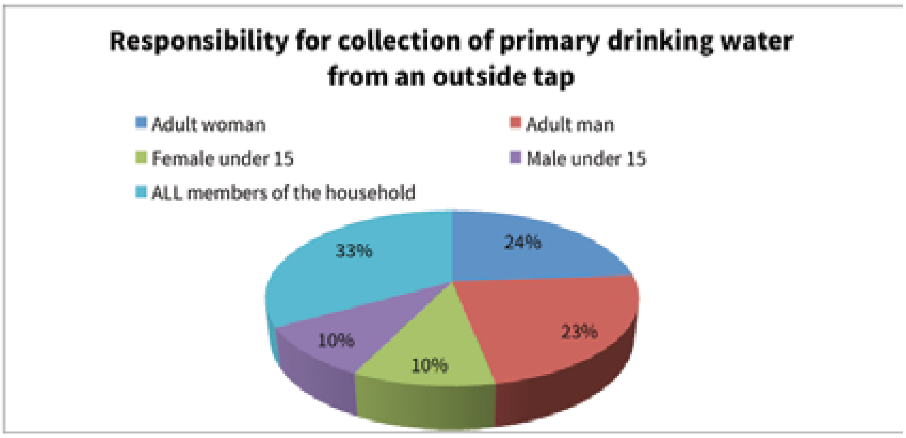


Figure 18. Responsibility for collection of primary drinking water from an outside tap

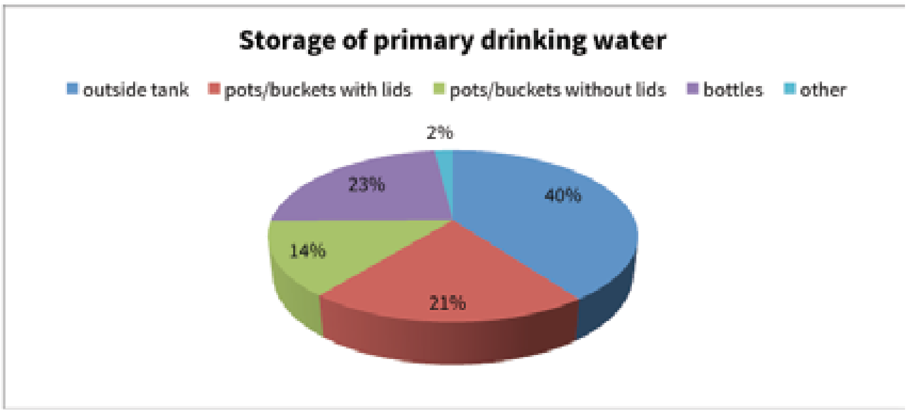


Figure 19. Storage of primary drinking water

The survey suggests (Figure 19) that 40% of people collected water directly from the external tap as required. People who stored water inside their dwellings were more likely to use bottles and buckets with lids. Reduced potential for contamination was expected where bottles and buckets with lids were used for storing water.

5.3 Water use

The household survey provides information on how households on Lifuka use water. It was possible for households to use more than one source for the same purpose. For example, one household might cook with both TWB water and rainwater.

The pie charts in Figures 21 and 22 indicate the source of water for different activities, including cooking, clothes-washing, personal bathing, and gardening/outdoor. As is to be expected, there was greater reliance on well water and rainwater where households did not have access to TWB water.

Table 5 illustrates the percentage of households with access to flush toilets, washing machines, showers, outside taps, and kitchen sinks, and what percentage of these appliances relied on particular water sources. Households with access to TWB water were more likely to own or have access to such appliances.

Where households had access to TWB water, 84% of them had access to a flush toilet. Where households didn't have access to TWB water, just 52% had access to a flush toilet.

Where households were connected to TWB water, 66% owned washing machines. Where households did not have access to TWB water, access to a washing machine was just 39%.

A total of 85% of households with access to TWB water had showering facilities, compared to 49% for households without TWB water.

In general, households with access to TWB water appeared statistically more likely to have access to water-using appliances such as flush toilets, washing machines, and showering facilities, compared to households without. This was likely to reflect a combination of the availability of access to a piped water supply and socio-economic factors.

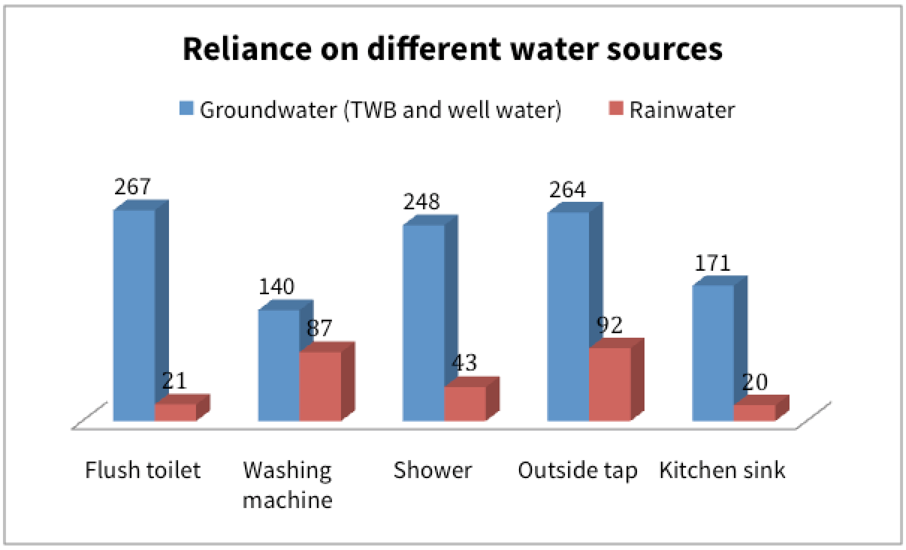


Figure 20. Reliance on different water sources

Figure 20 clearly shows the importance of groundwater.

Table 4. Water source reliance for all households, with and without access to TWB water

	Households without access to TWB water (122 total)				Households with access to TWB water (270 total)				All households (392 total)			
	Water source for cooking	Water source for washing clothes	Water source for personal bathing	Water source for garden and outdoor use	Water source for cooking	Water source for washing clothes	Water source for personal bathing	Water source for garden and outdoor use	Water source for cooking	Water source for washing clothes	Water source for personal bathing	Water source for garden and outdoor use
TWB	NA	NA	NA	NA	54%	51%	73%	82%	38%	35%	51%	54%
Rainwater	74%	76%	71%	58%	45%	48%	26%	17%	54%	57%	40%	31%
Well water	26%	24%	29%	43%	1%	1%	1%	2%	8%	8%	9%	15%

Table 5. Percentage of availability of water-using appliances to households and their reliance on a water source as a percentage

	Households without access to TWB water (122 total)					Households with access to TWB water (270 total)					All households (392 Total)				
	Flush toilet	Washing machine	Shower	Outside tap	Kitchen sink	Flush toilet	Washing machine	Shower	Outside tap	Kitchen sink	Flush toilet	Washing machine	Shower	Outside tap	Kitchen sink
TWB	NA	NA	NA	NA	NA	96%	67%	92%	76%	95%	84%	55%	77%	66%	80%
Rainwater	20%	59%	42%	33%	52%	4%	33%	8%	23%	4%	7%	39%	15%	25%	14%
Well water	80%	41%	58%	67%	48%	0%	1%	0%	0%	1%	9%	6%	9%	9%	6%
% of house-holds using identified appliances	52%	39%	49%	64%	26%	84%	66%	85%	100%	59%	73%	58%	74%	91%	49%

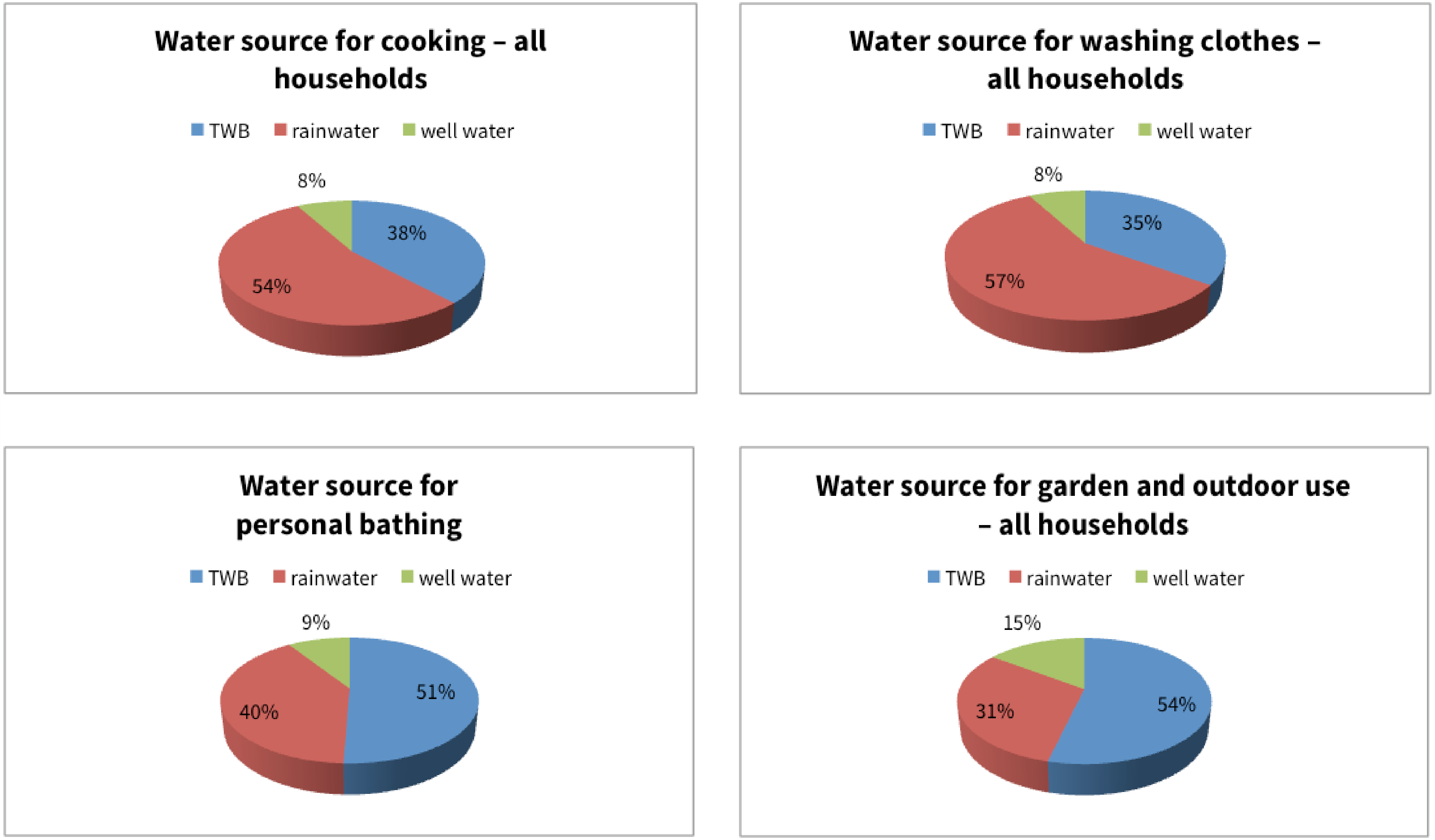


Figure 21. Charts showing percentage of usage from different water sources for specific household activities based on all surveyed households

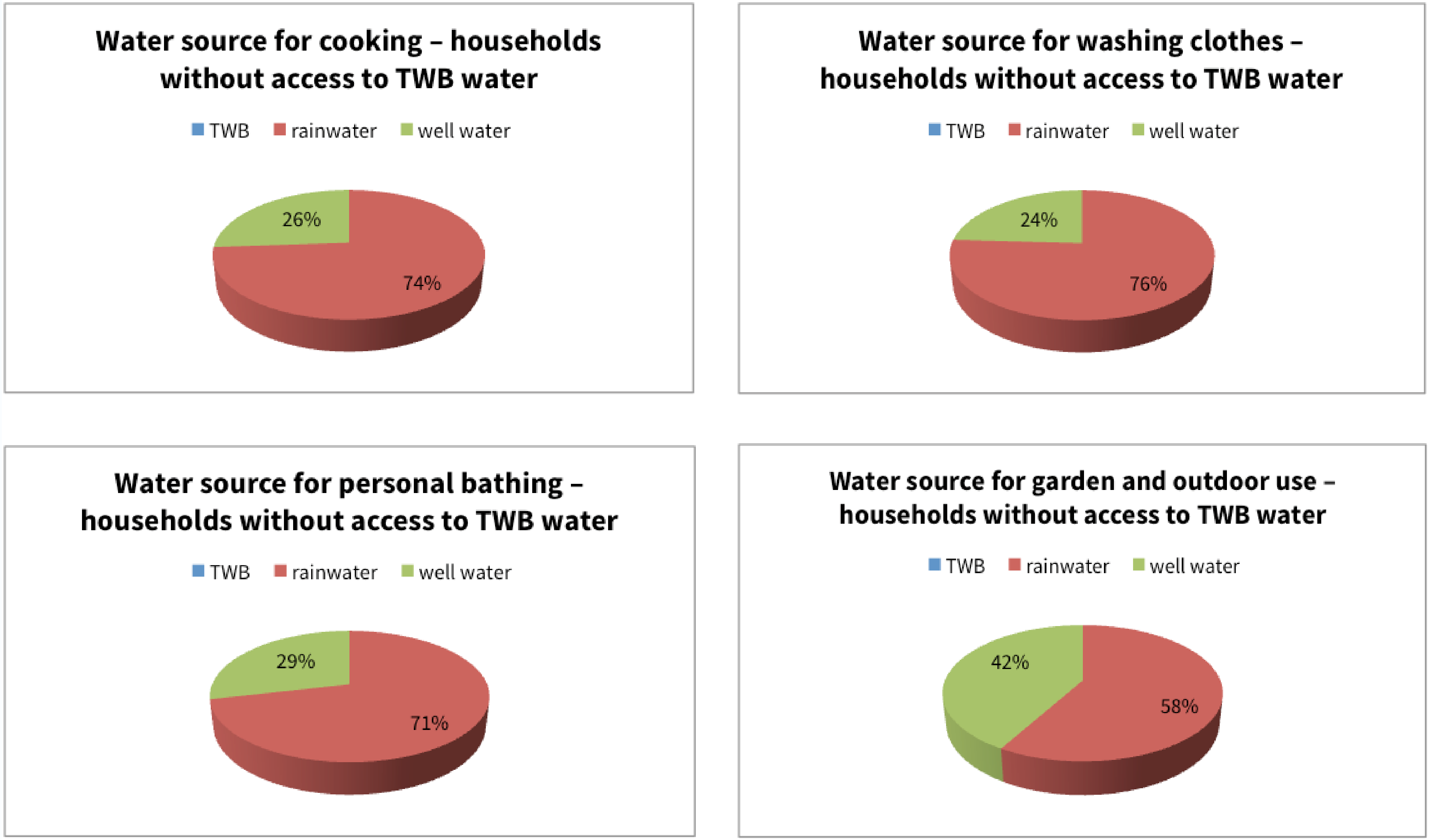


Figure 22. Charts showing percentage of usage from different water sources for specific household activities based on surveyed households that did not have access to or did not use TWB water

There was a strong preference for using rainwater for drinking, cooking and clothes-washing whether households had access to TWB water or not. There was some preference for TWB water or well water for personal bathing and garden/outdoor usage. These results will be useful in the development of water supplies on Lifuka.

TWB-connected households used, on average, 3.91 ML a month, or an estimated 78 L/p/day. With consideration to potable water needs (15 L/p/d), an estimated total water usage of 93 L/p/d was derived. Refer to Annex 5 for an overview of the TWB piped water supply.

Improvements in the assessment of usage and unaccounted-for water will be made where flow meters are placed on abstraction galleries and wells, and on the water leaving the treatment plant.

5.4 Water quality

Water quality is a significant factor in determining the suitability of a water source for a specific purpose. Brackish waters may not be suitable for drinking or irrigation, but may be suitable for flushing toilets. Similarly, bacteriological contamination can render water sources unfit for human consumption.

Salinity is measured in the field using electrical conductivity (EC) units of millisiemens per cm (mS/cm). In the Pacific, a threshold of 2.5 mS/cm is often used to distinguish between fresh water and saline water. This threshold limit for fresh water is often a function of acceptable taste rather than health implications, but is useful for identifying potential water supplies.

Escherichia coli or *E. coli* is an indicator organism for faecal contamination that is found in the gut of warm-blooded animals. Water contaminated by *E. coli* must be treated before it can be used for drinking.
Many chemical parameters can affect the suitability of a water source for a specific purpose. It is impractical and too expensive to test for all of these. Only where specific contaminants are likely or suspected should water testing be considered to determine the presence of the suspected contaminants and, where practical, the level of contamination.

A risk-based assessment approach such as water safety planning is promoted as the most efficient and practical approach to identify the level of risk. A water safety planning process considers risk based on likely hazards (septic tanks, chemicals, salinisation etc.), exposure (whether the water source is used for drinking or non-drinking use) and vulnerability (shallow water table, sandy soils, open or unprotected wells, over-abstraction of the water source). The process identifies the hazards and the areas of greatest risk, allowing appropriate action to be taken. Testing of specific parameters is normally used to identify baselines and to ensure that the risk-based water safety planning approach is effective.

Groundwater found within unconsolidated sediments associated with the western part of Lifuka is an important source of water for drinking and domestic needs, and supplies TWB, communal and domestic wells. The freshwater lens is thin, estimated to be no more than 5 m, below which there is a transition of brackish water to seawater. Unprotected wells with small parapets of 0.4 m and without concrete aprons are used to abstract the groundwater, using, in most cases buckets for abstraction. The TWB galleries and the communal wells are equipped with pumps, (yields from the TWB4 well are less than 0.5 L/s).

The soils overlying the freshwater lens are sandy in nature and offer very little barrier to contamination from surface activities through adsorption or increased infiltration time. Unsaturated soils have an average thickness of 2.6 m.

During the field survey, basic parameters of salinity, as well as presence and absence testing for *E. coli*, were undertaken to determine the extent of the freshwater lens and its potential bacteriological contamination.

In March 2012, domestic, communal, and TWB wells – some 42 wells in total – were sampled for salinity and *E. coli*. The measurements were taken from taps (11%), monitoring bores (12 %) and directly from wells (77%). Whilst the majority of wells were below the acceptable limit for salinity, nearly all samples tested positive for *E. coli*, indicating faecal contamination (Table 6). The sampling and analysis of *E. coli* was undertaken using the IDEXX methodology. The procedure followed is explained in Annex 4.

Table 6. Presence and absence test result

Well type	*E. coli*		Coliform
	Present	Absent	Present
Private well	30	2	32
TWB production well	5		5
Communal well	2		2

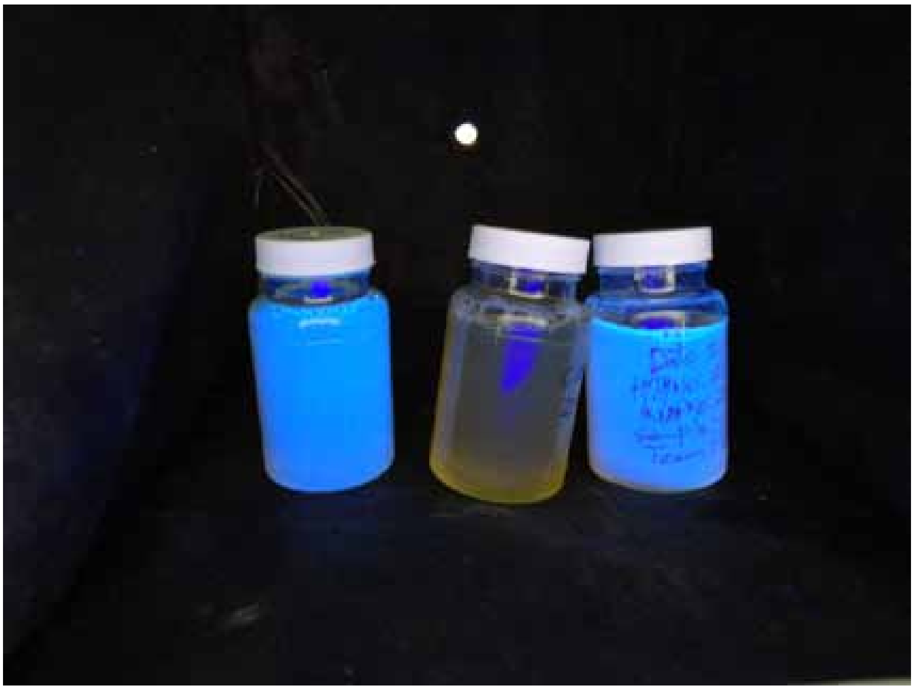


Figure 23. Water sample test results (fluorescence indicates the presence of E. coli)

The high number of positive samples for *E. coli* from wells across Lifuka is alarming. Samples returned from TWB production wells and galleries as well as samples along the TWB supply pipes also tested positive. The presence of *E. coli* is an indicator of faecal contamination in the water upon which the population relies for domestic purposes and some of its drinking water. People who ingest this water, untreated, are at higher risk of contracting a water-borne disease.

The results indicate that all groundwater on Lifuka should be considered contaminated by faecal matter. It is strongly advised that the people of Lifuka be made aware of this situation, and that adequate treatment of groundwater be undertaken at both the TWB treatment plant and at households prior to drinking. Treatment involving boiling or chlorination should be sufficient to reduce the risk to public health. Care should be taken not to ingest untreated water used for non-drinking purposes such as bathing.

The distribution of fresh groundwater and the *E. coli* results are identified in Figure 24.

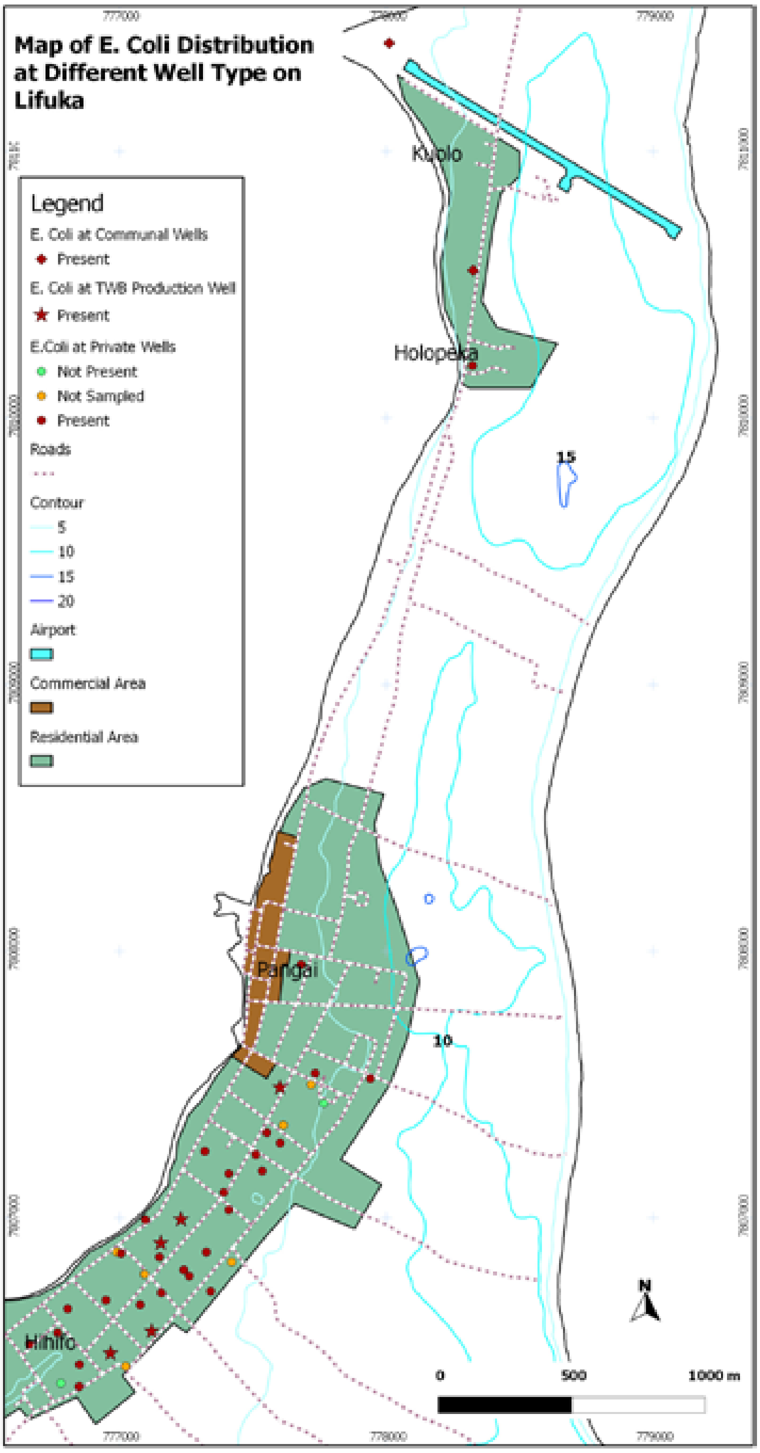


Figure 24. Map of sample points and E. coli *distribution*

(P – present; N – not present; NA – not available)

Faecal contamination is considered to have arisen for the following reasons:

- Poorly-constructed septic tanks and soakaway pits;
- The shallow and sandy nature of local soils, offering little protection;
- The density of housing and the increased number of on-site waste disposal facilities;
- The large number of roaming animals such as pigs and dogs that can access wells and areas with direct access to groundwater.

No sampling of rainwater from tanks was undertaken. Household water safety planning is the recommended approach for assessing the risk potential, and boiling of water is recommended where water is used for drinking.

The average salinity of the wells tested in March 2012 was 0.817 mS/cm, indicating that the water is relatively fresh (Table 7). Fieldwork investigations in September 2011 indicated higher salinity levels in groundwater monitoring bores due to reduced rainfall.

Table 7: Salinity of water (mS/cm) taken at the base of domestic wells - March 2012

Maximum	Average	Minimum	Median
2.6	0.817	0.288	0.704

Given the thin nature of the freshwater lens, the salinity of the water supplied by TWB as well as domestic and communal wells varies in response to rainfall. An extended period of low rainfall will have the effect of increasing the salinity, whilst increased rainfall will freshen the groundwater. Over-abstraction of the freshwater lens from over-pumping is a real threat in this type of hydrologic setting. However, observations to date do not suggest that salinisation of the lens from over-abstraction is occurring.

The salinity of groundwater in domestic wells could be improved by directing rain-tank overflow to wells. This would assist in freshening the groundwater in the immediate vicinity of the well.

5.5 Community views on improving water quality and quantity of supply

Householders had the opportunity to comment on issues or options that they felt would improve water quality and supply on Lifuka. Open-ended questions allowed interviewees to discuss their preferred options. In some cases, more than one issue or comment was identified by a householder, and these were then grouped into common themes. The following table identifies the common themes and the number of responses each theme received.

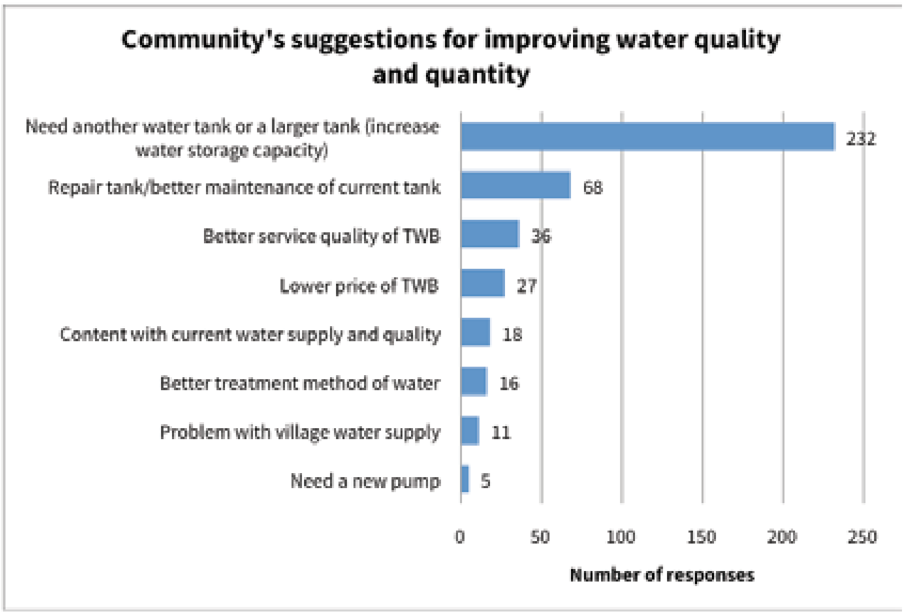


Figure 25. Community's responses to question on how to improve water supply

It is clear that the community wanted greater rainwater storage and improved rainwater collection.

It would appear that the community believed that installation and maintenance of rainwater harvesting equipment for households was the government's responsibility. We recommend that an awareness-raising programme that provides incentives to householders to maintain an efficient and safe rainwater harvesting system be considered. The programme, funded by the government or donors, could take a community-based approach to water safety planning, with the clear message that householders are responsible for maintaining an efficient and safe drinking-water supply. Financial and or social incentives developed by the community to support improvements in efficient rainwater harvesting systems should be considered. Such efforts would be more likely to be sustainable and have an overall impact on rainwater supply and quality. We recommend that this be considered as a topic for future discussion in community focus group meetings.

A total of 16% of all respondents believed that the piped water from TWB should be cheaper and the utility's service improved.

Given the importance of groundwater as a water source, it is important to ensure that the groundwater resource is able to provide sufficient supply of suitable quality water in the long term. Rainwater harvesting alone is unlikely to be able to meet demand. We recommend supporting the protection and future development of groundwater resources, as reliance on this resource is expected to increase during periods of low rainfall.

Lifuka has a conjunctive approach to water supply, where rainwater is used for drinking, cooking, and some washing needs, whilst groundwater is more likely to be used for personal bathing, gardening and outdoor needs. This conjunctive approach improves water security, as supply is obtained from more than one source. It is important that the community recognise its reliance on these sources and place sufficient value on them to ensure both protection and improvements to guarantee sufficient quality and quantity in the future.

It is interesting to note that just 4% of responses identified a need for improved water quality, suggesting that water quantity is considered to be more important than water quality. This may also reflect a general lack of awareness about the risks of poorly maintained and stored rainwater and the extent of groundwater contamination. Activities to increase householder awareness of the risks to the water sources and measures that can be taken to make improvements should be considered.

6. HOUSEHOLD QUESTIONNAIRE – COASTAL INUNDATION AND EROSION

6.1 Purpose

The purpose of the coastal inundation and erosion component of the survey was to gather information on the community's perception of coastal erosion, determine the exposure of the community to the impacts of coastal inundation, and estimate the extent of damage from past inundation. This information is used by the coastal modelling team to track the start of the coastal changes, estimate the rate of erosion and predict future changes to identify areas and infrastructure most under threat. The community's views on different ways to mitigate and adapt to coastal erosion were also sought.

Results will be used to fill the gaps in the data needed to undertake the impact assessment on Lifuka Island. The results will contribute to the two guiding principles of the overall project, which call for the strategy for adapting to sea-level rise on Lifuka to be (i) informed by robust evidence about coastal and related environmental processes, and social needs and values; and (ii) selected in association with the people of Lifuka. The data collected within this section, combined with outputs of other activities, will be useful in guiding both the coastal process analysis and community alike in understanding and development of mitigation options.

6.2 Methods

Questions on coastal erosion and inundation were asked as part of the household survey questionnaire. The questions were separated into four sections. The first section asked about community perceptions of coastal erosion. The second section referred to past events of inundation in general. The third and fourth sections concentrated on damage and losses specific to TC Rene (2010).

Regarding coastal erosion, households were asked whether they thought the beach closest to their house was increasing in area, decreasing or not changing. They were also asked when they think the change started, if applicable, and by how many metres it had changed. This information was collected to get an understanding of community's perceptions on coastal erosion, and to help the modelling of coastal changes. Respondents were also asked how they thought coastal protection should be enhanced. Answers were noted by the enumerators and were later processed and grouped by their similarities so as to facilitate analysis.

For the coastal inundation component, the main aim was to discover the severity and frequency of inundation in coastal zones. This information was used to identify current impacts and potential impacts under future inundation event scenarios, and to estimate exposure to damage due to storm surges and tsunamis. Five major events were identified by the questionnaire design team, in consultation with Government of Tonga, to have taken place on Lifuka in recent years. These were the tsunamis of 2006 and 2009 and cyclones Rene (2010), Wilma (2011), and Cyril (2012).

The earliest event included in the questionnaire, the 2006 tsunami, was reportedly caused by a magnitude-8.0 earthquake that occurred 160 km northeast of Nuku'alofa, Tonga, on 3 May 2006. The wave is thought to have reached 30 cm in height when it hit the shores of Tonga (Pacific Disaster Net, PDN, n.d.). Though data on the impacts of this tsunami on Tonga are limited, it was decided to include this event in the questionnaire.

Likewise, the tsunami of 2009 was created by a magnitude-8.0 earthquake that struck 196 km south of Apia, the Samoan capital, on the morning of 29 September 2009. The resulting wave is reported to have measured 50 cm upon reaching the shoreline of Tongan islands (Fisher 2009). Six people are reported to have died and six remain missing in Tonga following the 2009 tsunami (PDN, n.d.).

In 2010, TC Rene caused extensive damage throughout Tonga. The cyclone, which reached Category 4 at its peak, passed through the Ha'apai group on Monday, 14 February 2010, accompanied by heavy rain, strong winds and storm surges. The cyclone badly damaged roads in Ha'apai, damaged several residential houses, and had a major impact on the agriculture and tourism sectors (NEOC, 2010).

Cyclone Wilma passed through the Ha'apai group on 24 and 25 January 2011. At its peak, the cyclone reached Category 3. Reports by the National Emergency Operations Committee (NEOC) stated that 30% of roads on Lifuka became unusable following the heavy rains, and that more than 70% of root crops in Ha'apai were damaged, raising concerns about possible food shortages (Ministry of Works 2011).

The most recent major event included in the questionnaire was Cyclone Cyril, which reached the Ha'apai group on Tuesday, 7 February 2012. Though a Category 1 cyclone, it produced winds strong enough to cause structural damage (OCHA 2012).

To assess which areas on Lifuka are most at risk from coastal inundation in future storm surges, each household was asked whether their land and/or house had been inundated by seawater or hit by waves before. Possible answers were:

1) Yes, just once;
2) Yes, 2–3 times;
3) Yes, happens every year; and
4) No, my land has never been inundated before.

Where positive answers were given, the respondent was asked to specify during which of the tsunami or cyclone events the inundation occurred, and, where applicable, to rank the events in order of the height that the water reached. For the worst cyclone listed, respondents also indicated whether the maximum water level was below or above the living room floor. For the same cyclone, they also listed any damage that occurred, including damage to roads, houses, furniture and plants.

Figure 26. Example of the debris line resulting from coastal inundation in the aftermath of tropical cyclone Cyril (February 2012)

The survey concentrated only on TC Rene (2010). Just one event was chosen to ensure consistency and comparability between households, and Cyclone Rene was selected after consultations with locals revealed that Rene was far more damaging for Lifuka than other recent events (Fuka Kitekei'aho [National Project Coordinator, MECC, Tonga], personal communication, 19 March 2012).

Respondents were asked if their houses were inundated during Cyclone Rene, and, if so, the extent of the damage to house foundations and what appliances were lost. These data were later used to estimate the total damage caused by the cyclone. Households were also asked if they paid for repairs or replacement items, and if so, what funds they used, such as savings, charity, remittances, or insurance.

Information on non-material damage from TC Rene was also gathered, to put a figure on the total impacts of the event. Questions regarding the cyclone's effect on water supply, health and paid employment were asked regardless of whether householders reported inundation or not. The respondents were also asked the reasons for any effects on the water supply, and how long the effect lasted. Information was also collected on any illness in the household following the cyclone, and what type of health service, if any, was used to seek treatment. This information was later used to estimate the total cost of TC Rene on the community of Lifuka. Similarly, information was collected on whether any of the households lost paid days of work in the aftermath of the cyclone, and why.

6.3 Results

6.3.1 Coastal erosion

Results of the household survey questionnaire suggest that the community of Lifuka strongly believed that the coastline is eroding. In total, 98% said the width of the beach was decreasing. This showed a strong consensus within the population that coastal erosion was a serious concern. Only 1% of respondents said the width of the beach was either increasing or not changing (Figure 27). Another 1% of households did not want to respond as they were recent arrivals to Lifuka.

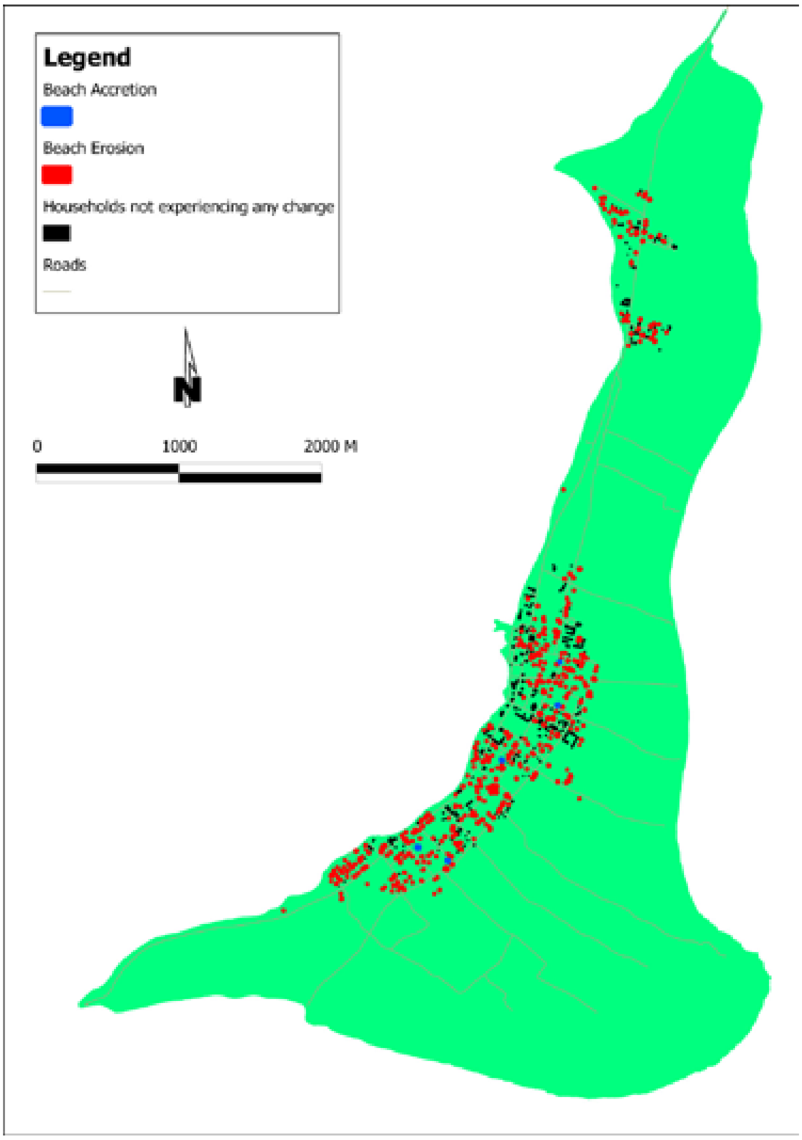


Figure 27. Location of households reporting accretion, erosion, or no change of beach width

Although the main purpose behind this question was to understand the community's opinions on coastal changes on Lifuka, the almost uniform answer that the width of the beach had decreased gave solid support to calls that coastal erosion was a grave concern.

It was also interesting to compare these community views with a preliminary analysis of satellite imagery by the SOPAC/SPC Oceanography team, which suggested that the beach in Pangai had receded up to 40 m over the last 44 years (Jens Kruger, Team Leader, Oceanography team, SOPAC/SPC, personal communication, 5 June 2012).

Responses to the household questionnaire suggested that the majority of people on Lifuka believed coastal erosion was a recent phenomenon, and that they often associated this with the 2006 earthquake. Of respondents who said the beach was smaller than before, 52.0% answered that changes had started in the last five years (since 2006). A total of 39.6% said changes had started before 2006 (Figure 28).

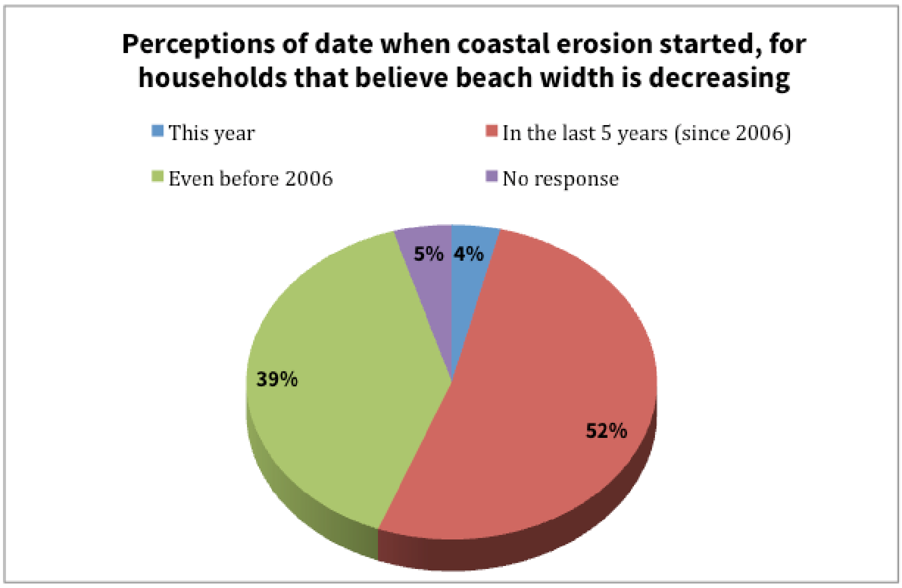


Figure 28. Perceptions of date when coastal erosion started for households that believe beach width is decreasing

While the community's perception that coastal erosion was due to the 2006 earthquake, preliminary analysis of satellite imagery and historic aerial photos suggests changes in shoreline date back to 1968, if not before (earlier imagery is unavailable). The perception could be biased by the ages of the respondents, with younger people not able to remembering pre-2006 changes. However, this was very unlikely as the majority of the respondents were not that young; their average age was 48.

Many of those who responded that erosion was a pre-2006 phenomenon said that while erosion had been happening for a long time, it had been drastically accelerated since the 2006 earthquake. This would have to be confirmed by analysis of satellite imagery, but is consistent with the general views of the community, and could explain why most of the population believed the earthquake caused coastal erosion.

Half of the Lifuka community (51%) said that the beach had receded by 1 m to 10 m since the start of coastal erosion. Another 28% stated that beach had receded by 10 m to 20 m. Figure 29 shows the distribution of responses to the question asking how much the beach has changed since the process of coastal erosion started, for those households that believed the width beach was decreasing.

Again, much of the Lifuka population seemed to underestimate how far coastal erosion had progressed. While the satellite imagery analysis suggests the beach has eroded up to 40 m since the first available aerial photo (1968), most of the answers in the household questionnaire placed the decrease in the range of 1 m to 20 m. This was most probably connected to the previous discussion, where the community predominantly expressed the belief that erosion started only after the 2006 earthquake.

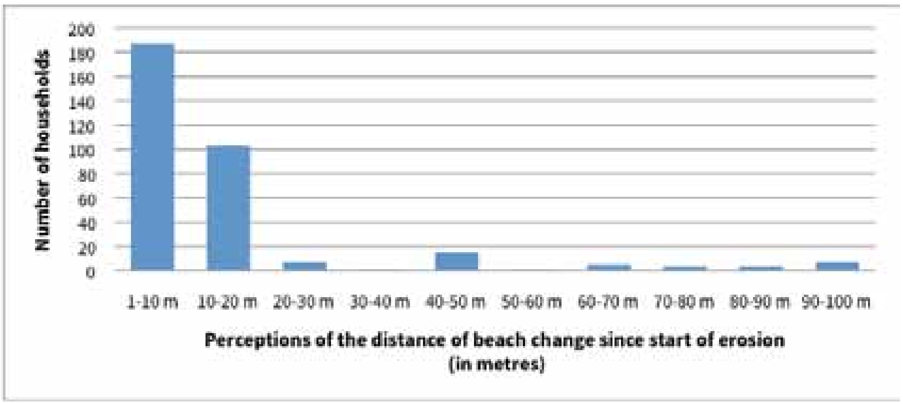


Figure 29. Perceptions of beach size change (for those households that believe the width of the beach is decreasing) since the start of coastal erosion

Answers regarding change in beach size varied between different villages, but not drastically. As expected, respondents in the villages of Pangai and Hihifo, where coastal erosion had been most noticeable, responded with higher average rates of beach change than those in the other two villages. In both Pangai and Hihifo, the perceived average change in beach size was 18 m. In Holopeka and Kuolo the perceived changes were 10 m and 17 m respectively (Table 8).

Table 8. Averages of all responses by village regarding community perceptions of the change in beach size, since erosion started, in metres

Village	Average perception of beach-size change (metres)
Pangai	18.0
Hihifo	18.3
Holopeka	10.1
Koulo	16.6

Answers to the above questions were reflections of community members' personal views and should not be taken as indicators of the actual extent of coastal erosion. The coastal modelling to be undertaken will provide scientific analysis and quantify the coastal erosion process. However, community perceptions of coastal erosion will be important in designing adaptation strategies for Lifuka.

In the final part of the coastal erosion component of the household questionnaire, households were asked to express their views on how coastal protection should be improved on Lifuka. The answers to an open-ended question were recorded by enumerators and later grouped by theme into eight different categories. Figure 30 displays the main options mentioned, and the number of households that mentioned each option. Note that the total number does not add up to the total number of households interviewed (392) as certain households expressed their support for more than one initiative.

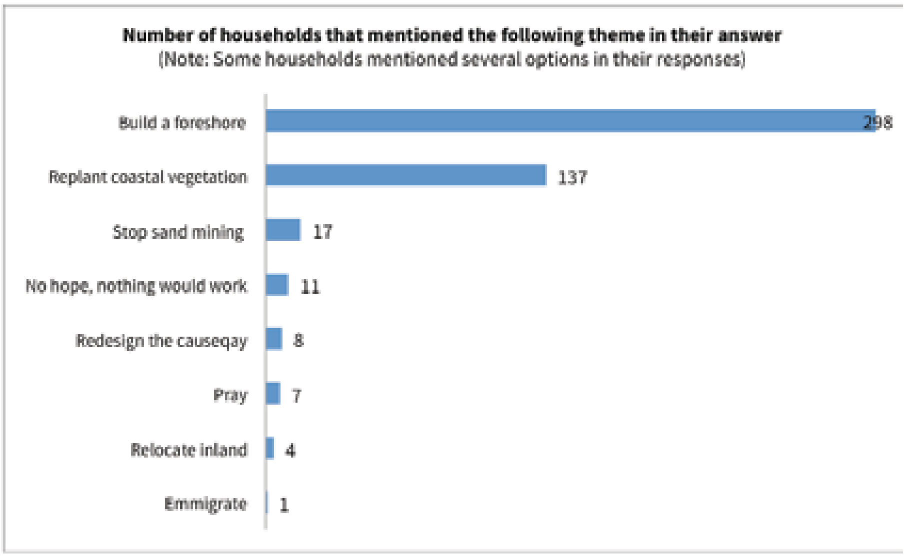


Figure 30. Views of the Lifuka community on options for coastal protection

Building a foreshore – that is, a sea wall – appeared to be the most popular option, and was mentioned by 298 households (76% of the respondents). However, many raised concerns over the quality of any foreshore that might be built. In general, the community believed that a foreshore in critical areas would be a solution to the erosion problem, but they were also aware that this would require ongoing investment in maintenance.

Replanting of coastal vegetation also appeared to be favourably received, with 137 households (35%) supporting this idea. Most of these households believed replanting of coastal vegetation could be a long-term, effective, natural solution to halting coastal erosion. Nevertheless, some stressed the importance of choosing the right types of trees and shrubs, as they said that many past planting attempts had failed because some types of trees planted lacked resistance to high water salinity.

The majority of households did not link coastal erosion with human activities on the island. Though roughly half of Lifuka's households reported mining aggregates from the beach (see section 7 on aggregate mining), just 17 households (4%) believed that stopping sand mining would halt coastal erosion. Similarly, only a small percentage of respondents believed the causeway connecting Lifuka and Foa to be responsible for coastal erosion, with only eight households (2%) suggesting it should be redesigned to prevent sand sedimentation on the Lifuka shoreline.

Figure 31. Photo of the causeway connecting Lifuka and Foa

Some interviewees had a fatalistic attitude to coastal erosion, with 11 households (3%) feeling that there was nothing that could, or should, be done to protect the shoreline, and that this natural process should be left to proceed. Another seven households (2%) believed that the phenomenon was God's will and that only prayer would help.

Relocating inland appeared to be an unpopular suggestion, with just four households (1%) suggesting this as a solution. This finding was especially relevant when considering set-back zones as a way of addressing coastal erosion. However, the lack of recognition of this option did not necessarily mean that the community was against relocating inland or introducing set-back zones. It is likely this option was rarely mentioned due to the cost of relocating public and individual infrastructure away from the coastline.

While a sea wall might seem to be a cheap short-term option, many people did not account for the long-term ongoing costs of maintaining the sea wall. Although a large one-off investment such as relocation inland might not initially seem to be a viable option, in the long run such a move could prove less costly. Additionally, it is possible that respondents felt that the construction of a sea-wall might be supported by public funding, whereas the cost of relocating homes could be considered an individual responsibility and was therefore a less appealing option.

6.3.2 Overview of coastal inundation on Lifuka

The process of coastal erosion has resulted in much of the infrastructure on the Lifuka shoreline becoming more exposed to inundation from ocean waves, tsunamis, or storm surges during cyclones. While it is important to understand the nature and frequency of these inundation events, the analysis of coastal inundation also indicates what infrastructure on Lifuka is most at risk from coastal erosion.

Coastal inundation appeared to affect a very small percentage of people in the Lifuka community. Of the 392 households interviewed, 92% (362 households) claimed that their land had never been inundated by ocean water. As the following discussion will show, inundation affected just a small percentage of households (8%) as most of the households (private infrastructure) are located further inland (Figure 32). Figure 33 shows the distribution of responses regarding how many times the land belonging to interviewed households has been inundated by ocean water or hit by waves.

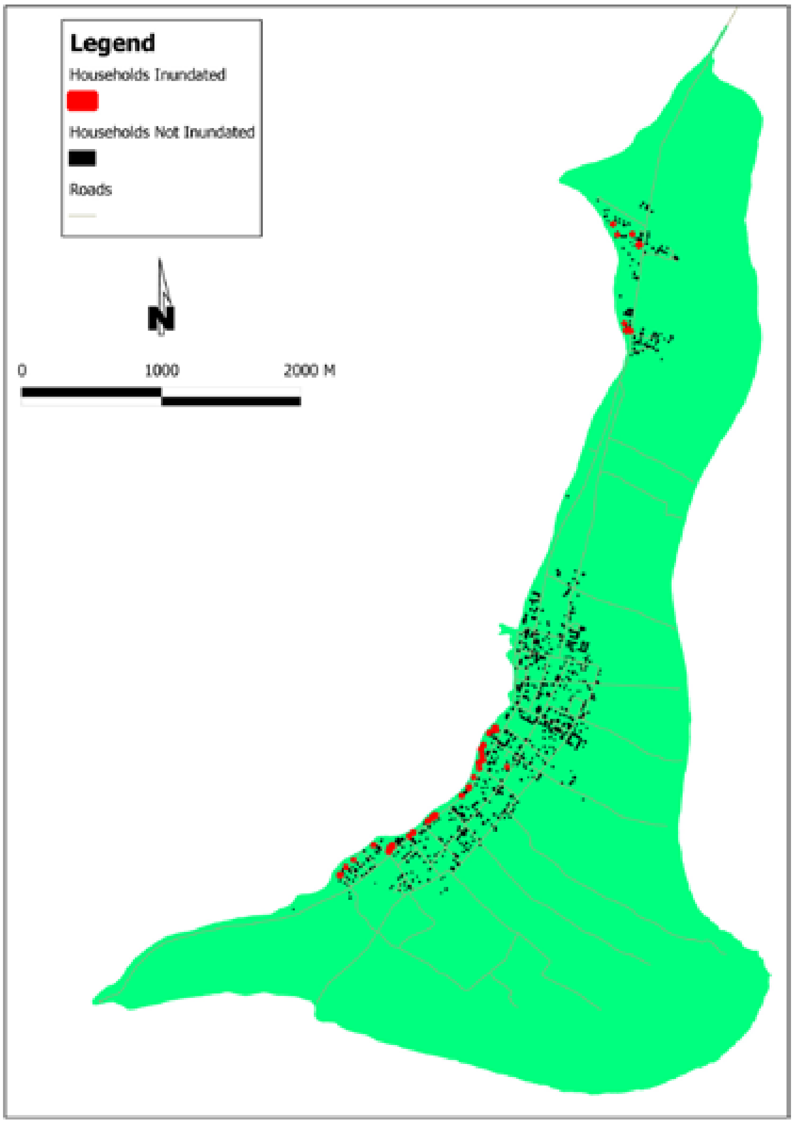


Figure 32. Location of households reporting inundation either due to tropical cyclone waves or tsunami

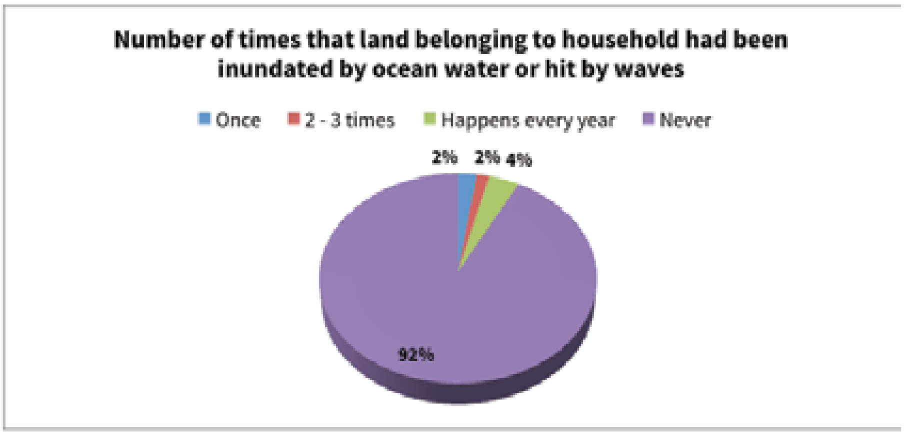


Figure 33. Frequency of land inundation

A total of 8% (30 households) reported that their land had been inundated, with 2% (9 households) saying it had happened only once in the past. Another 2% (6 households) claimed it had happened two to three times in the past, while around 4% (15 households) experienced inundation by ocean water or waves every year.

While inundation rates for the whole of Lifuka were low, since most residences are inland, flooding was a recurrent problem for the households close to the coastline.

We analysed the inundation rate for the infrastructure near the coastline, taking into account only households situated within 120 m of the shoreline – a preliminary coastal zone that is likely to be impacted by coastal erosion in the next 100 years (Jens Kruger, Team Leader, Oceanography team, SOPAC/SPC, personal communication, 5 June 2012). The results showed that some 29% of those coastal households have had their land inundated at least once in the past (Table 9).

Table 9. Percentage of households within 120 m of coastline on land that has experienced inundation

Village	% inundated at least once	% inundated every year
Pangai	39%	30%
Hihifo	25%	10%
Holopeka	29%	0%
Koulo	20%	10%
Total	**29%**	**14%**

Pangai appeared to be the most at risk, with a significant 39% of coastal households reporting inundation in the past. In Hihifo, Holopeka and Koulo, rates lay in the 20% to 30% range. Surprisingly, 30% of coastal households in Pangai had their land inundated every year, which was a noticeably higher percentage than in other villages (0% to 10%).

Figure 34 provides a map of Pangai showing which households reported inundation in the past. Houses coloured in red on the map reported having their land inundated every year. Those in orange reported that their land had been inundated two or three times, while those households in yellow reported that inundation had occurred just once. Households in white said their land had never been inundated. For the uncoloured houses, data are not available.

Figure 34. Map of Pangai with households that reported land inundation by ocean water marked

As can be seen from the map in Figure 34, the infrastructure alongside Pangai's coast is under great risk from coastal inundation and erosion. Though the map shows the frequency of inundation of private households, infrastructure is also under threat. Amongst the households in Pangai reporting that their land had been inundated, 29% said that the water level had risen higher than the living room floor on at least one occasion.

Figure 35 contains the corresponding map of Hihifo. As can be seen from the colours, coastal inundation was not as frequent as in Pangai. Most of the households here reported having had their land inundated two or three times in the past, but indicated that this was not an annual event. The hospital, one of the major pieces of infrastructure at risk, recently had a foreshore constructed to prevent coastal erosion. Nevertheless, hospital staff said that the land surrounding the hospital had been hit by waves several times, although the building itself has never been inundated.

Figure 35. Map of Hihifo with households that reported inundation by ocean water marked

Koulo and Holopeka appeared to be least affected by coastal erosion and inundation, as can be seen from Figure 36. A total of 17 households reported that their land had been inundated, although most households said that this had occurred just once in the past. Some of the households further inland indicated that their land had been inundated, and it was assumed that the land under that household's ownership stretched closer to the coast. Further north in the area around the airport, inundation seemed to be more frequent, with households reporting recurrent inundation of their land.

Figure 36. Map of Koulo and Holopeka with households that reported land inundated by ocean water marked

Those households that had suffered inundation were also asked which of several major events since 2006 had affected them. Households were asked to list which of the five mentioned events (tsunamis of 2006 and 2009, and cyclones Wilma, Rene and Cyril) resulted in the inundation of their land or house. Figure 37 shows the total number of households that observed inundation of their land. It appeared that inundation arising from TC Rene (2010) was the furthest-reaching, which supported the community's contention that it was the most destructive cyclone in recent years (Fuka Kitekei'aho, National Project Coordinator, MECC, Tonga, personal communication, 19 March 2012).

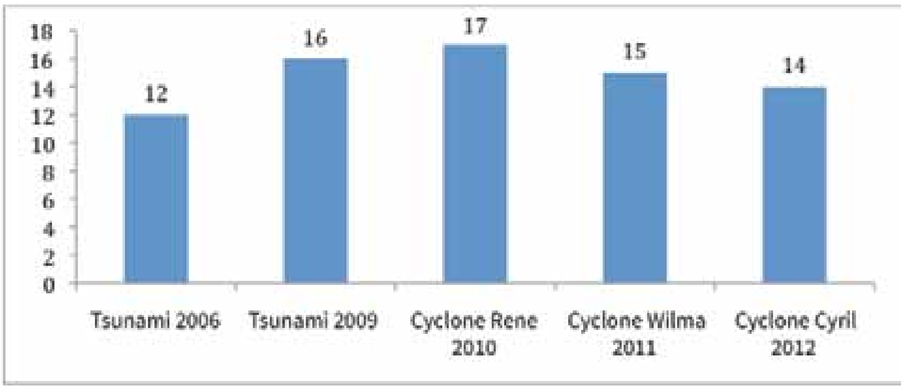


Figure 37. Number of households that experienced land inundation during each event

The 2009 tsunami also affected a considerable number of households. Many of the respondents living close to the coast recounted that they were not aware of the tsunami coming and were unprepared, which resulted in much damage to their gardens and items in houses.

Households commonly reported that the road near their house was covered in debris, or the plants on their property died from salt burn. Much less common were reports of damaged furniture or damage to house infrastructure. Figure 38 shows the distribution of the most commonly cited types of damage due to cyclones.

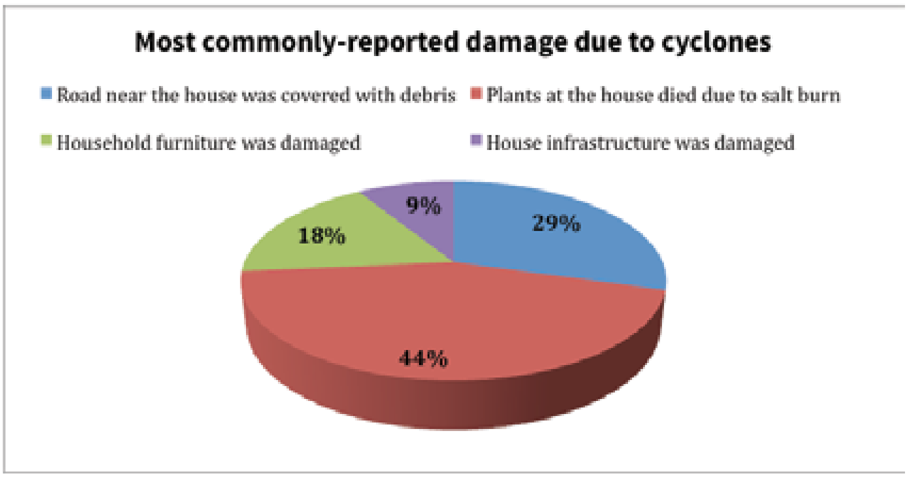


Figure 38. Distribution of answers regarding what type of damage the household experienced during what respondents perceived was the worst cyclone of the three

6.3.3 Material damages due to TC Rene (2010)

To obtain more detailed data on cyclone damage, households were asked to report only on the damage caused by Cyclone Rene (2010). TC Rene was chosen after consultations with the community suggested that it was the most devastating cyclone of the last two years. As it was relatively recent, it was thought that households would have a reasonable recall of its impact.

Of the 392 households interviewed, 11 (3%) reported that their house had been inundated as a result of TC Rene (Table 10). For this part of the questionnaire, we concentrated only on those households. Most of the inundated households were situated in Hihifo (seven houses), while the other four houses were in Pangai. The seven houses that were inundated in Hihifo represented 4.8% of all households interviewed in this village, giving Hihifo the highest (albeit still modest) inundation rate in Lifuka. Pangai village, on the other hand, had an inundation rate of 2.1%, while in other villages none of the houses recorded inundation.

Table 10. Number and percentage of households inundated during TC Rene (2010) per village

	Number of households inundated	Percentage of households inundated out of all households interviewed in village
		n=392
Hihifo	7	4.79%
Holopeka	-	-
Koulo	-	-
Pangai	4	2.11%

For those households that indicated inundation by TC Rene, six indicated that there was no observed physical damage to the foundation of their house. Five households recalled minor damage – a foundation that needed repairs but was still useable. None of the households reported major damage, which would have meant a foundation that had been extremely damaged and made unusable (Figure 39).

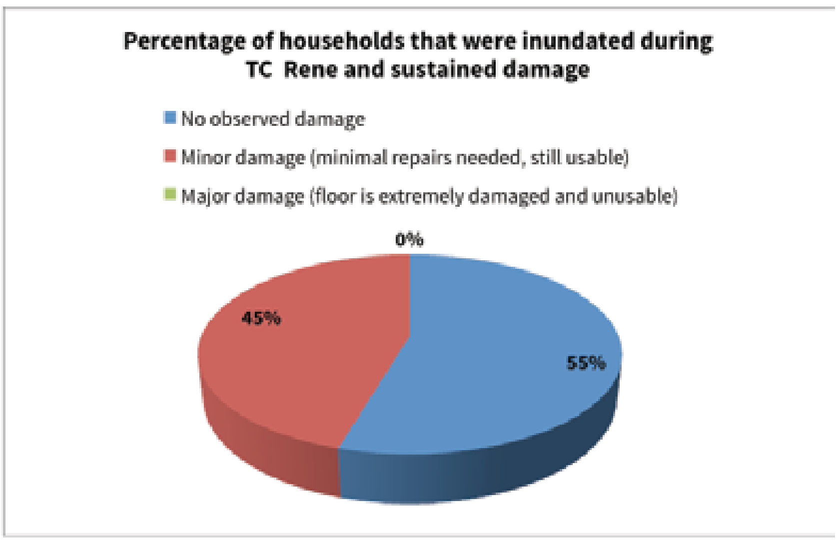


Figure 39. Damage to house foundations due to TC Rene, for households that reported inundation

As a result of inundation from TC Rene, several households reported losing various assets (Table 11).

Table 11. Household appliances/items reported to have been lost due to TC Rene

Household appliances lost due to TC Rene	Number of households	Percentage of sample
		n=12
Refrigerator	3	25%
Washing machine	2	17%
Floor coverings	4	33%
Beds or mattress, chairs, tables, or wardrobes	3	25%
Vehicles	0	0%
Other	0	0%

Just five households reported that they had repaired the damage to their houses or replaced lost items. Two houses used private savings to do so. One household relied on charity. One other household received aid from the government, and one household was compensated by insurance, which the interviewee explained was linked to the Free Wesleyan Church. Three households reported that they had not repaired damage or replaced their lost items.

6.3.4 Effects of TC Rene on water supply

Water supply can often be affected in the aftermath of cyclones. Most often, this is due to wind damage to roofs, guttering and tanks, or to power cuts that prevent water being pumped to households. A damaged water supply can increase the spread of water-borne diseases.

In the aftermath of TC Rene, 31% of households in Lifuka reported that their water supply had been affected. For those 122 households, the main causes were rainwater tank or roof damage (35%), a lack of power or fuel to pump water (26%) and concern over water quality (17%) (Figure 40). Many households reporting concerns over water quality stated that the water tasted salty for several days after the cyclone as strong winds blew ocean mist into the rainwater tanks.

During this period, the majority of the households in the community continued using rainwater (see Figure 41 for alternative sources of water used in aftermath of TC Rene). Just 12% of affected households switched to using purchased[1] or stored water,[2] suggesting that issues of water security during these events should be considered in disaster planning. The purchase of water supplies also imposes an increased cost on these households.

1 Purchased water refers to bottled water. Boxed water is not available for purchase on Lifuka.

2 Prior to a cyclone, households prepare by storing water in buckets and baths.

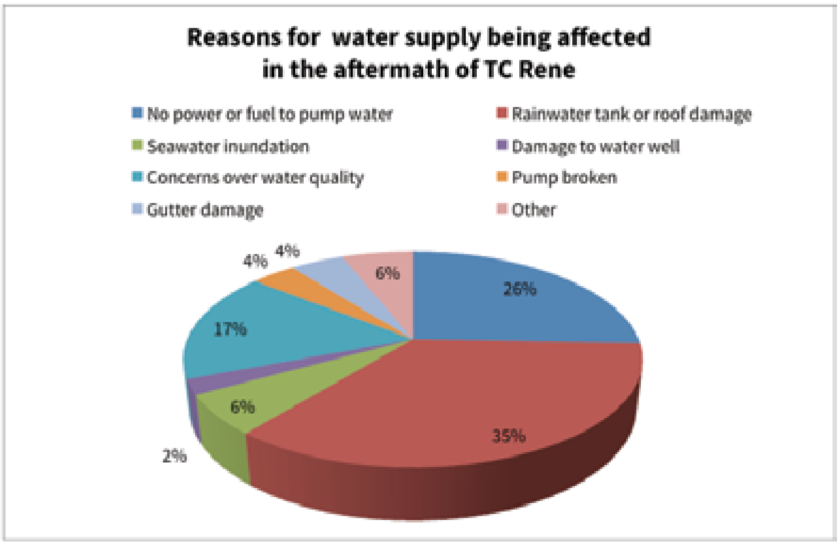


Figure 40. Reasons for water supply becoming affected in the aftermath of TC Rene

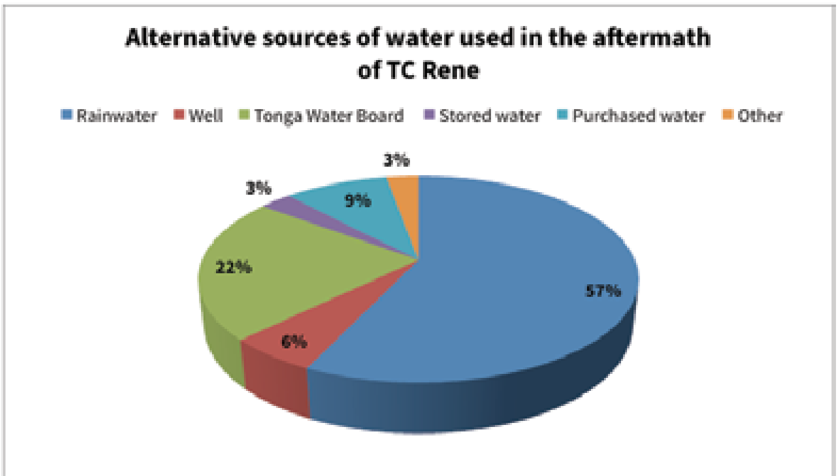


Figure 41. Alternative sources of water used in the aftermath of TC Rene

6.3.5 Health impacts and lost days of work due to TC Rene

In the aftermath of TC Rene, seven households (1.9%) reported having at least one person affected by a cyclone-related sickness. In total, two respiratory infections and six cases of high fever were reported. All but one respondent reported that medical care was sought at the Lifuka public hospital.

Nine households (2.3%) also reported losing paid days of work following TC Rene, with the most commonly cited reasons being the need to clean up and undertake repairs or take care of a family member. Of these, most of the households lost one to three days of paid work, although one household reported losing a whole month. The total number of lost days for the interviewed households was 41.

6.3.6 Community perspectives on sea-level rise

During the household survey, the Lifuka community was invited to comment on sea-level rise. All 366 households expressed concern about sea-level rise (Figure 42). However, just half offered additional information. This indicates that whilst many respondents were aware of sea-level rise, there was no clear or strong consensus as to what action was best.

A total of 75 respondents (20.5%) considered that sea-level rise was a serious threat to their livelihoods and would cause further damage to the coastline. Many of these households feared that Lifuka would one day be submerged.

Asked how sea-level rise could best be addressed, the most frequently cited solution (mentioned by 18%, or 32 households) was relocation locally or internationally. Respondents often quoted Australia and New Zealand as potential host countries, and suggested that the government should facilitate relocation.

This presented an interesting contrast. When asked earlier in the survey how coastal erosion could best be managed, most of the respondents didn't show much support for relocation (see Figure 30 in Section 6.3.1). However, when they were asked about sea-level rise, relocation was the favoured option.

It seems that Lifuka's people see coastal erosion as a local and visible phenomenon that can be dealt with through structural means, but sea-level rise appears to cause much more fear. None of the respondents suggested infrastructural solutions to cope with rising sea levels. This may reflect a lack of knowledge about the effects of sea-level rise.

Therefore, we recommend community engagement to raise awareness about this phenomenon.

This support for relocation would seem to link to a certain fatalism, with respondents (9%, or 33 households) saying there was nothing to be done or the phenomenon was God's will. A total of 5% of respondents (17) connected sea-level rise with man-made actions, identifying the need to reduce emissions and protect the beach from sand mining and tree clearing.

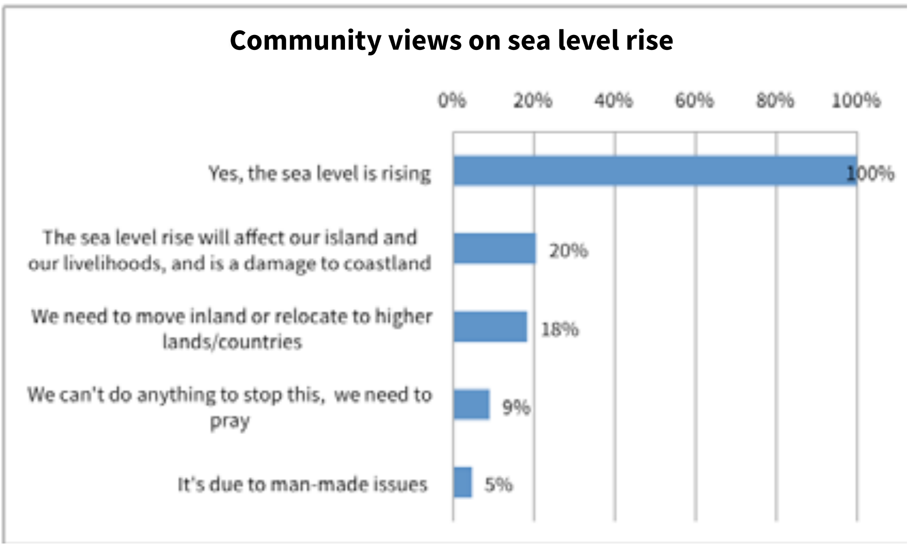


Figure 42. Community views on sea-level rise

6.4 Summary

Coastal erosion was a serious concern, with 98% of households expressing the opinion that the beach had receded in recent years. The community considered coastal erosion to be a recent phenomenon, with 52% of households stating that the erosion had started after the 2006 earthquake. Those who considered that erosion had started well before 2006 believed that it had accelerated in the aftermath of the 2006 earthquake. In general, the community believed the shoreline to have receded 10 m to 20 m.

Building a foreshore appeared to be the most popular option, suggested by 76% of respondents, although many expressed concern over the quality of any new foreshore. Replanting of coastal vegetation was the second most favoured option (35% of households), though many respondents stressed that special attention would need to be paid to the hardiness of vegetation planted.

Given that most infrastructure is inland, more than 92% of households reported no risk of inundation from ocean water. Just 8% (30 households) reported that their land had been inundated. Of the houses within a coastal zone up to 120 m from the shoreline, 29% were at risk of inundation. Pangai appears to be the most at risk from coastal inundation, with 39% of households located within its coastal zone reporting inundation in the past. Map analysis shows infrastructure alongside Pangai's coast to be under particular risk from inundation and erosion.

TC Rene (2010) appears to have been the most damaging event of recent years, resulting in inundation of 11 households on the coastline. The cyclone largely affected Hihifo and Pangai, and resulted in minor damage to household infrastructure at just under half of all houses that were inundated. One in three households did not repair the damage or replace lost items, which raises concerns over the community's ability to cope with or recover from disaster events.

One in three households reported having issues with their water supply in the aftermath of TC Rene. The main causes listed were rainwater tank or roof damage and lack of power to pump water. During this period, most households continued using rainwater as a water source. Seven households reported having a cyclone-related illness following TC Rene, and nine households lost days of paid work due to the need to clean up.

The community of Lifuka was unanimous in its concerns regarding future sea-level rise, with 100% of the respondents agreeing that it was occurring and it was an issue. The community expressed fears over the way the phenomenon would affect their island and their livelihoods, and many expressed the belief that the island of Lifuka would disappear altogether in face of sea-level rise. Some respondents urged relocation to higher land, or abroad, facilitated by the government.

7. HOUSEHOLD QUESTIONNAIRE: AGGREGATE MINING

7.1 Purpose

Aggregate beach mining contributes to and causes coastal erosion in atoll environments (Webb 2005). For this reason, removal of sand from the beaches without a permit from the minister has been prohibited by the government, as set out in the Land (Removal of Sand) Regulation (Government of Tonga 1936).

A government-approved office for the distribution of aggregates has been established in Lifuka, where sand and rocks are available for general sale at the price of TOP 120 for one truck (4 m^3) of sand and TOP 150 for the equivalent amount of rocks (Alamehi Taufui, Ministry of Works, personal communication, 21 March 2012). Observation of practices in Lifuka, however, showed that enforcement of this regulation was not complete and that private companies and households still mined from undesignated areas on a regular basis.

To assess the extent of and reasons for aggregate mining In Lifuka, households were asked whether they collected aggregates from the beach (sand, gravel or rocks) and were also asked to estimate how often they collected the aggregates and the average amount collected during each trip. This information was combined to estimate the total annual volume of aggregate mining in Lifuka. Furthermore, households were asked to list the purposes for which they collected aggregates. The results of this section of the survey are given below.

7.2 Results

7.2.1 Extent of mining

Of the sample interviewed, 180 households (46%) indicated that they mined at least one type of aggregate (sand, gravel or rocks) somewhere on the island. Of the households that actively mined, most (175 households or 97%) collected sand, while around a fifth (18%) mined gravel, and eight (4%) households mined rocks. Table 12 gives the detailed numbers and the percentage of households in each village that mined any type of aggregate. The village of Koulo had the highest percentage of households that mined (78%), while in the other villages, just 40% to 50% of households admitted to mining. Figure 43 is a representation of the locations mined and the frequency of mining from each location.

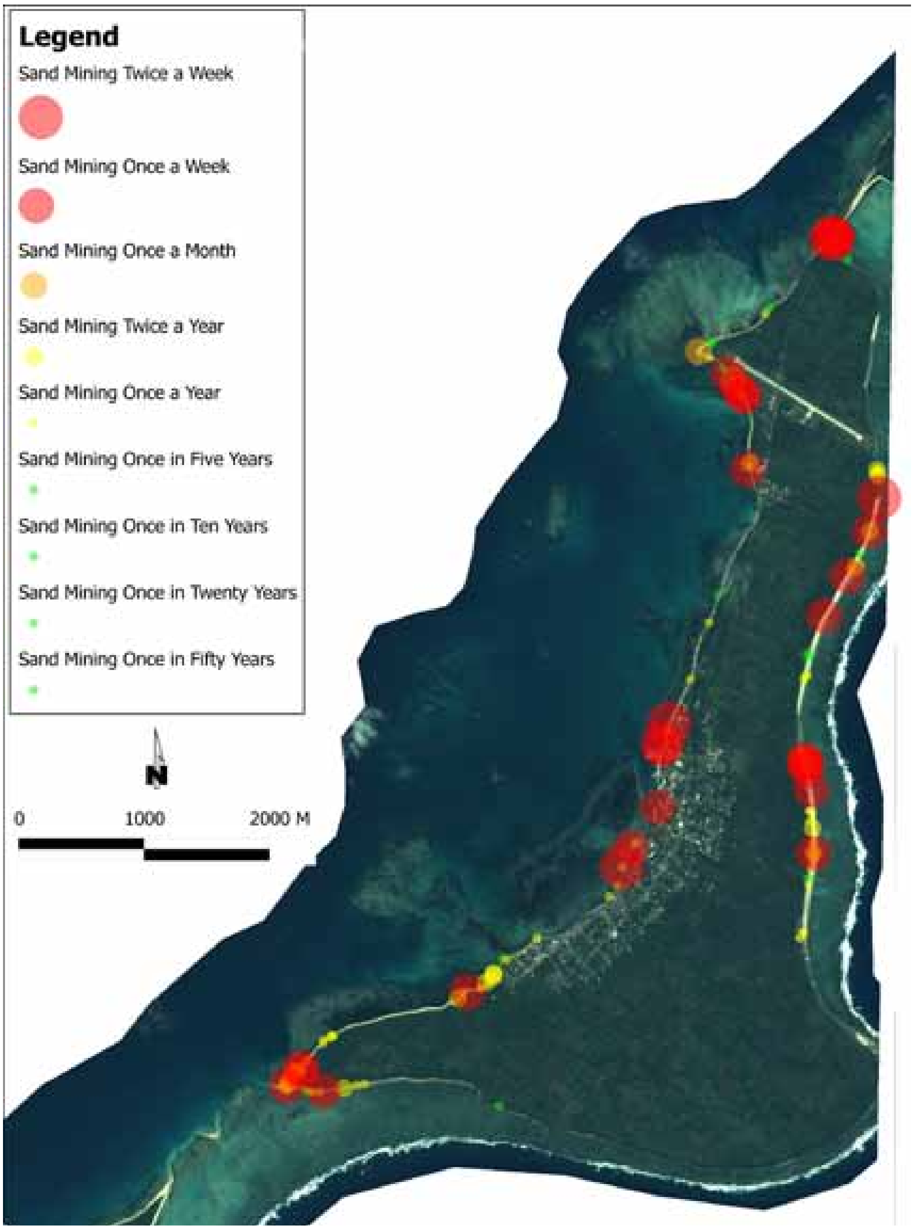


Figure 43. Map of beach mining locations and frequency on Lifuka

Table 12. Number and percentage of households that mined any aggregate, per village

	No of households that mine any aggregate	% of village sample	% that mine sand	% that mine gravel	% that mine rocks
	n=180	n=180	n=175	n=33	n=8
Hihifo	67	46%	96%	16%	2%
Holopeka	12	50%	100%	0%	0%
Koulo	25	78%	100%	36%	4%
Pangai	76	40%	97%	18%	8%
Total	**180**	**46%**	**97%**	**18%**	**4%**

n= number of households in the category

An equal percentage of male and female interviewees confirmed that members of their households mined. Of those households for which the sex of interviewees was recorded (363), 46% of female and 48% of male interviewees stated that they engaged in mining.

7.2.2 Frequency of mining

To estimate the total volume of aggregates mined in Lifuka and understand mining practices, households were asked to indicate how often their members mined. Table 13 indicates the percentages of households that answered, displaying the results by aggregate type. Sand is most commonly mined once per year (43%), while gravel tends to be mined more frequently, with the greatest number of households saying they mined it once per week (32%). Sample sizes for gravel and rocks mined are small (28 and 2 households respectively), so these results are indicative only.

Table 13. Frequency of aggregate mining, by aggregate

Frequency mined	Sand	Gravel	Rocks
	n=163	n=28	n=2
Twice a week	4%	4%	
Once a week	17%	32%	50%
Once a month	1%	4%	
Twice a year	11%	21%	
Once a year	43%	21%	50%
Once in 5 years	6%	11%	
Once in over 10 years	18%	7%	

n=number of households in the category

7.2.3 Estimated volume of aggregate mined for the interviewed sample

Estimations of total volume of aggregate mined in Lifuka for the interviewed sample were carried out by combining the information on frequency of mining per household and the average amount of aggregate mined on each trip. Data on amounts collected were originally recorded in units of rice bags or trucks, and later converted into cubic metres (see Annex 6 for details). For the interviewed sample, 334.5 m^3 of sand, 10.1 m^3 of gravel and 0.1 m^3 of rocks is collected annually from the beaches of Lifuka.

The community of Pangai appeared to carry out most of the mining, with an estimated 205.8 m^3 of sand and 10.1 m^3 of gravel collected annually, and Holopeka the least (Table 14).

Table 14. Total volume (m^3) of aggregate collected annually for interviewed sample

	Sand	Gravel	Rocks
Hihifo	74.0	5.0	0.1
Holopeka	20.5	-	-
Koulo	34.2	1.3	-
Pangai	205.8	3.7	-
Total	**334.5**	**10.1**	**0.1**

Figure 44 is provided to show an estimate of the volume of sand collected at each location.
The average volume of aggregate collected for the households that reported mining is estimated to be 2.4 m^3 for sand, 0.7 m^3 for gravel and 0.1 m^3 for rocks. Pangai had the highest average of annual aggregate mining by households, with 3.7 m^3 and 0.9 m^3 of sand and gravel, respectively, per year (Table 15).

Table 15. Average volume (m^3) of aggregate collected annually per household

	Sand	Gravel	Rocks
Hihifo	1.4	0.8	0.1
Holopeka	1.9		-
Koulo	1.8	0.3	-
Pangai	3.7	0.9	-
All	**2.4**	**0.7**	**0.1**

7.2.4 Total volume of aggregate mined on Lifuka

The total volume of aggregate extracted by private households in Lifuka was extrapolated by using the 2011 census data on the total number of households per village and the survey results on aggregate collection. The total annual volume was calculated to be 513.7 m^3 of sand, 29.1 m^3 of gravel, and 0.1 m^3 of rock. Total aggregate volume per village can be seen in Table 16. As is evident, most of the mining was undertaken by the village of Pangai. Detailed information on the assumptions used in the extrapolation is given in Annex 7.

Table 16. Extrapolated annual aggregate volume mined for Lifuka, per village, in m^3

	Sand	Gravel	Rocks
Hihifo	101.6	9.5	0.1
Holopeka	25.2	-	-
Koulo	52.0	3.5	-
Pangai	334.9	16.1	-
Total	**513.7**	**29.1**	**0.1**

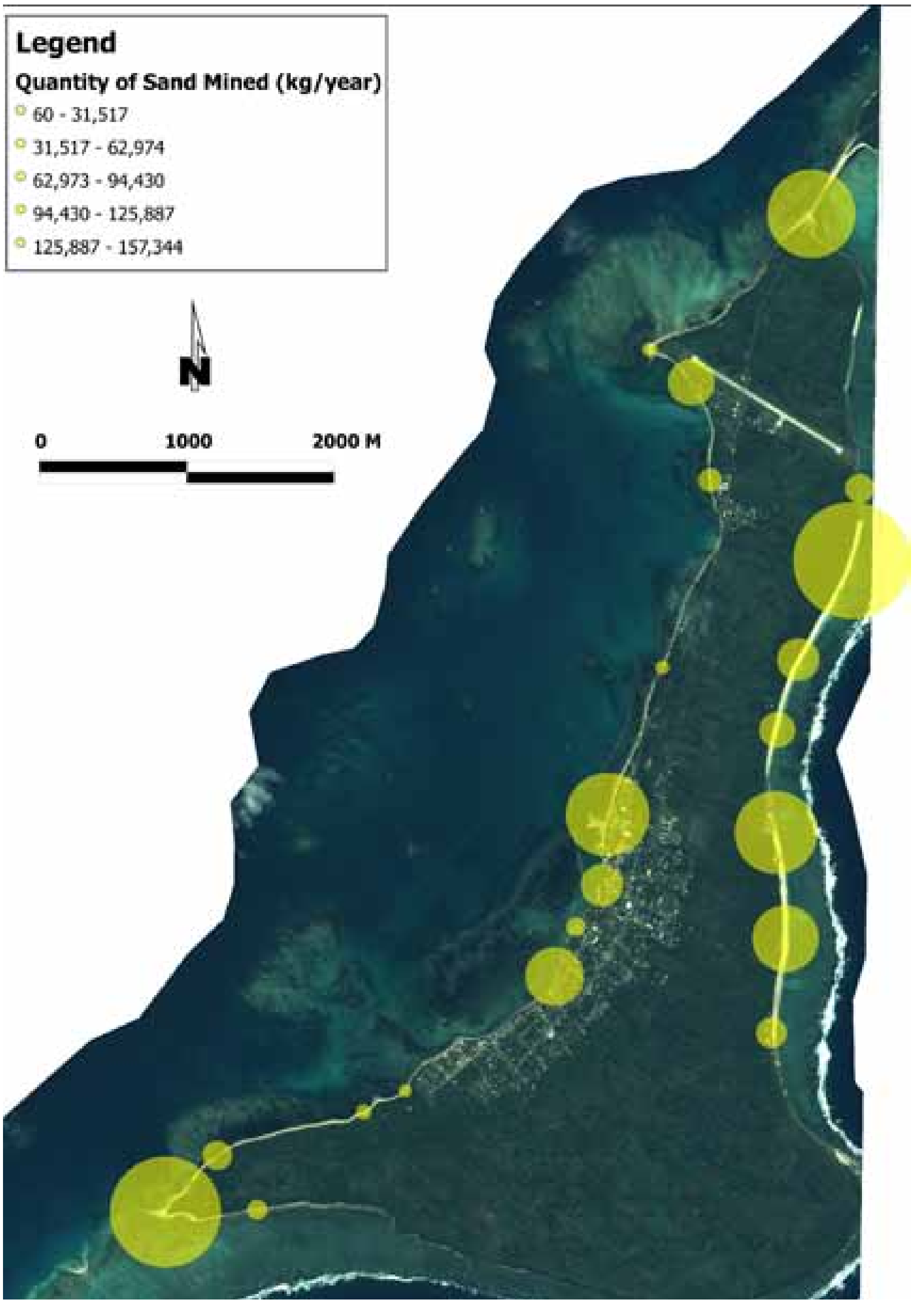


Figure 44. Map showing clusters of beach-mining locations by amount of sand mined in kg per year

7.2.5 Use of aggregates by households

Most of the aggregate, whether sand, gravel or rocks, was collected by households for general building purposes (69%), such as building or repairing a house or water tank. Aggregate was also frequently used around the house (25%), for example in the garden or for landscaping at the entrance of the house. A small part of the collected material (6%) was used for other purposes, such as maintaining graves that are traditionally covered by sand (Figure 45).

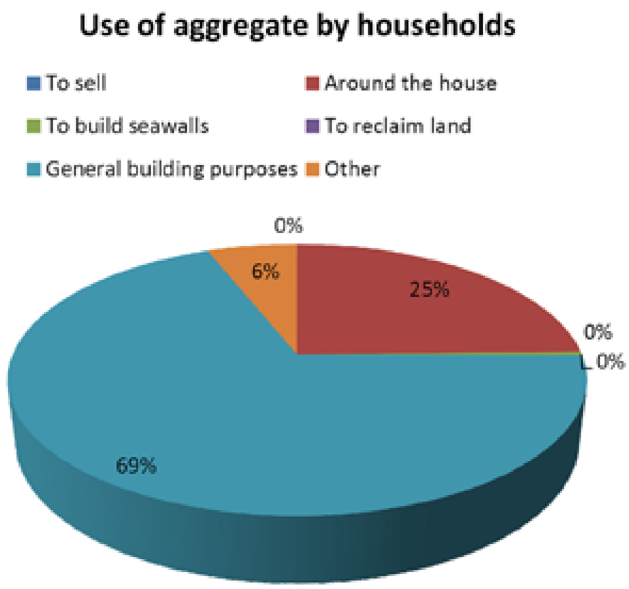


Figure 45. Use of aggregate by households

7.3 Conclusion

In absolute terms, the volume of aggregate extracted along the beaches of Lifuka did not appear to be large. However, without knowing more about the replenishment rate of the Lifuka coastline, it was difficult to determine how much aggregate mining was contributing to coastal erosion.

Nevertheless, it was notable that the heaviest level of mining appeared to occur in Pangai, the village with the highest reported number of inundations (Section 6.3.2), and a location that was already understood to have experienced coastline progression of up to 40 m over the last 44 years (Section 6.3.1). The fact that coastal mining was understood to undermine coastal defence on atolls (e.g. Webb 2005) and that some households acknowledged this by asking that mining halt (Section 6.3.1) suggested that the management of coastal mining around Lifuka should be revisited to increase communal resilience to inundation in the face of sea-level rise.

Given that the community requires a regular supply of aggregate, and that it is inappropriate to mine beaches identified as vulnerable, consideration of more appropriate locations would be worthwhile.

8. HOUSEHOLD QUESTIONNAIRE – SOCIAL INDICATORS

8.1 Purpose

Part of the household survey aimed to gather information on household and land tenure to find out more about the vulnerability of people of Lifuka to climate change. Such data on household and land tenure can be used to produce evidence on the sensitivity of livelihoods to sea-level rise and the capacity of households to adapt to change. For instance, not owning land or a house can increase a household's vulnerability to environmental changes when compared to someone in the same physical location who has sufficient economic resources to relocate to safer ground or adapt the infrastructure of the house to increase resilience.

This section gives a brief overview of the data collected in this part of the survey.

Figure 46. A coastal household

8.2 Results

Of the sample, 269 (69%) of households reported that they owned the house in which they lived (Table 17).

Table 17. Household tenure – does the household own the house it occupies?

Ownership	Number of households	Percentage of sample
		n=392
Owns the house	269	69%
Does not own the house	120	31%
N/A	3	1%

Of those households that reported not owning the house in which they lived, just four households (3.3%) paid rent for it (not shown in the table). The other households all said they occupied their house rent-free.

The majority of households reported living in a house built on their own land (231, or 59%) or on the land of extended family (78, or 20%). Another 28 households (7%) lived on government-owned land. Notably, 42 households (11%) marked 'other' as the landowners, most often indicating churches (Table 18).

Table 18. Land tenure – ownership of the land on which the house is built

Land ownership	Number of households	Percentage of sample
		n=392
Own	231	59%
Government	28	7%
Extended family	78	20%
Landlord	9	2%
Other	42	11%
N/A	4	1%

Of the 393 respondents, 220 were female (56%) and 173 male (44%). The average age of respondents was 48 years, seven months.

9. PHYSİCAL SURVEY OF GROUNDWATER AND RAİNWATER İNFRASTRUCTURE

9.1 Purpose

The physical survey of rainwater and groundwater assets collected specific information on the type and status of the infrastructure used to access water, including the measurement of tanks, the condition of gutters, and the depth and quality of the water in wells. This information will assist in assessing the effectiveness of water supply improvement actions and will guide adaptation actions.

9.2 Methodology

The physical survey was carried out concurrently with the household questionnaire and collected information on rainwater harvesting and groundwater well assets and features, including location, asset characteristics and condition, and identification of water-quality risks.

Survey sheets and satellite images of the study area were developed and used to record the location and measurements taken in the field.

The methodology used and a sample of the survey sheets are presented in Annexes 8 and 2, respectively.

9.3 Rainwater harvesting assets at houses

9.3.1 Overview

The physical survey included 462 buildings for which rainwater harvesting infrastructure was assessed, including houses, as well as some institutions, businesses, schools, churches and hospitals.

A total of 439 houses were surveyed, which included the 392 for which household questionnaires were undertaken and an additional 47 houses whose inhabitants were away or that were vacant at the time. Table 19 summarises the statistics on houses that were surveyed and that had access to rainwater harvesting infrastructure.

The definition of each category used in the survey can be found in Annex 8.

Table 19. Summary of rainwater harvesting household physical survey statistics

Category	Number
Approximate no. of tanks surveyed; includes residential, institutions and business	707
Total number of buildings (residential, business and other) that were physically surveyed for rainwater harvesting infrastructure	462
No. of **residential** buildings only for which a physical survey was undertaken and that had rainwater harvesting infrastructure (includes occupied and vacant houses and homes whose residents were away)	439
No. of residential buildings for which a physical survey was undertaken and that have a **connected** rainwater harvesting tank (includes occupied and vacant houses and homes whose residents were away)	360

Some 82% of all houses, (including occupied and vacant houses and those whose residents were absent) had access to a connected rainwater harvesting collection system; this increased to 92% for occupied houses.

9.3.2 Assessment of roofs

The area of roof or catchment for a rainwater harvesting system has been determined based on the digitised roof outline from the 2011 imagery. Roof material and condition are considered important with respect to the quantity and quality of rainwater collected.

Roof type
Almost 100% of the rooftops surveyed on Lifuka were constructed of permanent building materials using corrugated iron. One had a tarpaulin as a temporary cover due to cyclone damage.

Table 20. Roofing materials in use on Lifuka

Rainwater harvesting	Total houses	Total per cent
Metal (corrugated iron)	462	99.7%
Others	1	0.3%

Condition of roofing materials
A visual assessment showed that 11% of the house roofs surveyed were unsuitable for rainwater harvesting, and replacement was recommend. Of the remainder, 85% of roofs appeared suitable for harvesting rainwater, and the condition of 4% was unknown (Figure 47).

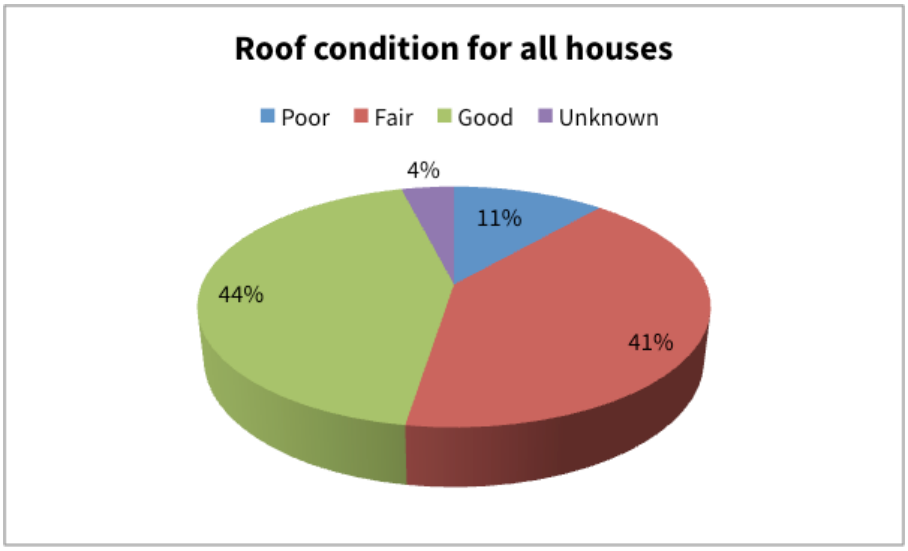


Figure 47. Condition of house roofs – physical survey

Roof deterioration, predominantly from rust, was common. It was estimated that some 52% of all houses required some roof maintenance, and, in some cases, replacement was required to improve the effectiveness and quality of rainwater harvesting systems.

Vegetation risk
Vegetation overhanging roof catchment areas can damage guttering and roof material and block guttering and downpipes, reducing the quantity of rainwater collected and its quality. Overhanging vegetation provides ready access for birds and other animals to roofs, which can introduce faecal contamination into water tanks.

The survey indicates that vegetation overhanging homes did not appear to be a significant problem on Lifuka (Figure 48). Some 75% of households surveyed had minimal, if any, vegetation overhanging the roof catchment, significantly reducing the risk of contamination to stored rainwater.

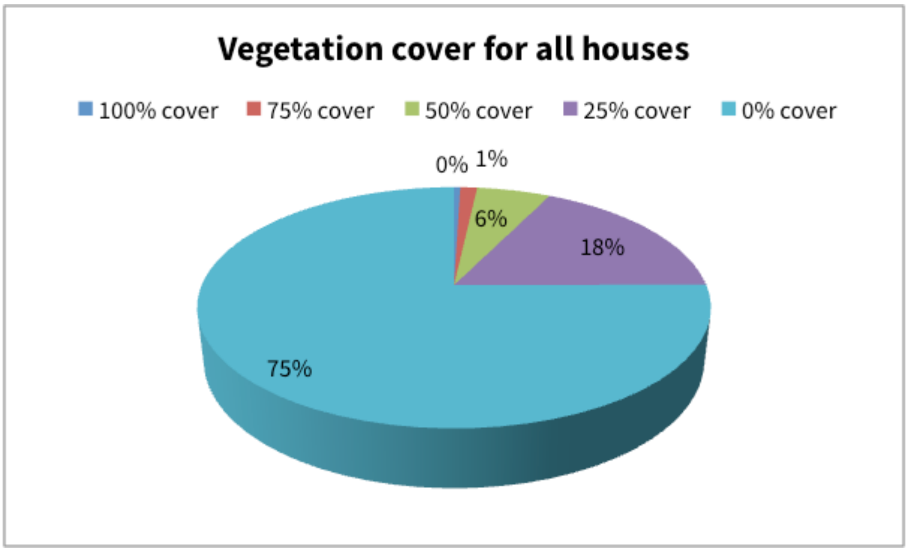


Figure 48. Vegetation cover over roofs

We recommend that those surveyed households with some vegetation cover (25%) clear it to improve their water quality.

9.3.3 Transmission systems – guttering and downpipes

Downpipe conditions

Downpipes transfer rainwater from the roof catchment to storage tank(s). Damaged, poorly fitted or missing downpipes can account for large losses of harvested rainwater.

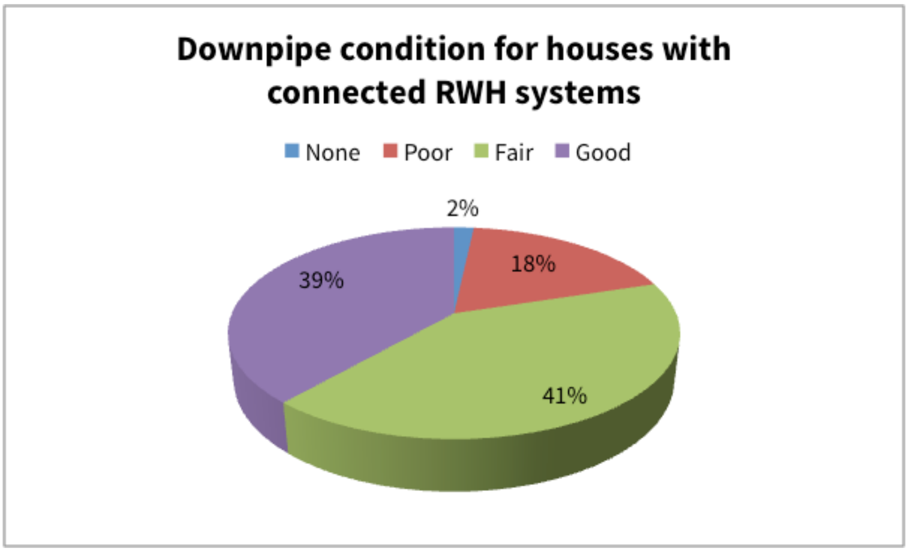


Figure 49. Downpipe condition for houses with connected rainwater harvesting systems

Figure 49 indicates the condition of downpipes for houses at the time of the survey. Less than 40% of all houses had efficient downpipes installed. An estimated 20% of all houses required downpipes to be replaced, while more than 40% of houses required minor repairs to downpipes.

An incentive scheme encouraging regular downpipe maintenance would significantly improve the efficiency of rainwater collection among households.

Percentage of roof catchment covered by gutters, and gutter condition
The percentage of roof catchment that is captured by guttering, with respect to the total roof catchment, provides some indication of the efficiency of the rainwater harvesting systems.

It is apparent from Figure 50 that significant improvement in the quantity of rainfall collected can be made with increased coverage by gutters. Just 6% of households were collecting the maximum amount of rainfall, whilst 94% of all households were collecting from 50% of the roof area or less.

Increasing the gutter coverage on houses would improve access to rainwater for most households. Future adaptation options to improve water supply should include increased guttering as an achievable solution that can be undertaken by householders and through a donor and community participation scheme.

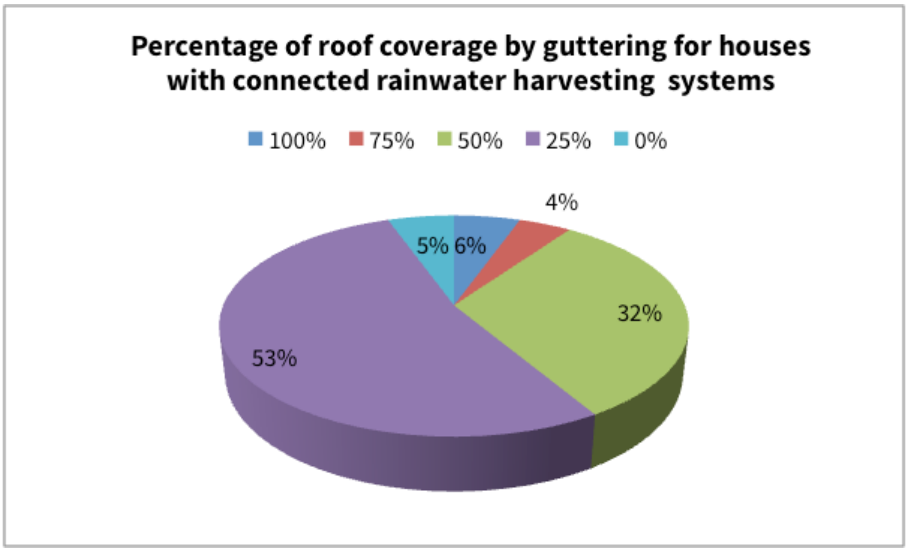


Figure 50. Gutter coverage of rainwater harvesting buildings

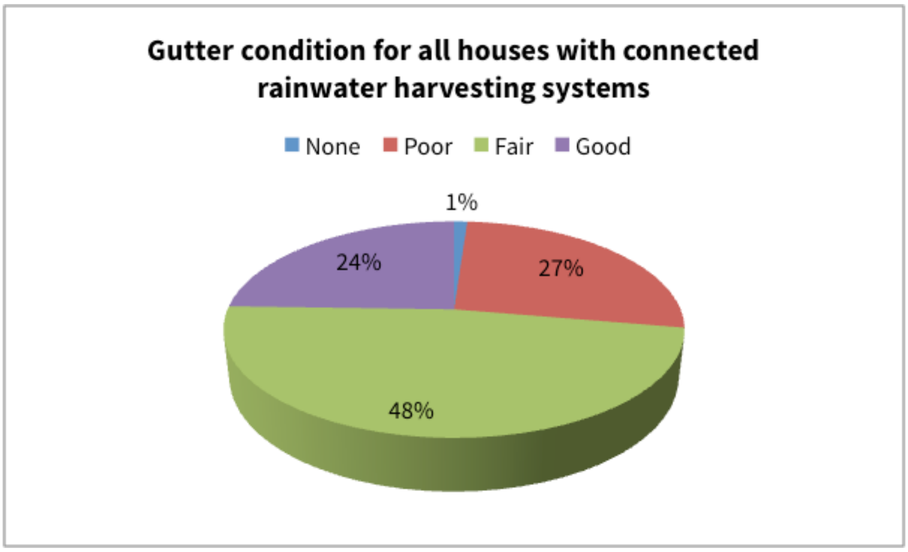


Figure 51. Gutter condition for all houses with connected rainwater harvesting systems

More than 75% of all houses had gutters that were improperly fitted, had sections missing or broken, or lost some water (Figure 51).

There was significant scope for improving rainwater harvesting yields through increased coverage and properly installed guttering. We recommend that adaptation options to improve water supply include increased guttering to maximise the available roof catchment area, as well as incentive schemes that actively encourage the maintenance of guttering to support sustainability and efficiency of rainwater harvesting.

9.3.4 Storage tanks and cisterns

The physical survey assessed a total of 704 tanks and cisterns for houses, institutions, and businesses with a combined total active storage of 6,634 $m^{3.}$

Households alone accounted for 535 tanks with a combined storage of 5,279 m^3. This volume of storage was distributed across 360 houses, providing 14.66 m^3 of connected storage per household.

Tank types
Four different types of tank were identified during the survey: cement tanks, cement cisterns, plastic tanks and fibreglass tanks. Tanks, in this case, referred to above-ground storage (normally cylindrical in shape), whilst cisterns were larger, often rectangular, and partially below ground.

The survey revealed that the most common tank type in Lifuka was made of cement, accounting for 75% of all tanks connected to a rainwater harvesting system (Figure 52). More recently, plastic tanks have become popular, and it is expected that this trend will continue, as has been seen in other parts of the Pacific.

This is, in part, due to the relatively cheap cost of plastic tanks, the flexibility to be able to move such tanks to a new site as required, less need for on-site construction, and increased structural integrity and quality assurance from plastic tanks. But due to their bulk, plastic tanks can be costly to transport.

It was noted that the majority of tanks surveyed in Lifuka appeared to have been provided under AusAID-funded projects spanning 1997 to 2011.

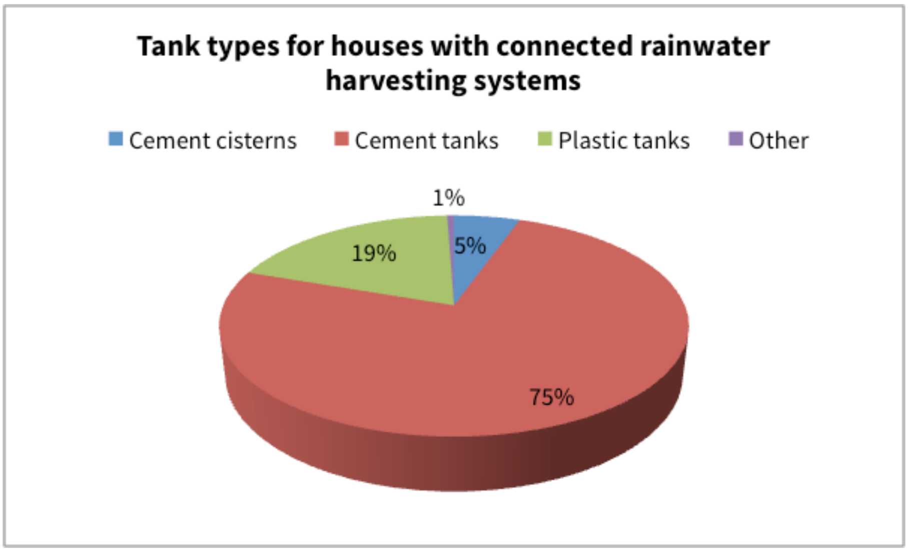


Figure 52. Distribution of tank types for surveyed households that had connected rainwater harvesting systems

Tank capacity

The median volume of cement tanks and plastic tanks was observed to be 10m³ and 5m³ respectively, whilst cisterns were larger, at 15m³ (Table 21).

Table 21. Comparison of tank capacity and tank type

	Tank volume m³			
Tank type	**max**	**min**	**average**	**median**
Cement cisterns	59.14	7.74	19.64	15.13
Cement tanks	28.59	3.18	10.35	10.00
Plastic tanks	13.43	1.70	5.71	4.99
Other (fibreglass)	9.66	9.50	9.61	9.66

Condition of connected tanks

Nearly 60% of all connected household tanks were considered to be in good condition and free of any observed leaks. An estimated 16% of connected household tanks were observed to be leaking and in need of repair or replacement (Figure 53).

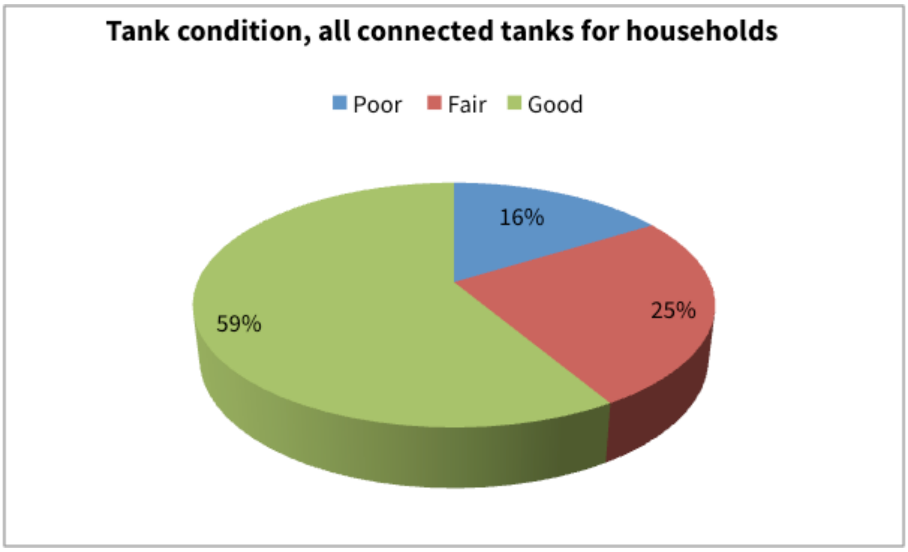


Figure 53. Condition of all connected tanks for households

A similar analysis was done for the different types of tanks, and the results are presented in Figures 54–56. Figure 55 indicates that 50% of the connected cement tanks were considered free of any external visible cracks or leaks.

An estimated 20% of the connected cement tanks were observed to be cracked and leaking, requiring immediate repair or replacement. The remaining 30% of connected cement tanks had external visible cracks and were likely to require repairs.

It is more difficult to determine if cement cisterns are leaking, as much of their structure is below ground. Based on observation, 72% of cisterns appeared to be in good condition, free of any visible cracks or leaks. An estimated 4% of the connected cement cisterns were observed to leak, and required immediate repair or replacement.

Plastics tanks were generally well maintained, with 88% of the connected plastic tanks considered to be in good condition. An estimated 4% of the connected plastic tanks were observed to be leaking at the time of the survey. This relatively high rate of plastic tanks in good condition may reflect the fact that they are generally newer than the cement tanks.

Three fibreglass tanks were also identified during the household survey. All appeared to be in good condition.

Overall, 40% of storage tanks observed required repairs, ranging from minor to complete replacement. We recommend regular tank inspections in combination with a gutter-maintenance incentive scheme to help identify cracks and leaks early and provide more time and resources for maintenance and rehabilitation.

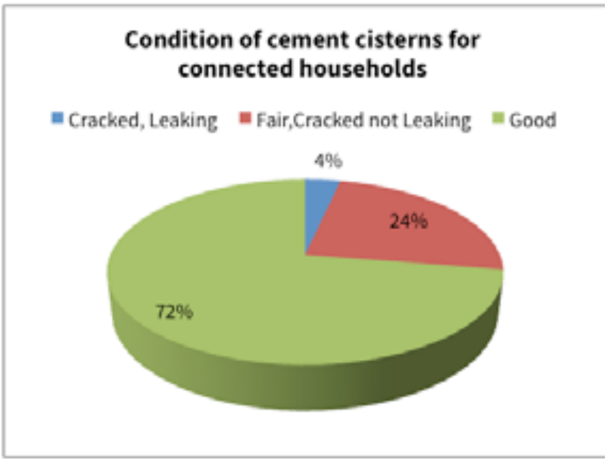


Figure 54. Condition of connected cement cisterns

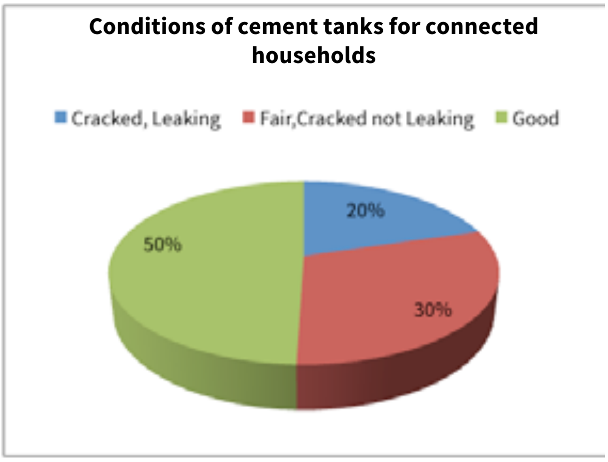


Figure 55. Condition of connected cement tanks

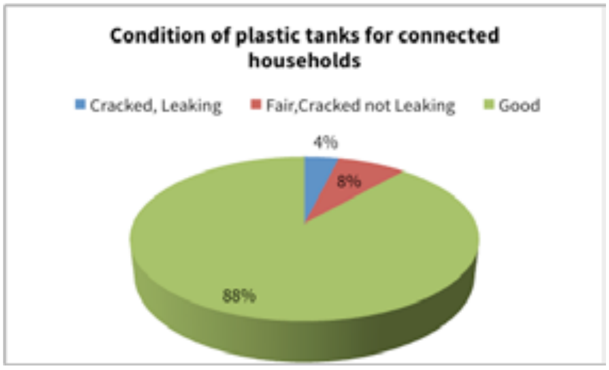


Figure 56. Condition of connected plastic tanks

9.3.5 Abstraction methods

Different methods were used to abstract water from storage tanks on Lifuka. These included taps at the tank outlet, pumps, piping directly from the tank to the house, and buckets.

The predominant abstraction method was through tap outlets – these were used in 64% of all connected tanks. An estimated 33% of connected households used buckets to abstract water from tanks. Only a small percentage of households had rainwater piped directly from the tank to the house, using a pump or alternate means (Figure 57).

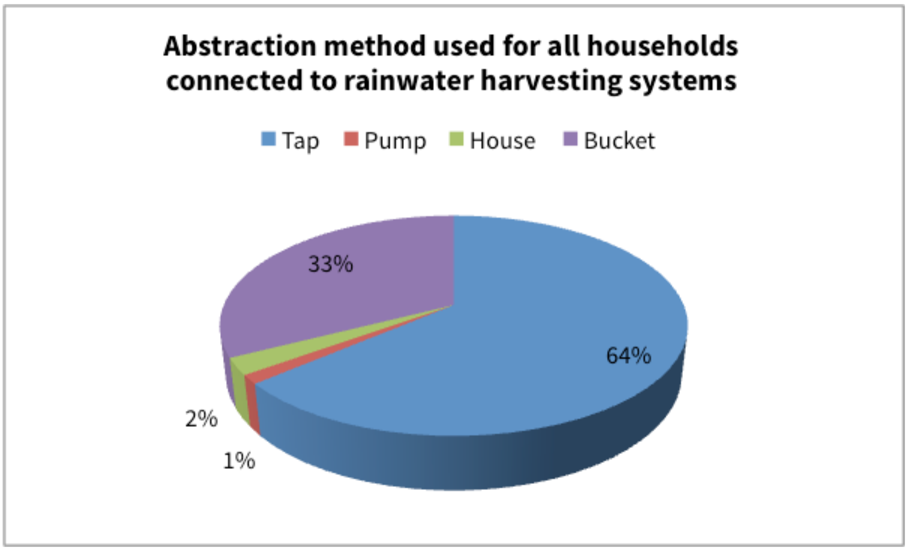


Figure 57. Abstraction method used for all households connected to rainwater harvesting systems

A similar abstraction analysis was done for the different types of connected tanks (Table 22).

Table 22. Abstraction methods used for connected tanks

Tank type	Number of connected tanks	Abstraction type			
		Tap	Bucket	Pump	House
Cement cistern	29	7%	72%	17%	4%
Cement tank	398	68%	30%		2%
Plastic tank	102	64%	30%		6%

The 17% of householders with cisterns that used pressure pumps to abstract their water were expected to have a higher rainwater consumption rate than most households, as their ability to access rainwater was improved.

Tank screens
Tank screens were used to cover entry points to tanks, including filling and overflow points, to reduce access by pests as well as the inflow of leaves and debris.

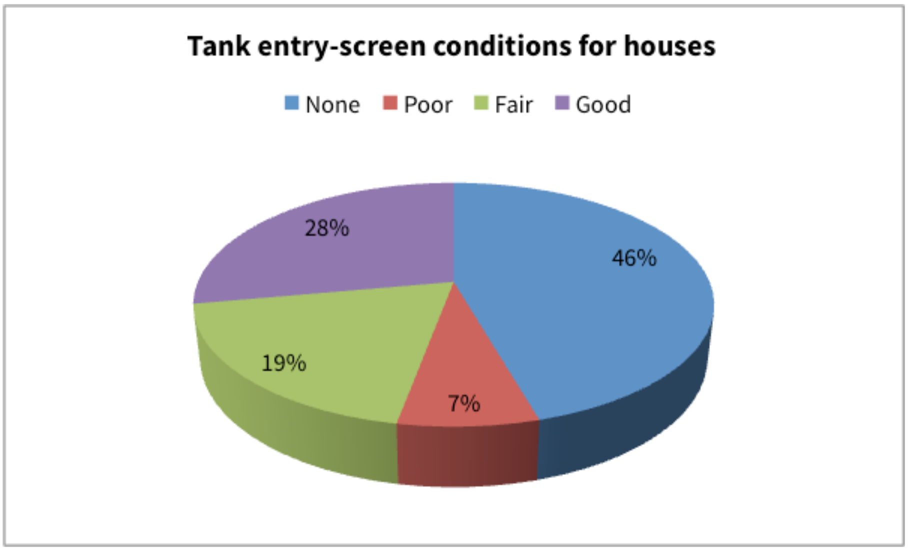


Figure 58. Condition of screens at tank entry points for connected household tanks

Some 46% of connected household tanks did not have any screens to filter debris. An estimated 72% of all connected household tanks required screens to be installed, repaired or replaced (Figure 58).
A similar analysis was done for the different types of connected tanks (Table 23).

Table 23. Screen conditions at tank entry points for connected tanks

Tank Type	Number of connected tanks	Screen condition			
		None	Poor	Fair	Good
Cement cistern	29	35%	17%	14%	34%
Cement tank	398	51%	8%	22%	19%
Plastic tank	102	28%	4%	9%	59%

Plastic tanks were more likely to have adequate screens in place, reflecting the fact that the plastic tanks were newer.

We recommend a community maintenance incentive programme that runs every six months, and supports householders with basic tools, materials, and technical knowledge regarding the importance of maintaining clean tanks and gutters, to improve water quality and security of supply.

9.3.6 Risk assessment for household rainwater harvesting systems

A water safety planning approach was used to assess the level of risk associated with water quality in rain tanks. The physical survey identified specific indicators that can be used to show the relative risk potential between households. No specific water-quality testing was carried out on rainwater tanks in Lifuka to verify this risk potential.

The following risk indicators were used:

- the percentage of vegetation cover over the roof, with increased vegetation cover suggesting increased risk;
- the screening of tank inlet points to prevent the ingress of organic matter and insects such as mosquitoes; and
- the abstraction type – for example, the use of buckets to abstract water carries a higher risk of contamination than water piped directly to the house.

Two-thirds of all household rainwater tanks in Lifuka were classified as having a moderate to high risk of contamination (Figure 59).

More than 90% of households relied on rainwater for their potable water needs, with the majority of households (79%), never treating their drinking water. This suggests a high risk of water-borne disease across Lifuka.

Boiling of water and safe storage in households prior to consumption is recommended.

Additionally, improvements to tank-water quality can be expected where first flush diverters (WHO 2004) are in use to divert the 'first flush' of rainfall, which can contain dirt and contaminants from the roof, along with basic screening and gutter maintenance programmes. It is recommended that first flush diverters be considered for future rain tank installations and form part of the building code for new buildings and extensions.

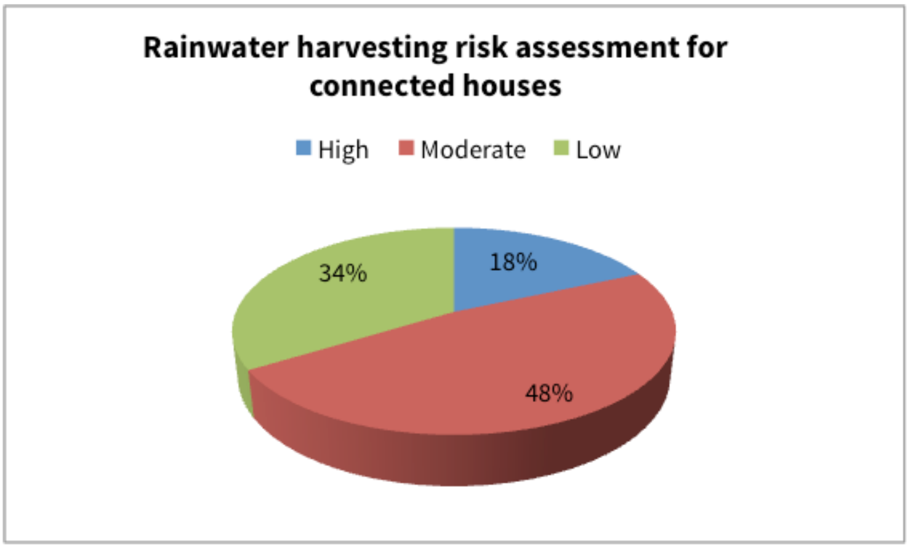


Figure 59. Assessment of risks to water quality of rainwater harvesting systems for connected households

9.3.7 Summary

A total of 92% of all occupied houses had access to rainwater harvesting collection systems. Households had an estimated combined storage of 5,279 $m^{3,}$ or approximately 14.66 m^3 of rainwater storage per household.

The majority of households (85%) had adequate roofing for rainwater harvesting, but 15% of roofs required replacement or substantial repair.

There was significant scope to improve rainwater harvesting yields and collection through improved maintenance of gutters and by increasing guttering to include more roof area. More than 85% of all households collected 50% or less of the rain falling on the roof. Improved downpiping will increase water collection for 60% of households.

We recommend that repair and replacement of downpipes and gutters be considered in future infrastructure improvement projects in conjunction with the development of a sustainable, community-led maintenance incentive programme.

A risk assessment on the quality of rainwater in tanks suggested that two-thirds of all households had a moderate to high risk of contamination, which increased the potential for water-borne disease.

Improvements can be made to reduce the risk of contamination, such as ensuring tank openings are screened, regular clearing of gutters, removing any vegetation overhanging roofs, keeping buckets clean and out of reach of animals, and protecting rain tank taps from animals.

In general, rainwater harvesting systems require low but regular maintenance. We recommend that a scheduled maintenance check be carried out every six months to optimise yields and minimise contamination. Community support to lead and resource this type of activity is recommended.

9.4 Results of groundwater physical survey

9.4.1 Overview

Historically, private wells have been an important source of water on Lifuka. Well water is often preferred because it is affordable, reliable, and often less saline than TWB water. Some wells identified during the survey had been in use for more than a century and had family and community significance. The wells also provided water security for relatives and neighbours during periods of drought (Crennan 2001).

The groundwater physical survey included private, communal and TWB production wells, with a total of 45 groundwater wells identified and assessed.

Table 24 summarises the groundwater wells located during the survey.

Table 24. Summary of wells located in March 2012 during the household survey

Category	Number
Approximate no. of wells surveyed, including private, communal and TWB production wells	45
No. of private wells	38
No. of private wells in use at time of the survey	28
No. of TWB production wells	5
No. of communal wells	2

Table 24 indicates that on average, nearly 10% of all surveyed households living in Lifuka had access to a private well, while at the time of the survey, the percentage of all households actually using private wells was estimated to be 7%. Actual access to fresh groundwater was restricted to certain locations and was not equally available to all households. Table 25 shows access to fresh groundwater as a function of well ownership and village location; fresher groundwater was available in Hihifo and Pangai, while access was more limited in Holopeka and Kuolo.

Table 25. Well ownership and type on Lifuka, by village

Village	Private wells	Communal wells	TWB production wells
Hihifo	23		4
Pangai	14		1
Holopeka	1	1	
Kuolo		1	

A total of 84% of the wells identified during the survey were privately owned and maintained (Table 25). The majority of wells located were in Hihifo village (61%). Communal well water was used in Kuolo and Holopeka, where the water was piped without treatment to households.

Figure 60. Domestic well in Hihifo, Lifuka, in use, where the manual pump and header tank have been replaced with a bucket

Annex 9 identifies the locations of the wells in Lifuka and their type.

9.4.2 Well status

Well location, condition and basic water-quality data were collected. Details on the definition of criteria used to assess well status are found in Annex 8.

A total of 74% of all private wells surveyed were in use at the time of the survey (Figure 61), while 26% were abandoned or not used, either because of concern over water contamination or because the well was no longer required.

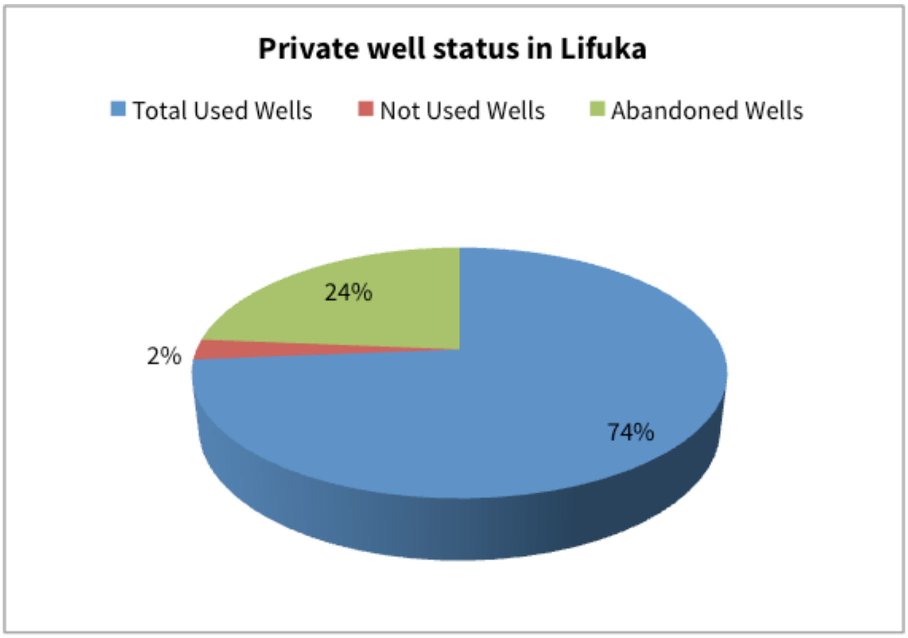


Figure 61. Status of private wells

9.4.3 Well-water abstraction for private and communal wells

Groundwater on Lifuka was abstracted from private, communal and TWB wells. Only private and communal groundwater abstraction will be discussed in this section; TWB water abstraction is discussed in Annex 5 of this report. Of the households that used private wells, 82% used a bucket with an approximate volume of 4 L to abstract the water. Pumps were used to abstract groundwater in 18% of private wells.

The Holopeka and Kuolo communities used an electric and diesel pump, respectively, to abstract groundwater. At the time of survey, the pump at the Kuolo communal well had experienced mechanical problems and was not operating. Abstraction data from these two wells were not available.

9.4.4 Well characteristics

Total depth of private and communal wells
The depth to which a village well is dug in Lifuka depends largely upon geology and the fluctuation in the depth of the groundwater table. The total depth of private and communal wells was investigated.

The average depth of private and communal wells on Lifuka was 3.2 m (Table 26).

On small, low-lying islands, wells are normally dug to ensure that they do not run dry at low tide but, importantly, are not so deep as to allow the entry of saline water at high tide. Mapping of well locations in Lifuka (Annex 9) indicated that the tops of most private wells were located below 5 m above sea level. Exact elevations were not investigated during the survey.

Depth to water table of private and communal wells

The depth to the water table was recorded. The average depth to water table of private and communal wells was 2.47 m (Table 26). The shallow nature of the water table increased the potential for contamination from daily activities and existing practices.

The differences in total depth and depth to water between villages were due to differences in ground elevation. Geophysical studies in 1993 (Furness 1993) indicated an eroded palaeo-shoreline that was subsequently partly buried by sand and volcanic ash. Refer to Annex 10 for a soil map of Lifuka.

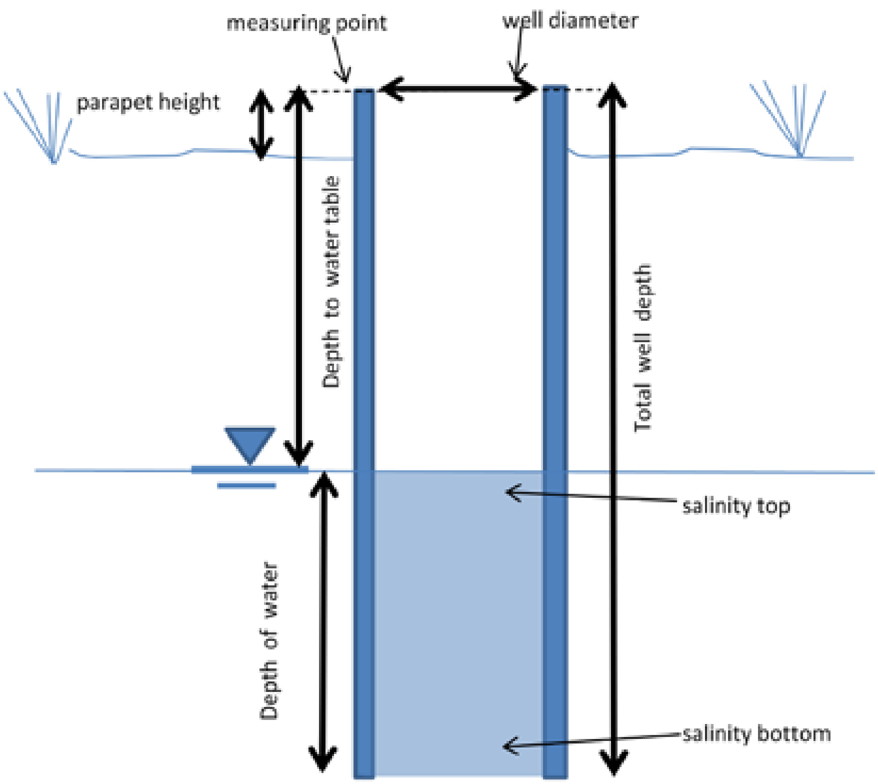


Figure 62. Schematic of village well identifying depth to the water table and total well depth

Table 26. Characteristics of private and communal wells on Lifuka

Well parameter	Well type	Maximum (m)	Minimum (m)	Average (m)	Median (m)
Total depth	*Private wells*	6.60	1.32	3.20	3.22
	Communal wells	3.70	3.50	3.60	3.60
	Combined	6.60	1.32	3.20	3.25
Depth to water table	*Private wells*	6.01	0.39	2.46	2.40
	Communal wells	3.17	2.09	2.63	2.60
	Combined	6.01	0.39	2.47	2.40
Depth of water	*Private wells*	1.60	0.20	0.86	0.88
	Communal wells	1.40	1.00	0.60	1.00
	Combined	1.60	0.20	0.87	0.87
Well diameter	*Private wells*	1.80	0.57	0.90	0.80
	Communal wells	3.20	2.40	2.80	2.80
	Combined	3.23	0.57	1.00	0.85

Note:

i. *Total depth refers to the distance between the well casing and the base of the well. The height of the casing above ground was not recorded for every well, but was estimated to be 40 cm above ground for most of the private wells, based on the observed and measured heights for some measured wells.*

ii. *Depth to water table refers to the distance between the ground level and the water level in the well.*

iii. *Depth of water in the well refers to the height of water in the well, or the difference between the total depth and depth to water table.*

iv. *Well diameter is the distance between the inside walls of the well.*

Casing type
Well casing refers to the structure that helps keep loose surface sand and gravel from collapsing into the well. It also helps prevent surface runoff from entering the well.

Details on the definition of criteria used to assess well casing are found in Annex 8.

A total of 89% of the private wells were cased, offering some protection against collapsed well walls and ingress of surface waters (Figure 63). Approximately 11% of the surveyed private wells did not have any casing and were at higher risk of contamination. Households with open wells could minimise contamination risks by casing wells, constructing a concrete apron, and restricting the access of animals.

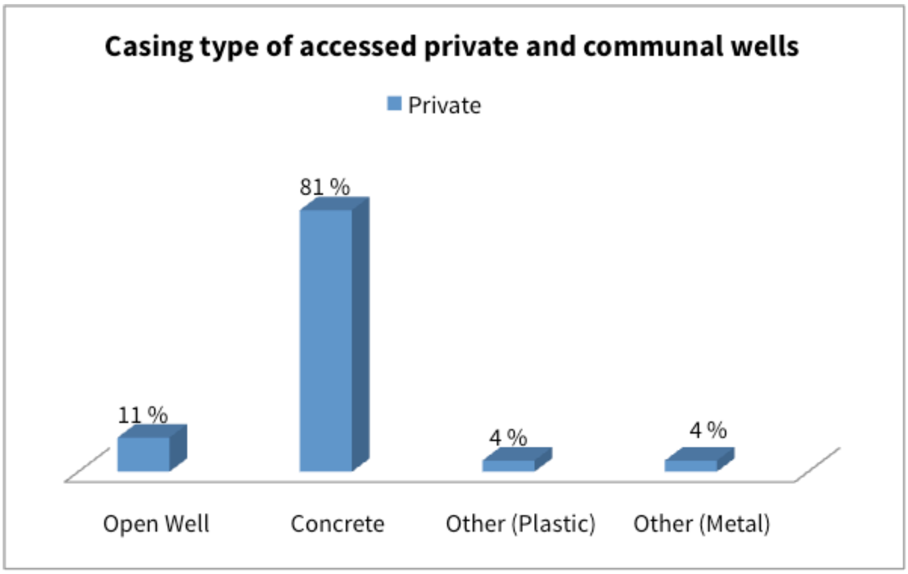


Figure 63. Private wells by casing type

9.4.5 Well water quality

Salinity levels
Geophysical investigations undertaken in September 2011 and subsequent groundwater monitoring results indicated that the freshwater lens on Lifuka was less than 5 m thick in most places. Natural factors such as tidal mixing, rainfall, and abstraction affect the salinity of the freshwater lens.

An upper salinity limit for potable atoll groundwater as suggested by Falkland (1999) is 2.5 millisiemens/cm (mS/cm), a unit used for measuring electrical conductivity (Table 27).

Table 27. Comparative conductivity value guidelines developed by Falkland (1999) for coral atoll groundwater lenses (mS/cm – millisiemens per cm; ppt – parts per thousand)

Type of water	Typical conductivity range (mS/cm)	Approximate salinity equivalent (ppt)
Rainwater	0.04–0.120	< 1
Very fresh groundwater	0.250–.500	< 1
Fresh groundwater	0.500–1.5	< 1
Limit of freshwater	1.5–2.5	< 1
Mildly brackish water	3.0–5.0	2–3
Brackish water	5.0–10.0	3–5
Very brackish water	10.0–25.0	5–15
Highly brackish water	25.0–50.0	15–33
Seawater	50.0–55.0	33–37

During the survey period, salinity levels of 33 private and two communal wells on Lifuka were recorded. All the samples for the private and communal wells were taken directly from the well, as per the water sample collection standard operating procedure outlined in Annex 11. The average salinity of privately-owned wells was 0.817 mS/cm (Table 28), within the acceptable limit. This made the water suitable for a range of household needs.

Table 28. Well salinity of private and communal wells, at the bottom of the well (mS/cm)

Well Type	Maximum	Minimum	Average	Median
Private well	2.600	0.288	0.817	0.704
Communal	3.750	1.748	2.749	2.749

The two communal wells in Holopeka and Koulo registered salinity levels of 3.750 mS/cm and 1.748 mS/cm respectively. These wells were close to the coast, where the freshwater lens thins and water was more brackish, limiting the use of this water to washing only. There were five monitoring bore sites which were monitored approximately every quarter, and provided a good indication of the salinity of the groundwater over time, including seasonal change in response to rainfall. Ongoing monitoring will be the subject of a separate investigation within this project. Monitoring bore LIF 6, located on the north side of Moa road, Hihifo, between Holopeka road and Lotokolo road, had a sampling tube, Tube 4, installed to a depth of 8.4 m below ground. This monitoring bore demonstrates the relationship between rainfall and groundwater salinity.

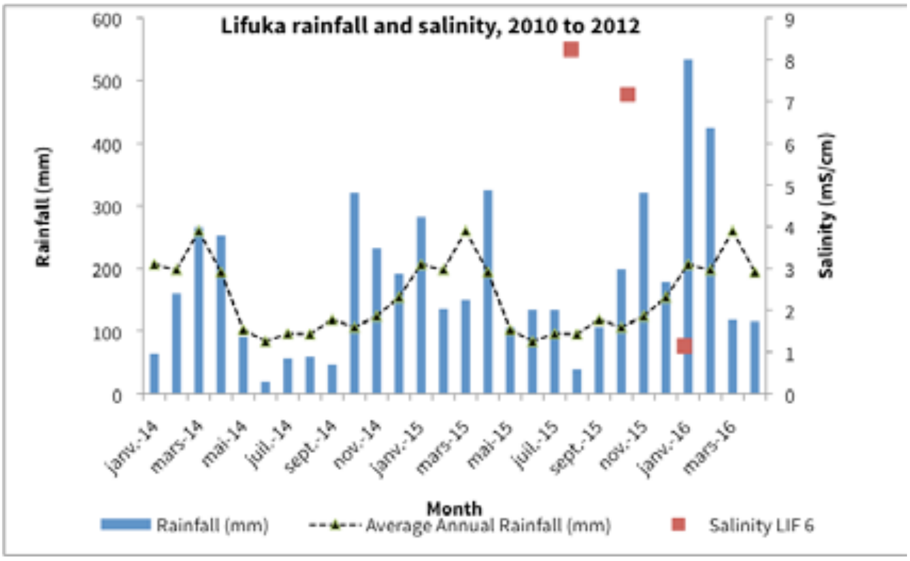


Figure 64. Rainfall data for Lifuka 2010 to 2012 and groundwater salinity from monitoring bore LIF 6, Tube 4

The salinity readings during the March 2012 monitoring suggest that groundwater quality was significantly affected by the extended wet period prior to the household survey (Figure 64). Increased rainfall results in a freshening of the groundwater lens from increased recharge.

9.4.6 Well water sampling

Presence and absence of bacteria (coliform and E. coli*)*

Presence and absence testing for coliform and *E. coli* bacteria was undertaken using IDEXX Colilert 18 reagents and followed the methodology outlined in Annex 4. *E. coli* is found in the lower intestine of warm-blooded organisms. *E. coli* bacteria are used as an indicator for faecal contamination and coliform is an indicator of the presence of pathogens in water.

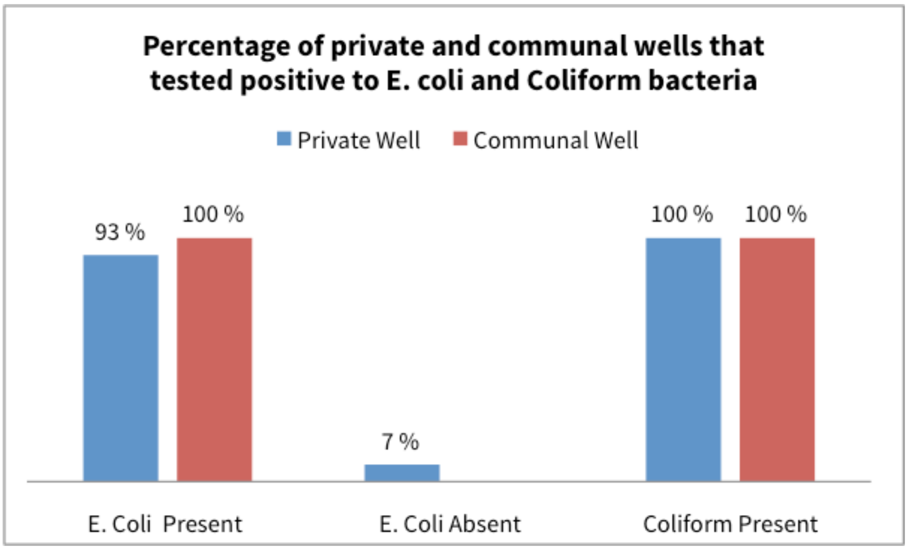


Figure 65. Percentage of private and communal wells that tested positive for E. coli *and coliform bacteria*

A total of 93% of private wells and both communal wells tested positive for the presence of *E. coli*, and all were positive for coliform bacteria (Figure 65). Evidently, there is a high risk of groundwater faecal contamination from current land activities and practices. Previous studies (Crennan 2001) have also indicated high levels of bacteriological contamination of groundwater.

The high concentration of pit latrines and poorly-constructed septic tanks was a contributing factor to this pollution, as was the high number of roaming animals, including pigs and dogs.

It is recommended that communities on Lifuka be informed about the level of groundwater contamination and the risks this poses to public health. Similarly, it is important for the community to recognise that water quality will not improve whilst current wastewater practices remain, and while large numbers of pigs and dogs are allowed to roam.

There were trials of 15 composting toilets in 2001 in Lifuka (Crennan 2001). Although this technology remains appropriate, these toilets were observed during the 2012 field work to now be unused and in a state of disrepair. In Tuvalu, improvements in composting toilet design and a planned approach to the introduction of the technology into the community has met with success. Efforts should be made to inform the Lifuka community of improvements in the technology and its popularity and use in other Pacific Island countries facing similar issues around groundwater contamination, such as Tuvalu, Nauru, and Marshall Islands. See http://www.pacific-iwrm.org/component/content/article/3-newsflash/88-gef-pacific-iwrm-highlights-video-2010-2011.html for more information.

9.4.7 Risk assessment of wells

A water safety planning approach that considered the risks of well contamination was used to consider the overall risk to well water quality. Covering wells reduces the risk of contamination. 'Threat' refers to the potential hazard that threatens the well and its water quality. Details on the definition of criteria used to assess well covers are found in Annex 8.

Well covers

A well-fitting cover reduces risks to water quality by reducing the potential for material to enter the well. Overall, 71% of the wells had adequate covers; 29% of wells were not covered at the time of the survey. Leaving wells uncovered or only partially covered provides minimal protection against the ingress of surface water and other potential contaminants.

Of the two communal wells surveyed, only Holopeka communal well had a secure cover that was in use. Kuolo communal well was not covered.

Figure 66. A typical uncovered well on Lifuka

Factors such as well and septic tank construction, shallow soil depth and the high water table, as well as roaming animals, are potential sources of contamination and are responsible for the high presence of faecal contamination in groundwater.

The threat of contamination is significantly increased where the bases of septic tanks or soakaway pits and pit latrines are unsealed (as is the case for the majority of septic pits/soakway pits on Lifuka) and are also in close proximity to wells.

The distance from wells to the closest septic tank/pit latrine was observed. Results indicated that approximately 46% of private wells were less than 25 m away from pit toilets and latrines (Figure 67). A total of 90% of wells were within 75 m of pit toilets and latrines.

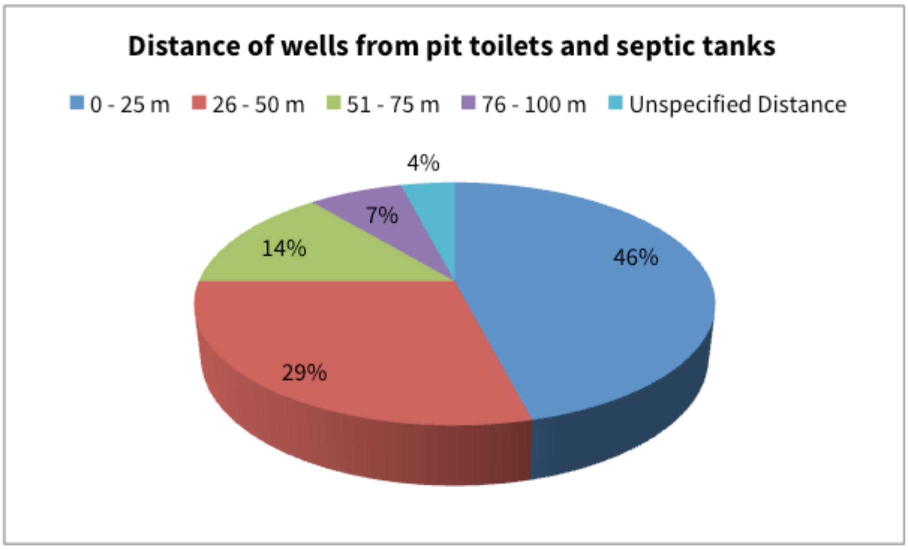


Figure 67. Distance of wells from pit toilets and septic tanks

An attempt was made to establish a relationship between the distance of a well from the closest septic tank or pit toilet and the presence of *E. coli* in the groundwater. No obvious relationship was established (see Figure 68). A UNESCO-funded groundwater pollution study in Lifuka in 2001 (Crennan 2001) suggested that there was no safe distance for construction of wells in relation to toilet facilities in the villages of Pangai and Hihifo.

Strategies such as source control and water treatment are required to reduce the negative impacts of groundwater pollution. Crennan (2001) further concluded that most of the 300 house-sites in Pangai-Hihifo had one pit latrine at the time of the survey, which was moved every six to 12 months around the house-site. This density of at least 300 toilets per square kilometre had the potential to cause widespread contamination of the aquifer over time and was the dominant source of groundwater contamination.

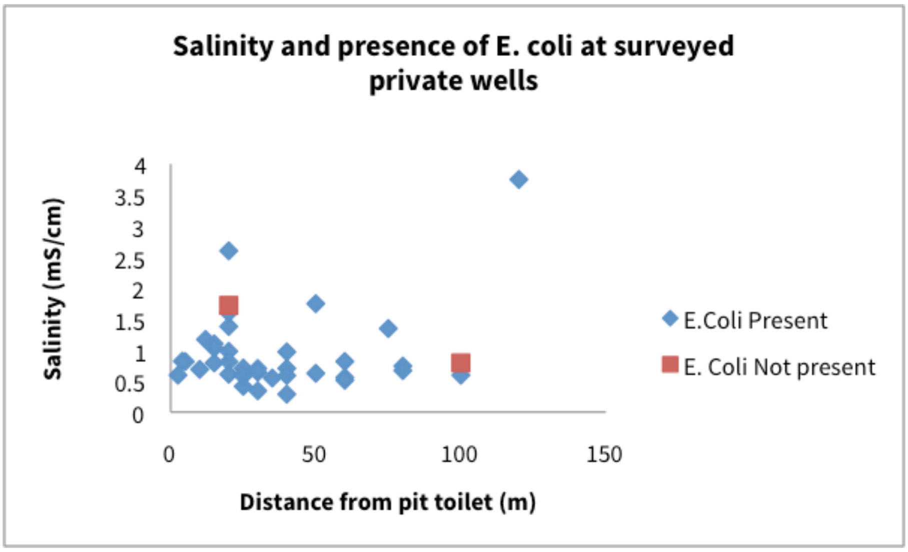


Figure 68. Salinity and E. coli *values for wells*

No obvious relationship was observed between the distance of a well from a septic tank or pit toilet and the presence or absence of *E. coli* or salinity.

Animal waste is a direct source of bacteriological contamination and a potential threat. Rubbish around well sites attracts animals, and this contributes to the potential threat of contamination.

9.4.8 Summary

Groundwater is an important water source for Lifuka. TWB provides piped groundwater from three galleries and one well, whilst houses in Holopeka and Kuolo are provided with piped water from communal wells. In addition, there are a number of private wells which are regularly used by households.

Results from sampling indicated bacteriological contamination of Lifuka's fresh groundwater resources: a total of 93% of groundwater samples tested positive for *E. coli*. This contamination was due to faecal matter from warm-blooded animals entering the groundwater system and migrating to wells. The contamination was believed to be due to the continued use of septic tanks and pit latrines that allowed faecal matter to seep into shallow groundwater.

Alternative options for waste disposal, such as properly installed and maintained composting toilets and enforced building codes for onsite wastewater handling, are required. Without improved on-site wastewater disposal, the incidence of water-borne diseases will be high and ongoing.

It is recommended that an alternate waste disposal option, such as composting toilets, be considered for Lifuka. Composting toilets were piloted in 2001, but many of the 15 original composting toilets were no longer operational at the time of this survey. Improved designs in conjunction with a structured and supported implementation programme would improve the success rate for longer-term acceptance of this appropriate technology.

The shallow depth of the water table in Lifuka, around 2.5 m from ground level, placed the aquifers at higher risk of contamination as there was limited capacity for adsorption of contaminants.

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ANNEXES

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Annex 3:	List of enumerators and physical surveyors
Annex 4:	Colilert 18 presence and absences test procedure
Annex 5:	Overview of the reticulated water supply – Tonga Water Board
Annex 6:	Assumptions used for conversion of aggregates mined into volume
Annex 7:	Calculation of total aggregate demand for Lifuka
Annex 8:	Methodology of physical survey for rainwater and groundwater assets
Annex 9:	Location and type of wells in Lifuka
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Annex 1: Household survey questionnaire

ASSESSING WATER RESOURCES AND COASTAL INUNDATION - LIFUKA HA'APAI, KINGDOM OF TONGA

HOUSEHOLD QUESTIONNAIRE

Census Block Number: ☐☐☐☐ Map number: ☐☐ Village Name: ____________

Household Number: ☐☐ Name of Interviewer: ____________

Location: (refers to the main entrance door) S: ☐☐ W: ☐☐☐ ☐☐☐☐☐ Team Name ☐ Date: ☐☐ / ☐☐ / ☐☐

Name of Interviewee: ____________ Age: ________

Relationship of this person to the head of household: ____________

(for e.g. Head, wife or husband, son, daughter, brother, sister, father, mother, etc)

Roster of Household Members (List the age and sex of all persons residing in the household)

	Name	AGE	M/F
1	**Head:** ____________		

	AGE	M/F		AGE	M/F		AGE	M/F		AGE	M/F
2			7			12			17		
3			8			13			18		
4			9			14			19		
5			10			15			20		
6			11			16			21		

Clip all field measurements and forms together to this Household Schedule

Answer the following questions for the household. CIRCLE the appropriate response code and ENTER in the box (es) provided

H1 DRINKING WATER

The following section refers to the household's **drinking water.**
We will use this information to identify options for improvement to the drinking water needs of the household.

1. What are the Primary and Secondary water sources for drinking purposes of this household?

Primary: main drinking water source
Secondary: alternate drinking water source for household

Source of drinking water	**P**	**S**
1. Tonga Water Board		
2. Rainwater		
3. Well water		

2. How often does this household face shortages of primary drinking water? ☐

1. Monthly
2. 3 monthly
3. 6 monthly
4. Yearly
5. Rarely
6. Never

3. Does this household treat its primary drinking water source? ☐

1. Yes
2. No **(Go to Q. 7)**

4. How often does this household treat its drinking water? ☐

1. Always
2. Mostly
3. Sometimes
4. Rarely

5. What treatment does this household use? (tick all that apply)

1. Boiling ☐
2. Chlorination ☐
3. Filtration ☐
4. Solar disinfectant ☐

6. Who is responsible for treating drinking water in this household ? (tick all that apply)

1. Adult woman ☐
2. Adult man ☐
3. Female under 15 years ☐
4. Male under 15 years ☐
5. All ☐
6. Don't know ☐

7. Is the primary drinking water plumbed into the household? ☐

1. Yes **(Go to Q.9)**
2. No

8. If no, then who is responsible for collecting drinking water? (tick all that apply)

1. Adult woman ☐
2. Adult man ☐
3. Female under 15 years ☐
4. Male under 15 years ☐
5. All ☐
6. Don't know ☐

9. How does this household normally store drinking water?

1. Outside tank ☐
2. Pots / buckets with lids ☐
3. Pots / buckets without lids ☐
4. Bottles ☐
6. Other **> > specify** ________ ☐

H2 WATER USE

The following section refers to ALL of household's water uses.

10. Which type of water sources does your household use for the following activities?

Source of water	Different activities of using water				
	Cooking	Washing (clothes)	Shower & Bath	Gardening & outdoor	Other
TWB					
Rainwater					
Well water					
Other (eg sea-water)					

11. HOW MANY of these items are both connected and regularly used by the household and their water sources?

Source of water	Flush toilet	Washing machine	Shower & bath	Outside taps	Kitchen sink	Other
TWB						
Rainwater						
Well water						
Other (eg sea-water)						

12. Which type of water abstraction does your household use for each of the following water sources?

Source of water	Type of water abstraction			
	Tap	Bucket	Pressure Pump	Other
TWB				
Rainwater				
Well water				
Other (eg sea-water)				

H3 WELL WATER USE

This section refers to the well water or groundwater use only for any household water needs

13. If you access a well, who owns the well where you access water from?

1. The household
2. Neighbour
3. Communal well
4. Other >> specify ____________
5. Not applicable, we don't access water from a well

H4 SANITATION

14. What type of toilet facility does this household use?

1. Flush/pour (septic)
2. Flush/pour (soakaway)
3. Pit latrine
4. Bush/beach
5. Other >> specify ____________

H5 RAINWATER HARVESTING

15. If you do NOT collect rainwater for any of your water needs, why not?

1. Do not require
2. Setup too costly
3. Do not trust quality of water
4. Don't know
5. Other >> specify ____________
6. Not applicable, we collect rainwater

H6 WATER PURCHASE

16. Do you currently pay for any of your water needs?

1. Yes
2. No
3. I don't know

OPEN QUESTION

17. Do you have any views on how to improve water quality and quantity of supply in the future?

____

____

____

____

____

H7 HOUSEHOLD TENURE QUESTIONS

18. Does this household own this house ?

1. Yes
2. No

19. What is the tenure of this house?

1. Rented
2. Rent free

20. Who owns the land where this house is built?

1. Own
2. Government
3. Extended family
4. Landlord
5. Other >> specify ____________

21. Has anybody moved into this household for any of the following reasons?

1. Yes - Improved access or quality of water
2. Yes - Reduced exposure to coastal inundation
3. Yes - Decreased impact of coastal erosion
4. Yes - Other reduction of exposure to natural hazards >> specify ____________
5. No **(Go to Q.23)**

22. How recent was the move?

1. 1-3 years
2. 4-6 years
3. 7-15 years
4. Greater than 15 years

H8 COASTAL INUNDATION

23. Has this house or land been inundated by sea water or been hit by waves before?

1. Yes, just once
2. Yes, 2 - 3 times
3. Yes, happens every year
4. No, my house has never been inundated by saltwater or hit by waves **(Go to Q.32)**

24. Which of the following tsunami events resulted in inundation at your house? (tick all that apply) Please rank in order of inundation height, 1 being the greatest level of inundation.

	Inundation?	Rank
1. 2006 tsunami		
2. 2009 tsunami		
3. None		

25. Which of the following cyclone events resulted in inundation at your house? (tick all that apply) Please rank in order of inundation height, 1 being the greatest level of inundation.

	Inundation?	Rank
1. 2010 cyclone ((Rene		
2. 2011 cyclone ((Wilma)		
3. 2012 cyclone (Cyril)		
4. Other >> specify ______		
5. None **(Go to Q.32)**		

26. For the most severe cyclone event in Q25, how high did the water level reach?

1. Below the floor of the living room
2. Above the living room floor

27. For the most severe cyclone event in Q25, what was the extent of damage caused by inundation?
Select all appropriate choices.

1. Road near my house covered with debris
2. Plants at my house died (salt burn)
3. Household furniture was damaged
4. My house was damaged
5. None
6. Other >> specify ______

H9 CYCLONE RENE DAMAGE QUESTIONS

In this section we would like to know more about how Cyclone Rene (2010) affected your house and your belongings. When answering the questions, please answer only in relation to Cyclome one Rene (2010)

28. Was this house inundated or hit by waves during the 2010 Cyclone Rene?

1. Yes
2. No } **(Go to Q. 32)**
3. Don't remember }

29. What was the damage to the foundation of your house or floor / matting due to the sea water inundation or waves from the Cyclone Rene?

1. No damage
2. Minor damage (minimal repairs needed, still usable)
3. Major damage (floor is extremely damaged and unusable)

30. Did your household lose any of the following household appliances because of the sea water inundation or waves from Cyclone Rene?
(answer all that apply)

1. Refrigerator
2. Washing machine
3. Floor coverings
4. Beds or mattress, chairs, tables, or wardrobes
5. Vehicles
6. Other >> specify ______
7. Can't remember
8. None

31. How did you pay for repairs of your house and/or replacement of items after Cyclone Rene?

1. Didn't repair/ didn't replace
2. Insurance
3. Private savings
4. Extended family
5. Charity
6. Money sent by family overseas
7. Government
8. Other >> specify ______

H10 CYCLONE Rene - OTHER EFFECTS

In this section we would like to know more about how Cyclone Rene (2010) affected the members of your household. When answering the questions, please only refer to the Cyclome Rene (2010).

32. Because of Cyclone Rene, was your water supply affected?

1. Yes
2. No **(Go to Q. 35)**
3. Don't know

33. If yes , did you use any of the following alternate sources of water because of the effect of Cyclone Rene on your water supply? Tick all reasons that apply.

1. Rainwater
2. Well
3. Tonga Water Board
4. Stored water
5. Purchased water
7. Other >> specify ______

34. Why was your water supply affected? And how long did each effect last? Tick all reasons that apply.

	Tick if applies	Duration (in days)
1. No power or fuel to pump water		
2. Rainwater tank or roof damage		
3. Seawater inundation		
4. Damage to water well		
5. Concerns over water quality		
6. Pump broken		
7. Gutter damage		
8. Other >> specify ______		

35. After the Cyclone Rene, did you or other members of your household suffer from any sickness?
Tick all reasons that apply.

1. No sickness **(Go to Q. 38)**
2. Diarrhoea
3. Respiratory infection
4. Dengue
5. High fever
6. Typhoid
7. Other >> specify ______

36. How many members of your household suffered from the sickness(es) mentioned in previous question?

people

37. **For the sicknesses mentioned above, did any member in the household seek care from the health services after Cyclone Rene ?**

1. No - did not seek care
2. Yes - public hospital
3. Yes - private doctor / clinic
4. Other >> specify ____________________

38. **After Cyclone Rene did you or any members of the household lose paid days of work?**

1. Yes
2. No **(Go to Q.41)**

39. **If yes, what was the reason for the lost days of paid work?**

1. Damage to vehicles, so could not go to work
2. Damage to road
3. Damage to work building
4. I had to clean up/repair after the cyclone
5. I had to take care of family or friend
6. I was sick
7. Other >> specify ____________________

40. **If yes, how many days of income did you or member of the household lose? (total for household)**

____________________ days lost

H11 COASTAL EROSION

The following section refers to the changes of the coast near to your household. We will need this information to analyse how the beaches are changing in Lifuka.

41. **Looking at changes, is the beach nearest to your house:**

1. Smaller than before
2. Larger than before
3. No change **(Go to Q.44)**

42. **When did the change in beach size begin?**

1. This year
2. In the last 5 years (since 2006)
3. Even before then

43. **By how much has the beach changed? (in meters)**

____________________ meters

OPEN QUESTION

44. **In your opinion, how should the coastal protection be improved?**

____

____

____

____

____

____

H12 BEACH MINING

The following section will ask you about the collection of sand, gravel, rocks for household needs

45. **Do you or members of your households collect sand, gravel or rocks from the beaches or shoreline?**

1. Yes
2. No **(Finish questionnaire)**

46. **What kind of material do you collect?**

1. Sand
2. Gravel
3. Rocks

47. **Where do you collect the material from? (please mark the corresponding letter on the map)**

	Code
Sand	**S**
Gravel	**G**
Rocks	**R**

48. **How often do you collect the aggregates?**

	Twice a week	Once a week	Once a month	Twice a year	Once a year	Once in 5 years	Once in 10 years	Once in 20-50 years
Sand								
Gravel								
Rocks								

49. **How many bags of sand do you collect on average for each trip? (No. of rice bags)**

Dispay 20kg bag of rice as indicator

	Number of rice bags
Sand	
Gravel	
Rocks	

50. **How do you use the aggregates you collect? (Tick all relevant answers)**

1. To sell
2. Around the house
3. To build seawalls
4. To reclaim land
5. General building purposes
6. Other >> specify ____________________

51. **OPEN QUESTION**

Do you have any comments on sea-level rise?

____

____

____

____

____

____

Thank you for taking the time to answer this questionnaire. We will carefully look at all the answers, and the results of the analysis will be presented to the Lifuka community at a later stage of the project.

ANNEX 2

Assessing Water Resources and Costal Innundation - Lifuka - Kingdom of Tonga

Island Code:
Team leader:
Date:

Identification											Storage										Roof			Guttering			Risks		
				Household Number		House Location (front door)		Type of building 1. house, 2 business, 3 guest house, 4.church,	Building type	Elevation of the ground floor from ground on ocean side (m)	Cement cistern			Cement tank		Tank Plastic		Tank Volume	Tank connected	Tank condition	Roof Material	Roof Condition	Fascia Board	Down pipe condition	% roof covered by gutter	Gutter Condition	% Vegetation Cover of roof	Screens present on entry points to tank	Abstraction type
Date	Team no.	Map No.	CBN	Household Number	Household Unique ID	S	W	Type of building 1. house, 2.business, 3 guest house, 4.church, 5.school, 6 Government 7.Other	a) 1 level timber walls b)1 level masonry or concrete walls c) 2 level timber walls d) 2 level masonry or concrete e) other (specify)	Elevation of the ground floor from ground on ocean side (m)	L (m)	W (m)	H (m)	D (m)	H (m)	D (m)	H (m)	m3	Y/N	a) cracked, leaking b) fair, cracked not leaking c) good not cracked not leaking	A: Metal B: Thatched C: Tile D: Other	A: poor B: fair C: good	A: none B: poor C: fair D: good	A: none B: poor C: fair D: good	A: 100% B: 75% C: 50% D: 25% E: 0%	A: none B: poor C: fair D: good	A: 100% B: 75% C: 50% D: 25% E: 0%	A: none B: poor C: fair D: good	A: Tap B: Pump C House D: Bucket E: Others

Assessing Water Resources and Costal Innundation - Lifuka - Kingdom of Tonga

Island Code:
Team leader:
Date:

Identification					Well Characteristics					Water Quality				Well water sampling					Contamination				
		Well Location		Well Owner	Age of Well	Abstraction type	Well			Casing Type	Salinity	Salinity	Temperature					Sample source				Other observed potential contamination	
Household Number	Household Name	S	E	P: private C: communal Unk: Unkown	Yrs or mths	A: Pump B: Bucket C: Other	Well Diameter m	Depth to Water m	Total Depth m	A: open well B: rock lined C: Concrete D: Other (specify)	Top mS/cm	Bottom mS/cm	°C Base	Sampled Y/N	Sample No	Coliform Result P/A	E Coliform Result P/A	A: Well B: Tap C: Other	Distance from closest septic tank/trench or pit latrine to well (m):	no. Of septic tank/trench or pit latrines within 20m	Is the well covered Y/N	A: Pigs B:Rubbish in well C: Agriculture	Potential for inflow of surface waters Y/N

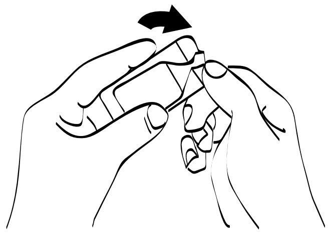
Annex 3: List of enumerators and physical surveyors

Team A		
Enumerator 1	Maliu Takai	Disaster Unit, Ministry of Works, Tongatapu
Enumerator 2	Maikolo Talanoa	Youth Leader, Hihifo, Ha‘apai
Surveyor 1	Zulfikar Begg	SPC
Surveyor 2	Takataka	
Team B		
Enumerator 1	Soana Otuafi	PMU, Ministry of Environment and Climate Change (MECC)
Enumerator 2	Poese Vi	Farmer, Lifuka, Ha‘apai
Surveyor 1	Amit Singh	SPC
Surveyor 2	Suva Havili	Farmer, Lifuka, Ha‘apai
Team C		
Enumerator 1	Geolyne Tonga	Geocare & Petroleum Consult, Tongatapu
Enumerator 2	Malakai Finau	MECC, Lifuka, Ha‘apai
Surveyor 1	Siale Vailea	Ministry of Land, Survey and Natural Resources (MLSNR)
Surveyor 2	Sinia Fainga’anuku	Weaver, Lifuka, Ha‘apai
Team D		
Enumerator 1	‘Apai Moala	MLSNR
Enumerator 2	Lusi Fonokalafi	MECC
Surveyor 1	Peter Sinclair	SPC
Surveyor 2	Alamehi Taufui	Ministry of Works, Lifuka, Ha‘apai

Colilert 18 presence / absence test

Test procedure

1. Carefully separate one Snap Pack from the strip, taking care not to accidentally open adjacent pack.
2. Tap the Snap Pack to ensure that all of the Colilert powder is in the bottom part of the pack.
3. Open one pack by snapping back the top at the score line.



Caution: Do not touch the opening of pack.

4. Add the reagent powder to the sample bottle.
5. Aseptically cap and seal the vessel.
6. Shake until the reagent powder dissolves.
7. Incubate for 24 hours at 35° ± 0.5°C. (Used Esky for incubation for this survey.)
8. Read the results at 24 hours.

Result analysis

Upon incubation, if no yellow colour is observed, the test is negative.

For samples with observed colour change:

- If the sample has a yellow colour, the presence of total coliforms is confirmed. If colour is not uniform, mix by inversion then recheck.
- If yellow is observed, check for fluorescence by placing a 6 watt 365 nm UV light within five inches (13 cm) of the sample in a dark environment, ensuring the light is facing towards the sample bottle. Fluorescence indicates presence of *E. Coli*.

Annex 5: Overview of the reticulated water supply – Tonga Water Board

A total of 68% of all households in Lifuka have access to and use piped water for domestic purposes from the Tonga Water Board (TWB).

Piped water from TWB is not available to every household in each village. Survey results indicate varying levels of access by household to TWB water by village (Figure 1). Note that Kuolo and Holopeka have water supplies piped to households from communal wells.

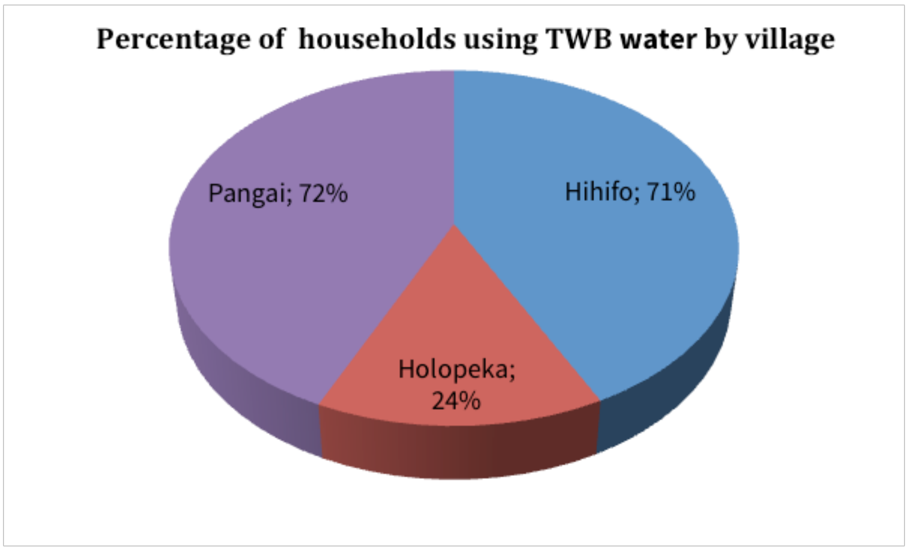


Figure 1. Percentage of households accessing TWB water by village; note that an estimated 68% of all households in Lifuka have access to TWB piped water

TWB currently abstracts groundwater from three galleries (Hihifo North rugby field, Pangai North rugby field and Hihifo East) and one well in Hihifo known as TWB4. The location of the galleries and wells are shown on the map in Figure 2.

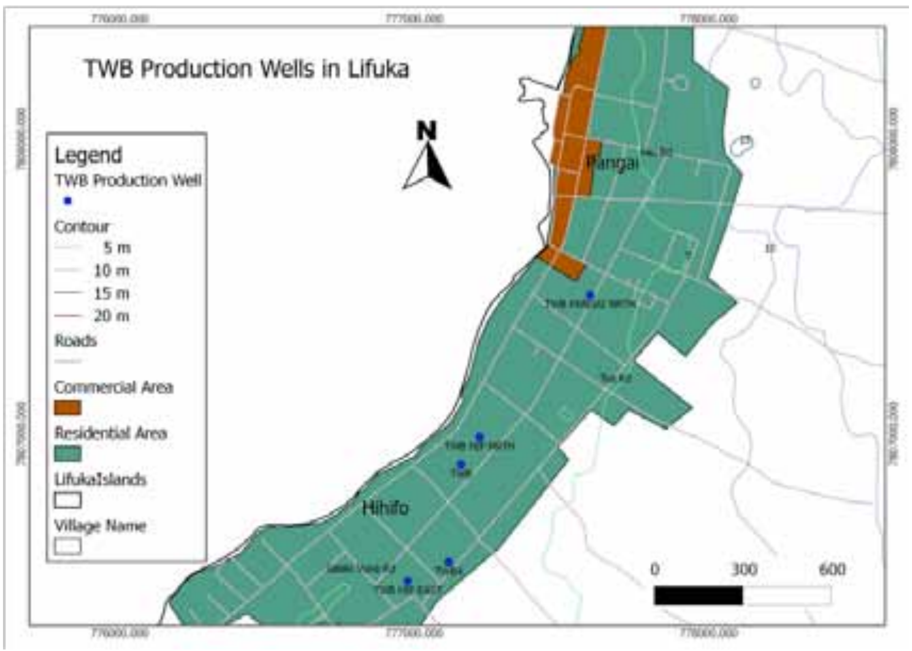


Figure 2. Map of TWB production wells on Lifuka

Tonga Water Board operation

Two of the galleries (Pangai North and Hihifo North rugby fields) were completed in 1999, and Hihifo East gallery was completed in mid-2000 (Falkland 2000). Both Pangai North and Hihifo North were constructed with two abstraction wells for each gallery, with each well originally equipped with a pump for abstraction. In each case, only one of the two pumps originally fitted is currently operational, which limits the volume of water abstracted. There is a solar pump operating at Pangai North and an electric pump operating at Hihifo North. The other pumps for these sites have been decommissioned and are awaiting replacement or refurbishment.

A diesel pump is used for abstraction from Hihifo East and an electric pump is used for abstraction at TWB4. Only one production well site, TWB4, has a working water flow meter attached for measuring abstraction. Instantaneous abstraction rates from the working meter for TWB4 have been measured at 0.46 L/sec. or an estimated 39.7 KL/day. Water-flow meters purchased under the PASAP project are to be attached to the three unmetered raw groundwater abstraction points (TWB Hif East, TWB Hif North Electric, and TWB Pangai North Solar). An additional meter was purchased and installed to measure flow from the treatment plant to the main pipeline to consumers. Information from the flow meters will allow improved abstraction management and better understanding of the relationship between abstraction rates and water quality. The flow meter attached to the outflow from the treatment plant will measure the volume of water leaving the treatment plant towards the households, helping improve water supply budgeting and assisting in leak detection.

Figure 3. TWB production well in Hihifo

The water provided from these four pumping sites is then piped to the TWB treatment plant in Hihifo, where it is stored in three 45,000 L fibreglass tanks.

Figure 4. Inside the TWB treatment plant – addition of chlorine to treat water

The standard operational procedure for water treatment on Lifuka is for 500 ml of chlorine granules to be mixed into each of the three 45,000 L raw water storage tanks every day. There are times when this procedure fails and/or treatment of the water with this volume of chlorine is insufficient, as was the case during the March 2012 water-quality sampling.

The treated water from the connected storage tanks is then pumped via the No.1 storage tank to the 20 m elevated header tank (22,000 L) which then distributes the treated water via gravity to the connected households on Lifuka. Currently, the outflow meter from the header tank is not operational and as indicated will be replaced under the PASAP project.

Operating procedures at the treatment plant (Tuitakau pers. comm., 2011) require that water quality samples be taken monthly by TWB staff from each of the operating abstraction wells, from the treatment plant, and from eight distribution points (the same households are used each time) along the distribution line to test for levels of free available chlorine (FAC). FAC should be greater than 0.6 mg/L. The samples are provided to the TWB water officer in Tongatapu to undertake the analysis. TWB staff in Tongatapu inform Lifuka TWB staff when samples do not meet FAC requirements. One improvement that could be made would be to have the FAC analysis performed by Lifuka staff. TWB staff in Tongatapu could undertake the training of the Lifuka-based TWB staff to allow them to do the FAC sampling and analysis.

Each household connected to the piped water supply has a water meter attached, with meters read monthly. TWB charges households a monthly TOP 12.70 service fee and TOP 2.11 for each m^3 of water used. The water supply can be disconnected at the household if the monthly payment plan is not maintained.

Results and analysis of household survey questionnaire

The results from the household survey were used to analyse the percentage of households that have a preference or reliance on a particular water source and are connected to the TWB water network. Those households that do not use or cannot access TWB water were excluded.

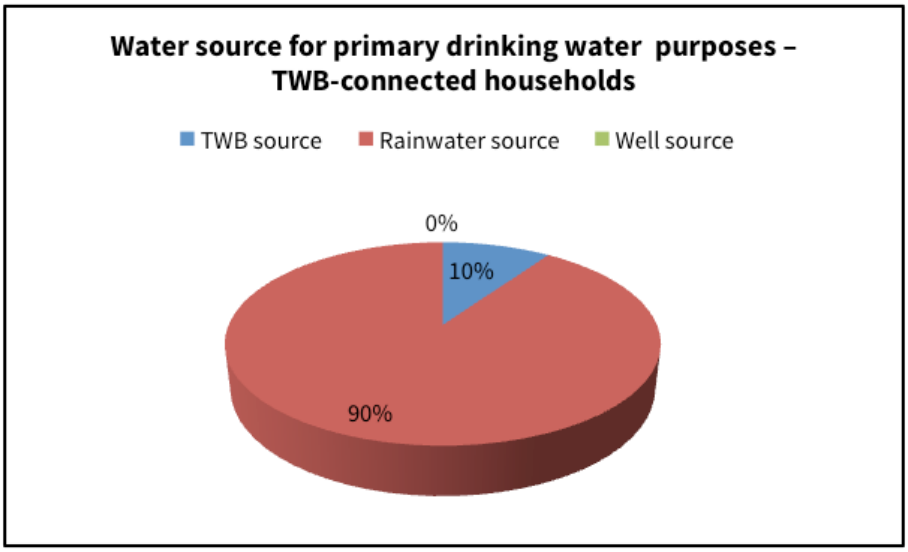


Figure 5. Reliance or preference for different water sources for primary drinking water purposes for TWB-connected households

The survey indicates despite having the option to use TWB water, 90% of TWB-connected households still prefer rainwater as their primary source of drinking water (Figure 5).

The main driver for the preference of rainwater is thought to be the taste. TWB water has greater hardness and higher salinity than rainwater and is less palatable than rainwater for most consumers. They may perceive that rainwater is a safer water source than TWB water. (Craig Airey pers. comm., March 2012).

An estimated 54% of households use TWB water for cooking, while 45% of households prefer rainwater, indicating that householders perceive that TWB water is suitable and/or convenient for cooking. Reliance on domestic well water is very low, estimated to be 1%.

In comparison, 73% of TWB-connected households use reticulated water for showering and bathing. It is suggested that pressure from the piped system is a significant factor in determining the preference for TWB water for this purpose. In general, rain tanks are not set up to provide the same pressure.

Regarding water used for washing in households with piped water, 48% relied on rainwater and 51% TWB water. Convenience of access and perceived quality are important factors determining the preferential use of TWB water over another water source by any one household. Reliance on domestic well water is very low at 2%, suggesting that the cost of TWB water was not a major consideration in the source of water used for washing. If the cost of TWB piped water were a major issue for householders, more people could be expected to have wells for domestic needs.

The survey suggests a strong preference for or reliance on piped TWB water (82%) for gardening, indicating that householders prefer to use rainwater for other purposes, including drinking, cooking and washing, and that water quality (salinity, hardness and possibly bacteriological considerations) have a role in determining a preference for one water source over another. It is interesting to note that the reliance on well water for gardening is also quite low, suggesting that TWB water is perhaps cheaper or more convenient than constructing a domestic well and equipping it with a pump.

TWB water usage

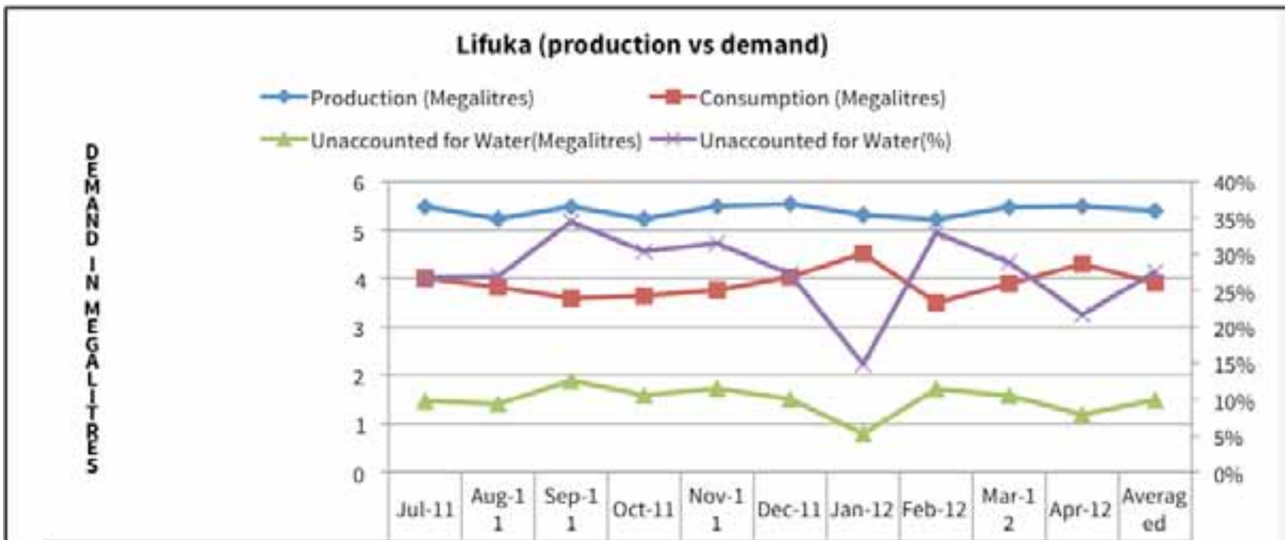
As stated above, there is currently only one operating water meter for the TWB4 well. There are no working flow meters on any other abstraction bores or galleries or at the treatment plant.

Flow meters will be provided as part of this project, making it possible to improve management and confidence in assessing abstraction volumes at any production well or gallery and the total volume of water leaving the treatment plant. The current production numbers provided by TWB Lifuka in Figure 44 also include calculated abstraction totals based on abstraction rates of the wells when the water meters were previously working, and an estimation of pumping hours (pers. comm., Quddus Fielea, August 2012).

There are, however, household meters for TWB water, which are monitored monthly. The information from these meters indicates that the metered average use for TWB water on Lifuka was 3.91 ML/month for the period July 2011 to August 2012. This suggests that for the estimated 268 households connected to TWB water, their usage of TWB water averages 14,500 L/month/household, or an estimated 477 L/day/household. Using this figure and 2011 census data indicating an average of 5.2 people per household, we can calculate an average estimated usage of 92 L/person/day for TWB water. This excludes metered consumption from businesses, churches, guest houses and schools. Bouchet (2011) has indicated that usage in Nauru was estimated to be 90–140 L/person/day, suggesting that the estimate of usage of TWB water by the households would appear to be reasonable.

Water abstraction and usage data

The usage data in Figure 6 have been provided by the TWB Lifuka office and reflects the TWB metered monthly consumption data and the calculated production and unaccounted-for water.



	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	Averaged
Production (Megalitres)	5.48	5.23	5.48	5.23	5.49	5.54	5.31	5.22	5.47	5.49	5.39
Consumption (Megalitres)	4.01	3.82	3.59	3.64	3.76	4.03	4.52	3.5	3.89	4.3	3.91
Unaccounted for Water(Megalitres)	1.47	1.41	1.89	1.59	1.73	1.51	0.79	1.72	1.58	1.19	1.49
Unaccounted for Water(%)	27%	27%	34%	30%	32%	27%	15%	33%	29%	22%	28%

Figure 6. Monthly water abstraction and usage data (Source: Tongan Water Board, 2012)

The fluctuations observed in the unaccounted-for water for January 2012 appear anomalous. It is suggested that this anomaly is an artefact of the data due to an increase in consumption measured against a relatively stable 'calculated' production volume, resulting in an apparent drop in unaccounted-for water.

The following explanation for the graph is provided from the Tonga Water Board (Quddus Fielea pers. comm., August 2012).

The increase in water usage during November and December is a combination of the following factors:

- *Increase in population due to Christmas holidays;*
- *Prolonged average to low rainfall in the months prior to November and December where there was a depletion in rainwater availability with increasing summer weather (School holidays with kids at home waste a lot of water);*
- *Lapse in the monthly reading of consumer water meters whereas Dec was shorter and Jan was an accumulation of water use (later part of Dec + Jan). Production was approximated on a monthly basis whereas the actual usage was around 40 days to cover the Christmas break;*
- *Unaccounted-for water should still be around the average of 28% if the production was adjusted to the same time-frame for the meter readings.*

Rainfall for this period is provided in Figure 7. There appears to be a lag between metered consumption and rainfall. That is, higher rainfall results in reduced usage the following month. TWB indicates that this apparent anomaly is a result of increased population and an additional period of metered usage associated with that month.

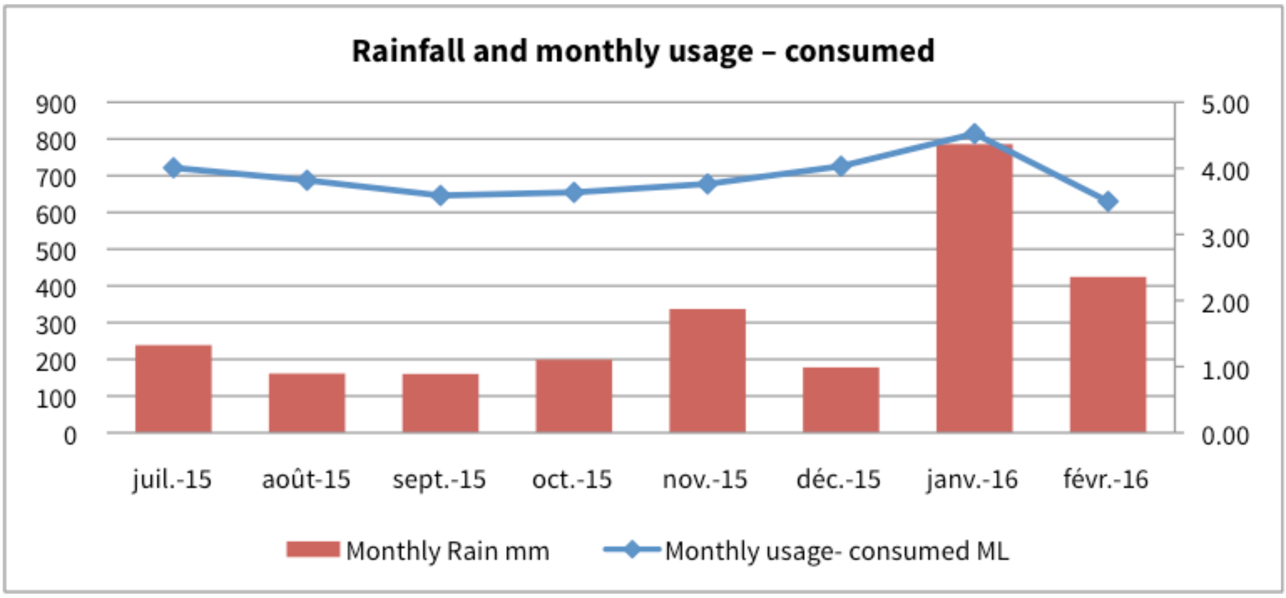


Figure 7. Rainfall and monthly metered usage – Lifuka, Ha'apai, Tonga

Summary

The survey suggests that 68% of all households have access to piped TWB water, and for metered households usage of TWB water is estimated to be 92 L/person/day.

Of the households with access to TWB water, only 10% of households relied upon this water as their primary drinking water source, while 90% of households used rainwater for drinking. By comparison, TWB water is predominantly used for gardening (82% of households) and personal bathing (73% of households), with a mostly even spread of households using rainwater and TWB water for cooking (54%) and other washing (51%).

Among households with access to TWB water, reliance on groundwater from domestic wells is very low; approximately 1% of these households rely upon domestic wells for their surveyed household needs. It should be noted that individual wells are likely to be important to specific households as a source of water, but in general, the reliance on domestic wells is small.

The reason for the relatively low use of TWB water for drinking (10% of households), cooking (54% of households) and washing (51% of households), compared with less-conveniently-accessed[1] rainwater supplies, is believed to be householders' taste preferences (salinity and hardness) and, to a lesser extent, bacteriological contamination concerns. This should be a consideration when developing strategies for improved water supply and protection of water sources in the future.

The installation of new water meters on the production bores and at the treatment plant under the PASAP project will improve the management of the abstraction and distribution of water, including identifying more accurately the volumes of unaccounted-for water.

It is recommended that TWB undertake weekly recording of the meters installed on all production bores to determine the volumes of water abstracted and daily readings on the distribution outlet line at the treatment plant.

Testing of water samples taken at the treatment plant and along the distribution line revealed all samples tested positive for bacteria, both coliforms and *E. Coli*. TWB's water treatment at the time of the survey was found to ineffective in removing these contaminants, suggesting that better enforcement of standard operating procedures or improved treatment is required.

It is recommended that regular review of operations and enforcement of standard operating procedures be undertaken to ensure that the treatment of the raw water before it leaves the plant guarantees that the water meets a minimum standard for safety when it arrives at households.

1 Rainwater is predominantly accessed by filling a bucket from a tap at the base of the tank. Water is not plumbed to the house. TWB water is piped into the house and is under pressure.

Annex 6: Assumptions used for conversion of aggregates mined into volume

Assumptions used for conversion of aggregates mined into volume

When questioned on the average amount of aggregate collected during each trip, respondents were able to provide answers in the following units: sand bags, kilograms, tonnes or trucks. Sand bags were specified to be 20-kg rice bags, while the truck was explained to be a four-tonne truck regularly used in Lifuka (Altamaha Taurus [Ministry of Works], personal communication, 21 March 2012).

This section describes the assumptions made when calculating the conversion rates between different units and cubic meters (m^3).

Volume of rice bags and densities of different aggregates were sourced from a previous technical report by SOPAC/SPC on aggregate mining in Kiribati (SOPAC 2007).

Sourcing from this publication, one 20-kg rice bag was assumed to have a volume of 0.02988 m^3 (SOPAC 2007).

The densities of different aggregates given in the same publication were:

Sand: ρ = 1046.7 kg/m^3 (SOPAC 2007)

Gravel: ρ = 848.6 kg/m^3 (SOPAC 2007)

Limestone: ρ = 1554 kg/m^3 (SOPAC 2007)

Given these assumptions we were able to calculate the conversion rates as follows.

a) Sand

Using the density of sand, the conversion between the weight of sand and its volume can be calculated by applying the formula:

Density (kg/m^3) = Mass (kg) / Volume (m^3)

Therefore, for one tonne of sand:

Volume (m^3) = Density (kg/m^3) / Mass (kg)

= 1000 (kg) / 1046.7 (kg/m^3)

= 0.95538 m^3 of sand

b) Gravel

In a similar manner, the volume equivalent of one tonne of gravel was calculated as follows:

Volume (m^3) = Density (kg/m^3) / Mass (kg)

= 1000 (kg) / 848.6 (kg/m^3)

= 1.17841 m^3 of gravel

c) Limestone

Using the same method, the volume of one tonne of limestone was calculated as follows:

Volume (m^3) = Density (kg/m^3) / Mass (kg)

= 1000 (kg) / 1554 (kg/m^3)

= 0.6435m^3 of limestone

d) General

Using the assumptions listed above, the following conversion rates were applied as well:

One truck of any aggregate = 4 m^3

One 20-kg sand bag of any aggregate = 0.02988 m^3

Using these estimates, all the answers could be converted into a single unit, the cubic meter (m^3).

Annex 7: Calculation of total aggregate demand for Lifuka

Calculation of total aggregate demand for Lifuka

Data on household aggregate mining collected during the survey were combined with census 2011 data to obtain an estimate of total annual aggregate demand on Lifuka.

The known variables were:

a) Number of households in each village – obtained from 2011 census;

b) Number of households that mine each type of aggregate, per village, for the interviewed sample;

c) Total amount of each aggregate collected, per village, for the interviewed sample.

Using this information, the percentage of households that mine aggregates was estimated as follows:

*% households mining = Households that reported mining / Households in the sample*100%*

This was repeated for each village and each aggregate separately.

In a similar manner, the average annual volume mined per household was also calculated. Again, this step was repeated for each village and each type of aggregate. The calculated estimates of average annual collection can be found in Table 15.

Average volume of aggregate mined per household annually = Total volume of aggregate mined annually / Number of households that mine

Finally, the estimate of the total annual volume of aggregate mined on Lifuka was extrapolated by multiplying the average annual volume of aggregate mined by the percentage of households that mined, and multiplying that by the total number of households in each village. Again, village-specific and aggregate-specific estimates were used in the calculations.

*Total annual aggregate mined = Average volume of aggregate mined per household * Percentage of households that mine * Number of households in each village*

Field maps were created from rectified 2011 satellite imagery. These maps included a map number and census block number (CBN) and were used to identify and locate households and wells. (Refer to Annex 13.)

Houses in each CBN were allocated a unique identification number corresponding to the map number, CBN number and house number, e.g. map number 13, CBN 1040, and household number 38 would have the unique ID 13104038. The house numbers used correlate in most cases with the census block listing provided by the Tonga Statistics Department. An example of a marked up field map showing the household numbering is provided as Annex 14.

The survey was conducted with six survey teams each consisting of two Tongan speaking enumerators, and two physical surveyors from 21 to 29 March 2012.

The physical survey sheets for each household collected information on rainwater harvesting and groundwater well assets and features. Each of the survey sheets was divided into parts, including identification, asset characteristics and condition, water quality risks and sampling of wells. A sample of the field survey data collected and a definition of the parameters collected for both rainwater harvesting and groundwater follows.

Rainwater harvesting survey parameters

At each household with rainwater harvesting infrastructure, information on the following parameters was recorded.

Identification of storage tanks

The house or roof to which the storage tank and rainwater harvesting infrastructure was attached was recorded, including census block number, household number, GPS location, building type and building elevation on the ocean side. This information correlated to the household questionnaire.

Storage tank characteristics

Tank volume

The dimensions of each tank and cistern were recorded to enable the calculation of the tank volume.

Tank condition

A visual assessment of the tank condition at the time of the survey was recorded. *Good* refers to storage tanks that are neither cracked nor leaking. *Fair* refers storage tanks whose walls have visible external cracks, but which were not leaking at the time of the survey. *Cracked* refers to tanks that are have extensive visible cracks on the tank wall or were leaking at the time of the survey.

Tank connection

The existence of a connection to the tank with a functioning downpipe from the catchment was recorded as either yes or no.

Roof type and conditions

Type of roof material

Roof material was recorded as *metal, thatched, tile* and *other. Metal* refers to a roof made from corrugated iron, tin or aluminium. A *thatched* roof *refers* to use of vegetation such as coconut, pandanus, or other natural non-permanent roofing material. A *tiled* roof refers to use of tiles as a roofing material. *Other* refers to the use of other materials.

Figure 1. A metal roof (left) and a thatched roof (right)

Roof conditions

A visual assessment of the roof condition was made based on observation. Where the roof was poorly constructed, or there was significant rusting and it was observed that holes had started to appear, or temporary patches were observed, the roof was considered to be in *poor* condition. Where the roof was observed to have significant rusting and appeared relatively old, but no holes were observed, the roof was considered to be in *fair* condition. If the roof appeared to be well constructed and materials were relatively new and no holes or significant rusting could be observed, the roof was in *good* condition.

Figure 2. A rusted roof (top) and one in good condition

Fascia board

An assessment of the condition of the fascia board to which the guttering normally attaches was made for each house. If no fascia board was present, *none* was recorded. If the fascia board was present but rotted or not properly affixed and therefore not suitable for attaching guttering, and in most cases where a replacement fascia board would be recommended, *poor* was recorded. If the fascia board was in reasonable condition, of suitable material, and appeared functional for the purposes of attaching guttering, *fair* condition was recorded. If the fascia was relatively new, well maintained with only minor signs of wear, if any, and of suitable material, *good* condition was recorded.

Downpipe condition

None was recorded where no downpipe connected the gutter to the tank. If the downpipe connecting the tank was makeshift or where it was clear significant losses in transmission of water from the gutter to the tank would occur, requiring replacement or significant maintenance, *poor* was recorded. Where the downpipe was of suitable material and sizing, but where it was observed that minor losses could result, or where minor maintenance may be required, the downpipe condition was considered to be *fair.* Where the downpipe was relatively new, of suitable material and sizing, properly constructed and fitted, and no leaks or losses were expected, the downpipe condition was considered *good.*

Percentage of roof catchment covered by guttering

The percentage of roof catchment area covered by guttering was recorded in terms of gutter coverage percentage. This reflects the maximum percentage of water that could be captured from the roof. The option *100% of roof covered by guttering* refers to situations where the total roof catchment area has guttering attached. The other options were *75%*, *50%* and *25%*. Where there is no guttering present on the house, *0%* was recorded.

Gutter conditions

A visual assessment of the condition of gutters was undertaken. *None* refers to situations where no gutters are present. *Poor condition* refers to gutters that may be improperly fitted, are broken, have holes or sections missing, have evidence of significant overtopping and sagging, are generally thought to require replacement, or are not able to transmit water from the roof to the downpipe efficiently or without significant water loss. *Fair condition* refers to guttering where there evidence of some sagging or overtopping, but that could be returned to good condition with minor maintenance. *Good condition* refers to gutters that are securely affixed to fascia boarding, have the correct fall, are constructed of suitable material, have proper sizing, are without sagging or evidence of overtopping, and are able to transmit water efficiently and with minimal loss from the roof catchment to the downpipe.

Contamination risk

An assessment of the factors which could increase the risk of contamination was recorded and included the following.

Vegetation cover of the roof

The vegetation overhang was recorded in terms percentage of roof covered by vegetation, where overhanging vegetation meant that organic matter would enter the gutter, increasing the risk of rusting and gutter failure, and the introduction of organic matter into the tank. Vegetation is a conduit for birds and animals to access the roof and introduce faecal contamination. If the roof was completely covered by vegetation, *100%* was selected. The other options were *75%, 50%, 25%,* and *0%* vegetation cover.

Screens at the entry points of the tanks

The presence of functioning screens on entry points to tanks can reduce the potential ingress of foreign material or mosquitoes. *None* means no screens are present on tank entry points. *Poor* means screens are present, but are improperly affixed or damaged so that they are ineffective and require replacement. *Fair condition* refers to screens that appear mostly functional but that may require some maintenance to ensure that they function efficiently. *Good condition* refers to screens that are securely affixed to tank entry points, are in good condition without holes, and that appear to be working efficiently.

Abstraction type

The abstraction method was recorded, as some methods may present a risk of contamination potential if they allow exposure to external hazards, such as being accessible to animals. *Tap* refers to the abstraction of stored rainwater through a tap located at or near the base of the tank. *Pump* refers to use of pump and pipes to supply water to the household and household appliances. *House* refers to the abstraction of rainwater from storage tank and cisterns, where it is piped to the house and household appliances. *Bucket* refers to use of a bucket to abstract water from the top of storage tanks and cisterns.

Figure 3. A good rainwater harvesting system (top) and a poor rainwater harvesting system

Groundwater survey parameters

Well feature measurements

The well diameter, depth to water and total depth of the wells were recorded using 8 m measuring tapes. Most of the wells on Lifuka are cylindrical and their diameter was measured from the inside wall of the well. The depth to water was recorded from the top of the well to the water surface and the total depth was recorded from the top of the well measuring point (top of the raised wall) to the bottom of the well.

In some cases, measurements could not be recorded for one of the following reasons:

- The well was securely covered;
- The well was inaccessible (e.g. covered by vegetation);
- The well was filled with rubbish.

At each well located, information on the following parameters was recorded.

Identification of wells

A unique identification code was generated for each well located with the following information: census block number, household number, GPS location, and well ownership type.

GPS locations of wells and households were logged using the Garmin GPS 76. For wells the GPS locations were taken over the well. Household locations were taken at the front door of each house and a photograph of the house was taken for incorporation in the GIS database. Each morning a GPS screen shot was taken and the cameras were synchronised with time and GPS track points for incorporation into the GIS database.

Well characteristics

Information collected on physical attributes of the privately-owned wells includes abstraction type, diameter, depth to water, total depth and casing type.

Abstraction type

- *Pump*: A pressure pump or alternate style pump is attached to the well for abstraction purposes.
- *Bucket*: A bucket of some sort (normally a 4 L tin can) is used to abstract well water.
- *Other*: An alternate type of abstraction, such as hand pump or windmill pump is used.

Diameter: Minimum distance (m) across the well taken from the inside of the casing, that is, diameter for circular casing or shortest side for rectangular casing.

Depth to water: The measured distance from the top of the casing or measuring point to the top of the standing water (m).

Total depth: The measured distance from the top of the casing or measuring point to the bottom of the well (m).

Casing type

- *Open well:* Well is constructed without any casing protection or lining. It can be regarded as a hole in the ground.
- *Rock lined:* Well is constructed with rock or coral to reduce the likelihood of the well collapsing.
- *Concrete casing:* Concrete is used to seal off the well and protect it from collapsing.
- *Other:* Includes any other sort of casing not fitting the above criteria, which may include steel or plastic casing.

Salinity measurements

Salinity was recorded in the field using a TPS WP 84 salinity meter with a five-metre cable. The salinity measurements were taken at the surface of the well water and 0.1 m from the base of the well. Before fieldwork each morning, the TPS conductivity meters were calibrated to ensure reliable and consistent results.

Bacteriological sampling

A presence and absence test was undertaken, and the results for the presence or absence of coliform and *E. Coli* bacteria using IDEXX Colilert 18 were recorded. The results were recorded as:

- *P* for presences of *E. Coli* and coliform; and
- *A* for absence of *E. Coli* and coliform.

Water quality sampling methodology and analysis

Well water was sampled for presence and absence of *E. Coli* and total coliform. The Colilert 18 method was used to test for presence and absence *E. Coli* and total coliform in well water samples. Members of each team were trained on sampling procedures as follows.

In the field, well water was abstracted directly from the well following normal sampling protocol (Annex 11):

- Bottle is rinsed three times before sampling and sterile sampling bottles are carefully filled.
- Sample ID, household number and time are recorded.

After the fieldwork in a controlled environment, the samples were then processed following the IDEXX protocol, involving the addition of addition of reagents and labelling (Annex 4).

In the absence of an incubator, the samples were transferred to an ice chest for the incubation period. Standard procedure requires the use of an incubator to keep the samples at a constant temperature of 35˚ ± 0.5˚C. As this was not available, and after testing by SPC under controlled conditions, an ice chest was used where conditions of 29˚–35˚C could be maintained for the period of incubation. During the fieldwork, temperatures in the ice chest were monitored with the use of a clinical thermometer, and temperatures of 34˚ ± 1˚C were recorded. The methodology was considered acceptable for the purposes of testing for presence and absence of *E. Coli* and coliform. As a form of quality control, each incubation batch contained a control sample of sterile water to ensure confidence in the field laboratory procedures.

The samples were incubated for a minimum of 20 hours before results were recorded. When total coliforms metabolise Colilert-18's nutrient indicator, the sample turns yellow, indicating a positive result for presence of coliform. When *E. Coli* metabolise Colilert-18's nutrient indicator, the sample fluoresces when exposed to UV light, indicating presence of *E. Coli*.

Well status

Well status was categorised as follows:

- *Abandoned* if the state of the well clearly makes it unusable or inaccessible (e.g. if it is filled with rubbish or completely covered by vegetation).

- *Unused if* householders have not used the well recently, but the well is still accessible and could be used if required.

Well contamination risk

The risk potential of well contamination was identified using the following parameters:

- Measurement of the distance from the well to the closest septic tank, soak away or pit latrine (m).

- Well covering at time of the survey was also recorded.

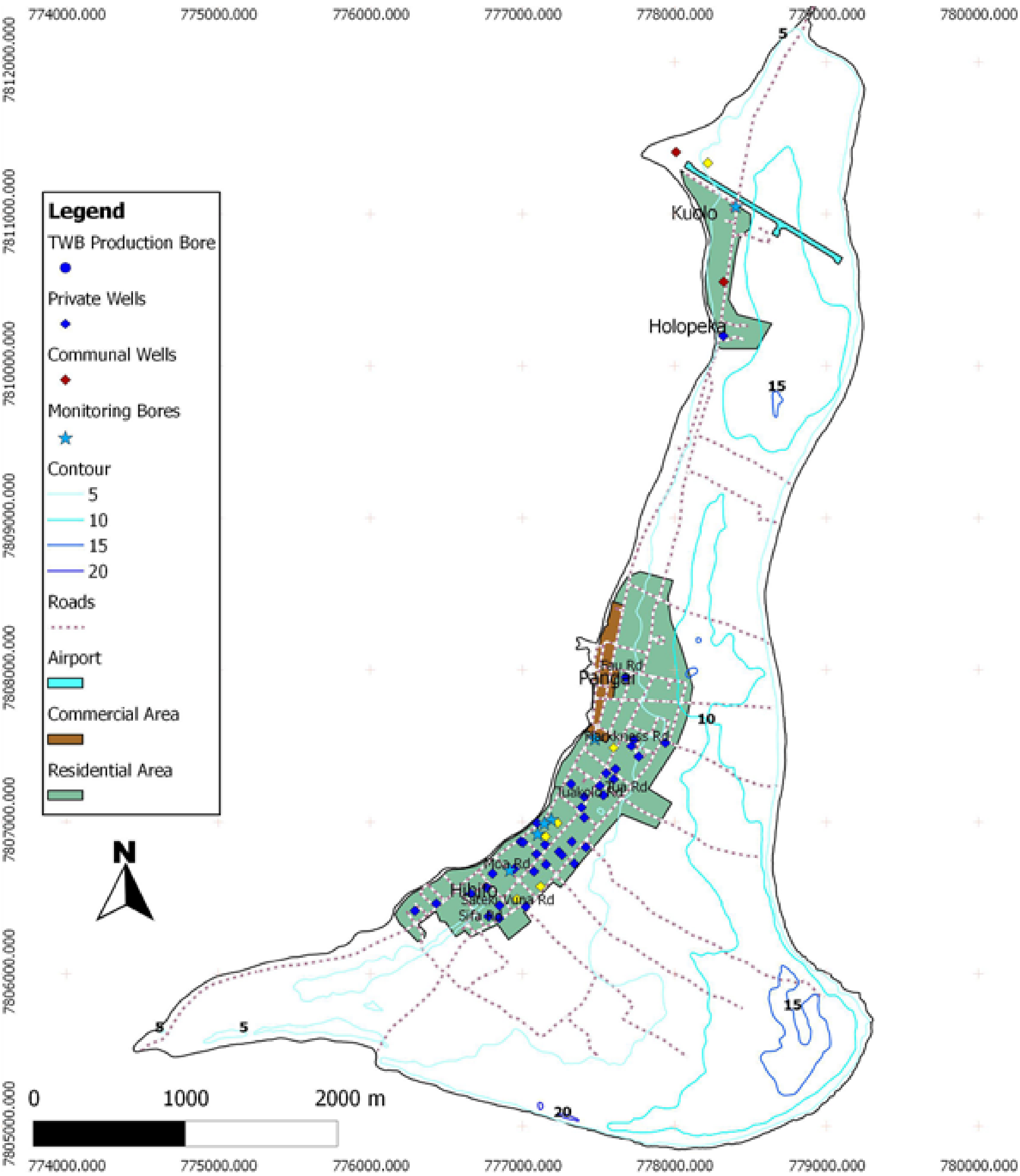
    - *Uncovered:* There is no cover over the well, or the cover is poorly fitted or not being used.

    - *Covered:* A cover is properly fitted and is heavy enough to not be easily removed by children or animals, and does not allow any outside material to easily enter the well.

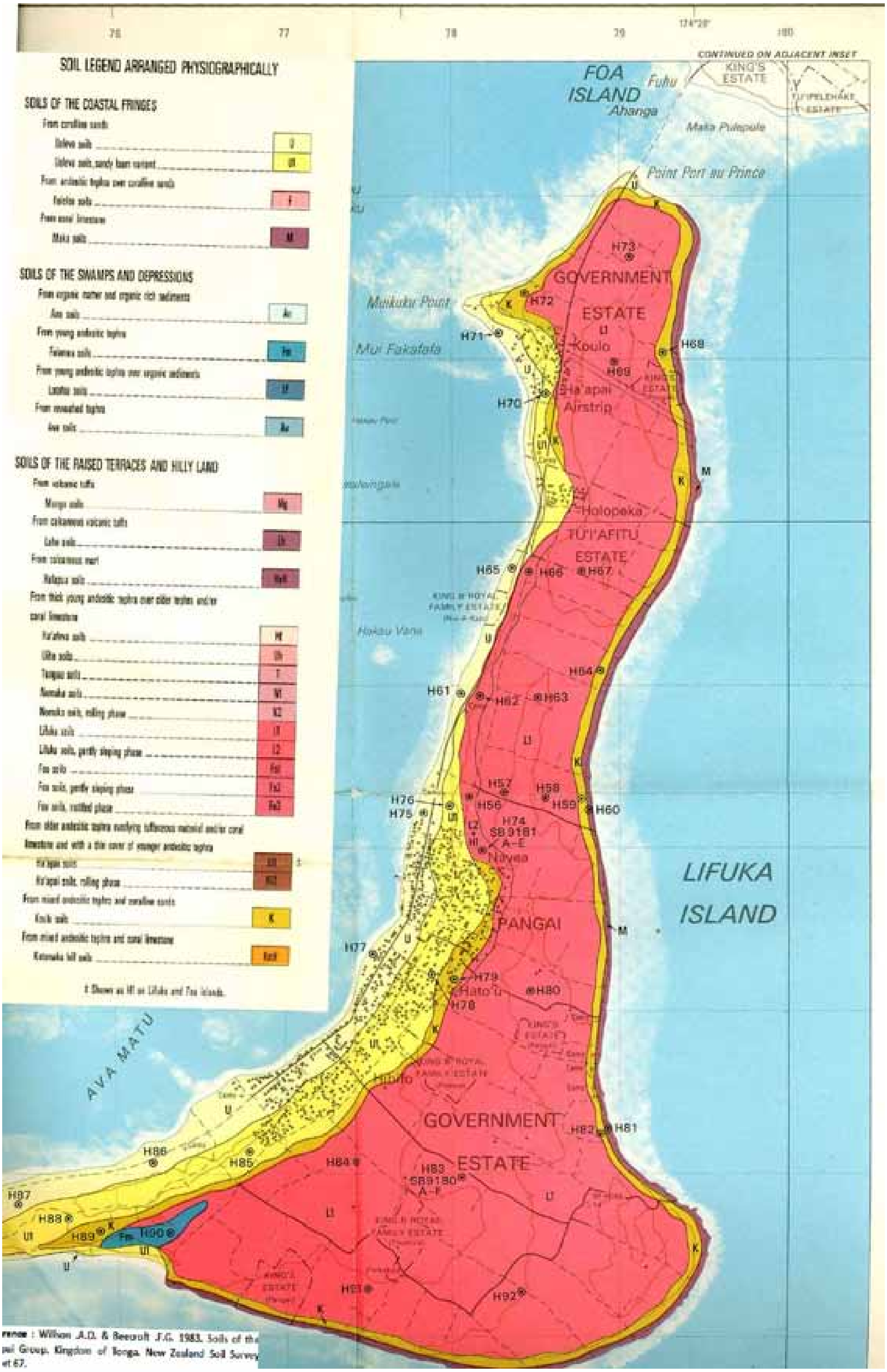
- Observations regarding access to the immediate well area by animals, the presence of rubbish, and nearby agriculture were recorded.

- The potential for inflow of surface water into the well was also recorded.

Annex 9: Location and type of wells in Lifuka



Annex 10: Soil map of Lifuka



Water sample collection – standard operating procedure

Sampling from well

1. Wash hands and dry with clean tissue.
2. Label the sample bottle appropriately: date, time, household number and census block number.
3. Abstract well water with use of clean abstracting bucket/tin can, ensuring that it does not touch the walls of the well.
4. Take sample from at least a depth of 30–40 cm.
5. Rinse the abstracting device with well water three times before taking the sample and transferring it to the sampling bottle.
6. With clean hands, carefully remove the cap of the sampling bottle and fill it with 100 ml of sample.
7. Strongly shake the sample to dissolve the sodium thiosulphate in the sample bottle. Securely close the bottle the by screwing the cap back onto the bottle.
8. Collect water in the bucket, which has been rinsed three times with sample water.
9. Record salinity measurement and temperature.
10. Record any other relevant comments on the groundwater physical sheet.

Sampling from tap

1. Remove any attachments from the tap.
2. Open the tap and flush the system for at least a minute.
3. Wash hands and dry with tissue.
4. Label the sample bottle appropriately: date, time, household number and census block number.
5. With clean hands, carefully remove the cap of the sampling bottle and fill it with 100 ml of tap water. Securely close the bottle by screwing the cap back onto the sampling bottle.
6. Strongly shake the sample to dissolve the sodium thiosulphate in the sample bottle.
7. Collect water in the bucket, which has been rinsed three times with sample water.
8. Record salinity measurement and temperature.
9. Record any other relevant comments on the physical sheet.

Annex 12: Water quality presence and absence sheet

Assessing water resources and coastal inundation – Lifuka, Tonga
Sample collection and analytical record: total coliform and *E. Coli* by Colilert-18 presence/absence method

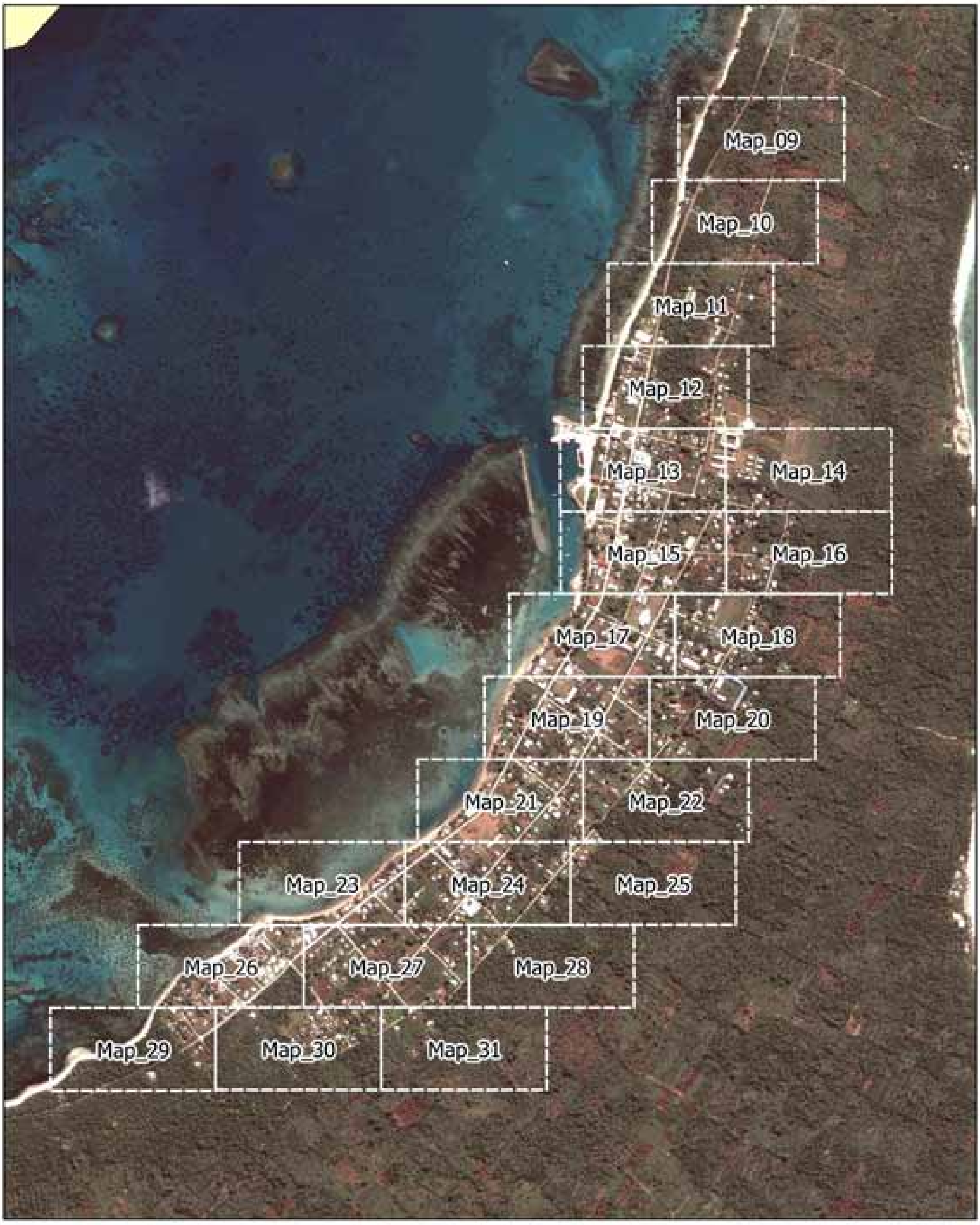
Sample collection record					**Incubation (35°± 0.5°C)**				**Results for presence/absence**	
					Start		End (18 hrs)		**Total coliform**	***E. Coli***
Sample #	Location/household name (map no.)	Type	Date	Time	Date	Time	Date	Time	Presence/absence	Presence/absence

Sampler: ______________________ Lab analyst: ________________________ Expected read-out date/time: ________________________

* After adding Colilert and shaking, is Colisure completely dissolved? (Y/N) ______

Colilert media: Lot #: ______________ Expiration date: __________________ Date approved by Lab Manager: __________ Signature: ________

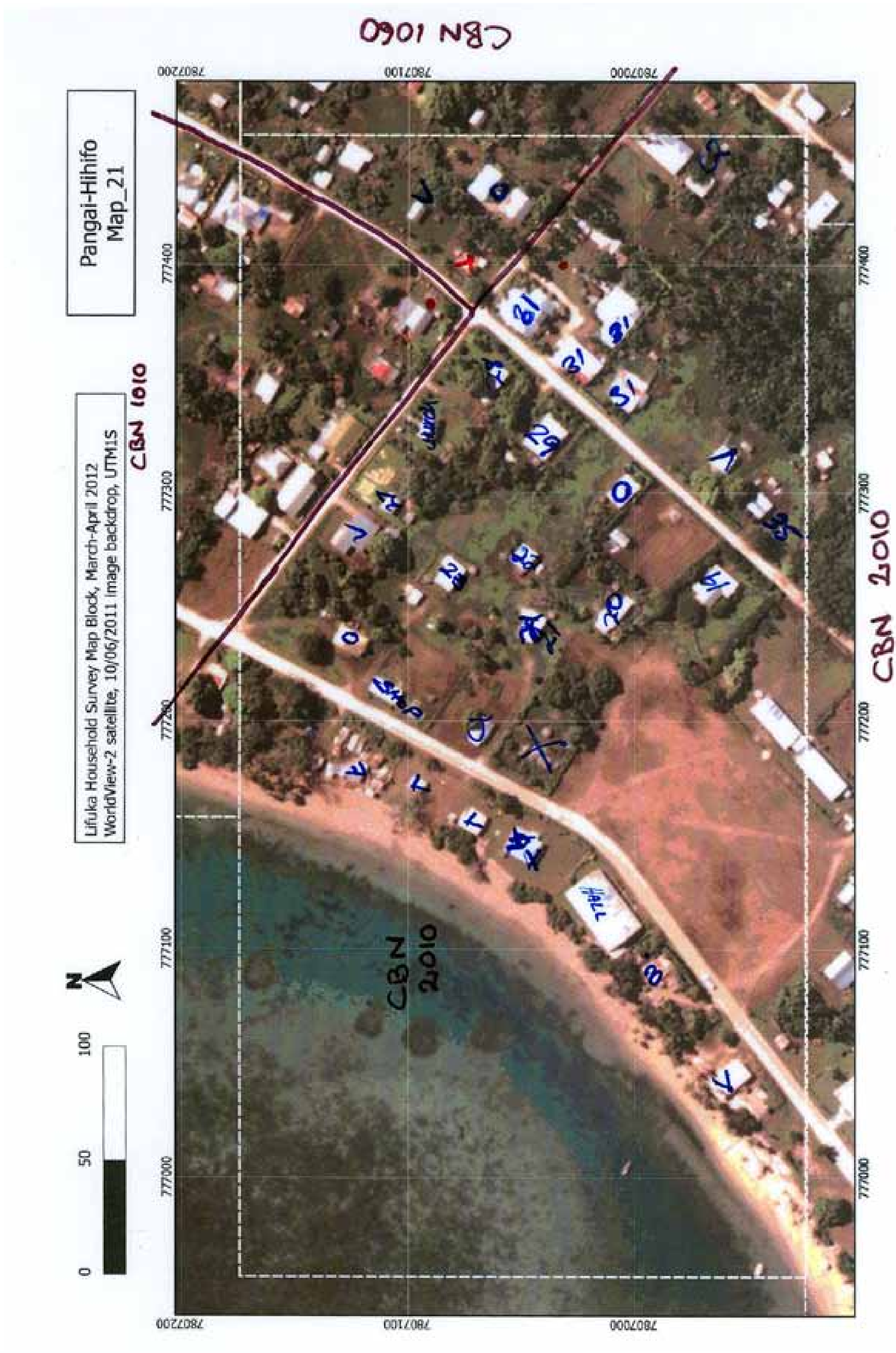
Annex 13: Field map



Lifuka household survey, March-April 2012
Pangai-Hihifo A4 survey map blocks overview

0 500 1000

Annex 14: Marked map



1. Map of Tonga

Figure 1: Map of Tonga (Source: CIA website)

2. Water resource assessment photographs

Figure 2. Connected cement cistern

Figure 3. Connected cement tank

Figure 4. Connected plastic tank

Figure 5. Connected fibreglass tank

3. Tonga Water Board production wells

Figure 6. Hihifo North production well

Figure 7. Hihifo South production well

Figure 8. TWB4 production well

Figure 9. TWB production well in Hihifo

Figure 10. TWB treatment plant

4. Coastal inundation photos – Tropical Cyclone Jasmine, February 2012

Figure 11. Sea wall in front of Lifuka Hospital

Figure 12. Sea wall in front of Lifuka Hospital

Figure 13. Road in Lifuka affected by coastal erosion following TC Jasmine

Figure 14. Damage to coastline after TC Jasmine

Figure 15. Damage to a house on the coastline following TC Jasmine

Figure 16. Inundated house following TC Jasmine

Figure 17. Marks of inundation by ocean waves

Figure 18. Inundated coastline

Figure 19. Wharf

Figure 20. Causeway following TC Jasmine

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