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PACC Demonstration Guide: Improving resilience of the water supply for Hihifo District, Tonga

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PACC Demonstration Guide: Improving resilience of the water supply for Hihifo District, Tonga

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This report is an output of the Tonga PACC project. It was written by Quddus Fielea, and reviewed by Paula Taufa (Tonga PACC Project Coordinator), Paul Maoate (Cook Islands PACC Project Coordinator), Peniamina Leavai (SPREP), Netatua Pelesikoti (SPREP) and Damien Sweeney and Martin Pritchard (Pacific Research and Evaluations Associates).

EXECUTIVE SUMMARY

The Pacific Adaptation to Climate Change (PACC) project in Tonga focuses on water resources management, and specifically on improving the water supply system in Hihifo District, Tongatapu. Adaptation measures demonstrated by the project include upgrading water infrastructure to improve water collection and storage, increasing the options for sourcing and distributing water, and improving water quality. The project worked with the six villages of Fo'ui, Ha'avakatolo, Kolovai, 'Ahau, Kanokupolu, and Ha'atafu.

Prior to the PACC project, Hihifo District had a public water supply system drawing on the groundwater. The system had shown a high level of unreliability and poor water quality for a number of years. The people of Hihifo used the piped water mainly for cleaning and flushing toilets, because of high salinity. Most used rainwater for drinking, although not every household had rainwater harvesting equipment, and many had to collect water from other houses or community buildings.

The early analysis stage of the project included a socio-economic assessment (SEA) in the Hihifo community, community consultations, and a water resource and supply assessment. These helped to clarify the decision to build a new water supply system that is resilient to current climate variability and future climate change. The technical design had a timeframe of 30 years.

Construction began in early 2011 and the new water system was completed in April 2014. This included the installation of three 45,000 litre water tanks, an overhead tank holding 22,500 litres, and 30 smaller household tanks that hold 10,000 litres each, which were distributed to selected households in the six villages. New monitoring and production boreholes were drilled, pipelines laid, water meters installed for each household, and solar powered pumps were installed (with back-up diesel pumps).

As a community-based adaptation project, the involvement of the Hihifo Village Water Committee (HVWC) in all stages of the project was crucial. A communications strategy guided community engagement, and involvement and ownership of the project activities. These included a quarterly project progress report and meetings with the HVWC, community workshops and community participation in project implementation.

After the water system improvements were completed, the project held a lessons learned workshop for the stakeholders to find out what had worked and what could be done better or differently next time. The workshop provided very useful feedback to the project team, and is a recommended best practice for future similar projects.

The use of renewable energy for pumping (solar pumps) to lower operating costs, decrease dependency on carbon-producing fossil fuel and minimise pollution of groundwater is also recommended as a best practice.

The Tonga PACC team has been central to the development of the National Water Policy and the integration of climate change into the National Water Resources Management Bill, prepared in 2006.

Following successful implementation of the project in Hihifo, Tonga was given additional funding in the next phase of PACC (called PACC+) for coastal zone management adaptation intervention. At the time of writing (November 2014), the PACC team had undertaken assessments including a coastal vulnerability and adaptation assessment, socio-economic assessment and environmental impact assessment.

ABBREVIATIONS

DMA	Demand management area
EC	Electrical conductivity
EEZ	Exclusive economic zone
ENSO	El Niño Southern Oscillation
HLT	High level tank (elevated water storage on a tank stand)
HPWC	Hihifo–PACC Water Committee
HVWC	Hihifo Village Water Committee
JNAP	Joint National Action Plan for Disaster Risk Management and Adaptation to Climate Change
LLT	Low level tank
MAFFF	Ministry of Agriculture, Forestry, Food and Fisheries
MLECCNR	Ministry of Lands, Environment, Climate Change and Natural Resources
mS/cm	microsiemens per centimetre (measure of electrical conductivity or salinity)
NGO	Non-governmental organisation (also called civil society organisation)
PACC	Pacific Adaptation to Climate Change (programme/project)
PACCSAP	Pacific–Australia Climate Change Science and Adaptation Planning Program
PCCSP	Pacific Climate Change Science Program
PMU	Project Management Unit
SEA	Socio-economic assessment
SPREP	Secretariat of the Pacific Regional Environment Programme
TMS	Tonga Meteorological Service
TSDF	Tonga Strategic Development Framework
TWB	Tonga Water Board
TWG	Technical Working Group

1. INTRODUCTION

The Pacific Adaptation to Climate Change (PACC) programme is the largest climate change adaptation initiative in the Pacific region, with activities in 14 countries and territories. PACC is building a coordinated and integrated approach to the climate change challenge through three main areas of activity: practical demonstrations of adaptation measures; driving the mainstreaming of climate risks into national development planning and activities; and sharing knowledge in order to build adaptive capacity. The goal of the programme is to reduce vulnerability and to increase adaptive capacity to the adverse effects of climate change in three key climate sensitive development sectors: coastal zone management, food security and food production, and water resources management. The programme began in 2009 and is scheduled to end in December 2014.

In Tonga, the PACC project is building resilient water supply systems in the district of Hihifo on Tongatapu. Adaptation measures demonstrated by the project include upgrading water infrastructure to improve water capture and storage, increasing the options for sourcing and distributing water, and improving water quality.

This report describes the process of planning and developing the project, through design and implementation, to monitoring and evaluation. It includes an important section on lessons learned and recommended best practices, with the hope that these will be useful to future climate change adaptation and/or water resources projects in the Pacific. The guide is mainly directed at government agencies, local non-governmental organisations (NGOs), regional organisations and donor agencies interested in developing similar projects in other parts of Tonga, or other Pacific island countries.

2. BACKGROUND AND CONTEXT

2.1. The Kingdom of Tonga

2.1.1. Geography and demographics

The Kingdom of Tonga consists of over 175 named islands spread between latitudes 15° and 23°30″ south and longitudes 173° and 177° west in the South Pacific Ocean (Figure 1). The total land area is 747 km^2 while the sea area extends over about 397,000 km^2. The population of approximately 106,000 lives on 43 of the islands with a total land area of 649 km^2. Tongatapu is the most populous island, with population of 75,416 (2011 census). By 2030, this is projected to increase by 19%, to just over 90,000.

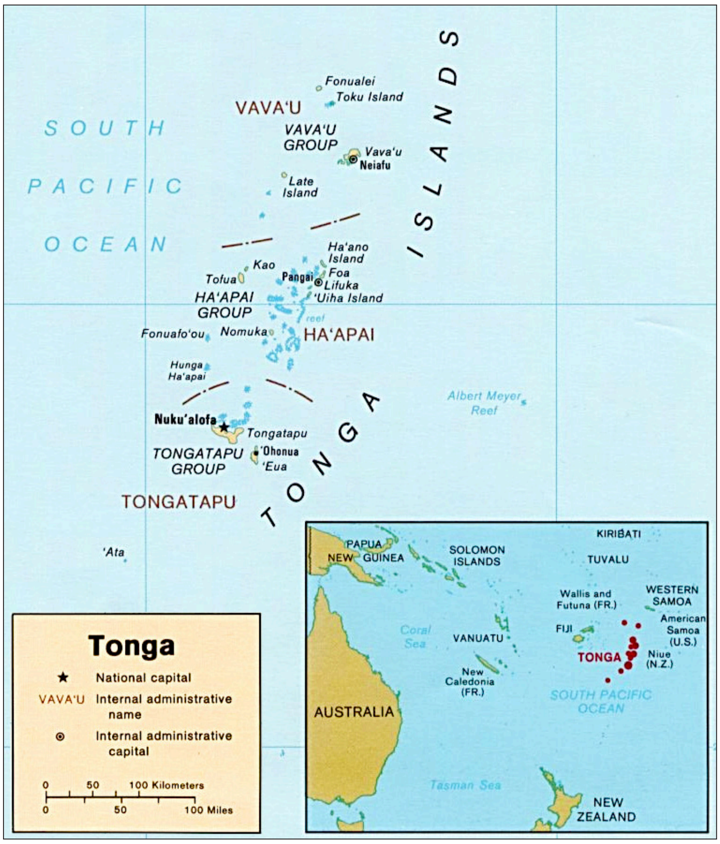

Figure 1. Map of Tonga. (Source: Wikimedia Commons.)

2.1.2. Socio-cultural background

Tongan society has been ruled by a monarchy since the 10th century AD. The King is at the top of the social pyramid, with nobles in the middle and often the highest rank in their village and estate. Commoners are at the bottom of the social pyramid. This structure has remained mostly unchanged through the centuries, except for the recent emergence of a new elite class of educated and business people, earning the same social status and privileges as nobles.

The establishment of the Constitution in 1875 was a landmark change for commoners as it gave them the rights to own and inherit land. The Constitution also formally established traditional chiefs as estate owners and they were expected to grant land from their estate to their subjects for dwelling and farming purposes. In return, commoners were expected to use their land productively to fulfil their obligations.

2.2. The demonstration site: Hihifo District

2.2.1. Geography and environment

The Hihifo District, which is located in the northwestern end of Tongatapu Island, has six villages; from the south these are Fo'ui, Ha'avakatolo, Kolovai, 'Ahau, Kanokupolu, and Ha'atafu (Figure 2).

The maximum height above sea level in Hihifo is 22 m. The villages are mostly situated at elevation between 0.5 m and 6 m, and therefore particularly vulnerable to the impacts of sea level rise.

Most of the islands of Tonga have a soil layer overlying coral limestone. The soils are mainly derived from andesitic tephra (volcanic ash). Other soils include coral sands and lagoon sands and mud.

Vegetation in the Hihifo District includes a variety of root crops, fruit trees such as mangoes, tava, and a variety of citrus, and native vegetables and grasses. In the settled areas of the District, much of the native vegetation has been cleared for coconut plantations, home gardens, villages, and commercial crops.

Figure 2. The Hihifo District of Tongatapu. (Source: Google Maps.)

2.2.2. Demographics and socio-economic situation

The total population of the six villages, according to a national census in 2006, is 2,353: 1,163 males and 1,190 females. The Hihifo PACC villages can be grouped according to the size of village population and number of households as follows:

- Two big villages, Kolovai and Fo'ui, each with a population of over 500, and combined population of 1,191 in 208 households.
- Two medium villages, 'Ahau and Kanokupolu, each with a population of slightly over 350 and over 50 households (combined population: 691; 110 households).
- Two small villages, Ha'atafu (38 households) and Ha'avakatolo (44 households), each with a population of slightly over 230.

The heads of households in the six villages are predominantly male. The percentage of heads that were female, for the six villages combined, was 19% (PACC, 2014a).

Sources of household income are mostly wages and salaries (50% of households). Nearly 30% of all income is derived from the household's own agricultural production activities, including women's craft productions. A high percentage of households also received overseas remittances (PACC, 2014a).

2.2.3. Water supply

Prior to the PACC project, Hihifo District had a public water supply system drawing on the groundwater. The system had shown a high level of unreliability and poor water quality for a number of years.

The public water system was operated by the Hihifo Village Water Committee (HWVC) under the jurisdiction of the Ministry of Health. Groundwater was pumped from a number of dug and drilled wells on the south-eastern margin of the district. Pumps on the dug wells were commissioned in the early 1960s, while pumps on selected drilled bores were commissioned in the 1990s. Water was pumped to consumer connections via a 100 mm PVC pipeline and an older 80 mm asbestos cement pipeline. No water storage was used in the system. The numbers and layout of consumer connections supplied from these two pipelines was not known.

Water from the public water supply system was used primarily for flushing toilets, cleaning the house, cooking and watering animals (PACC, 2014a). High salinity of the water was the main reason for its limited use.

In addition to the public water supply system, many houses had rainwater tanks. Based on a 2011 socio-economic study (PACC, 2014a), it was estimated that about 90% of households had rainwater collection systems. A recent Australian Government funded project provided further rainwater tanks and some houses had two tanks.

Rainwater was used by many households for most purposes during rainy periods, but in dry periods the use of rainwater contracted to drinking, cooking and sometimes washing (PACC, 2014a).

More information on the water supply system in Hihifo before the PACC project can be found in the Design Report, published as PACC Technical Report No. 7 (PACC, 2014b), and Section 3.3.2 below.

2.3. Climate

Climate information is derived from the Pacific Climate Change Science Program (PCCSP) (Australian Bureau of Meteorology and CSIRO, 2011) and the Pacific–Australia Climate Change Science and Adaptation Planning Program (PACCSAP) (Australian Bureau of Meteorology and CSIRO, 2014).

2.3.1. Observed trends

Tonga has a semi-tropical climate with moderate rainfall and high relative humidity. A seasonal trend is noticed with a relatively wet season extending from November to April and a relatively dry season from May to October. On average, approximately two-thirds of the annual rainfall falls during the wet season. Temperature varies throughout the year from a minimum of 17°C to a maximum of 30.1°C in Tongatapu (Figure 3).

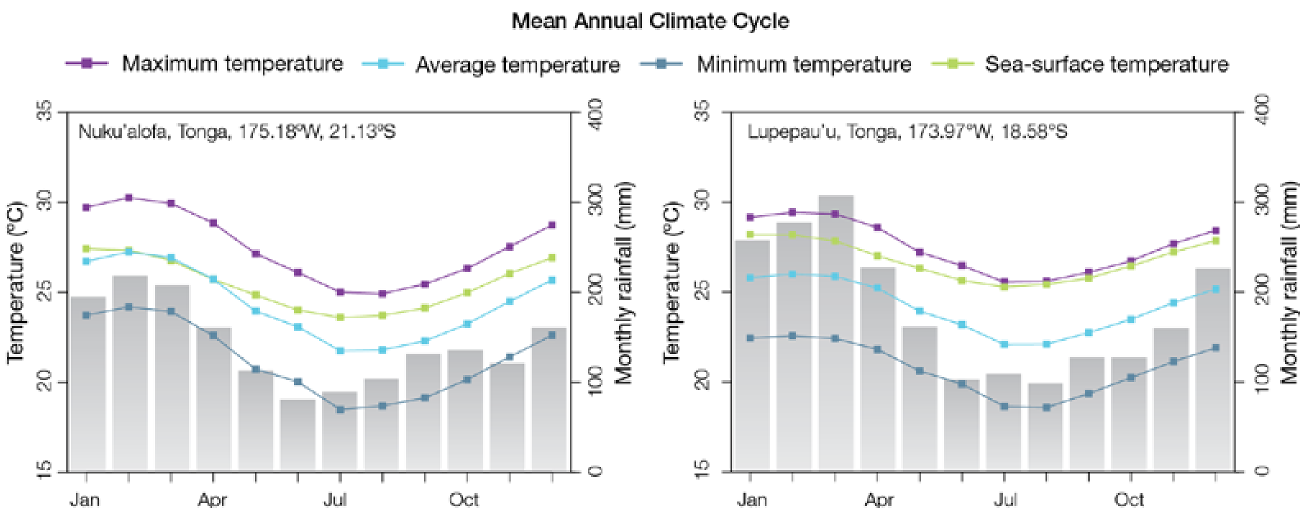

Figure 3. Monthly temperatures and rainfall for Tonga.
(Source: Australian Bureau of Meteorology and CSIRO (2011), reproduced with permission.)

The El Niño Southern Oscillation (ENSO) phenomenon, a feature of the climate of the Pacific Ocean, has a marked effect on the climate of Tonga, particularly the rainfall patterns. The El Niño phase generally brings drier conditions and La Niña wetter conditions.

Rainfall in Tonga has high variability from year to year. Both Nuku'alofa and Lupepau'u receive about three times as much rain in the wettest years as in the driest years. In Nuku'alofa, El Niño events tend to bring cooler temperatures, especially in the dry season, and also tend to bring lower than normal rainfall during the wet season. Similar impacts are seen in Lupepau'u except the temperatures in the wet season show no clear response to ENSO.

During the last 50 years, an increase (+0.16°C per decade) in temperature has been observed in Tonga (Australian Bureau of Meteorology and CSIRO, 2011). Sea level, measured since 1993 by satellite altimeters, has risen by more 6 mm per year since 1993. Ocean acidification has also declined from about 4.5 in the late 18th century to an observed value of about 4.0 ± 0.1 by 2000.

Tonga is vulnerable to two main extreme events: tropical cyclones and drought.

Tropical cyclones generally occur between November and April. Tonga is affected by an average of 20 cyclones per decade. Nineteen of the 55 tropical cyclones (35%) in the Tonga EEZ between the 1981/82 and 2010/11 seasons were severe events (Category 3 or stronger).

Drought is also a threat for the country as it relies primarily on limited groundwater and rainwater as a supplementary source for its water supply. The island group of Ha'apai tends to be particularly affected by droughts.

2.3.2. Projected trends

The PCCSP has recently published new trends for Tonga (Australian Bureau of Meteorology and CSIRO, 2011). According to the Program, future climate in the region will be characterised by:

1. An increase in sea surface and air temperatures (very high confidence);
2. More extreme events – both heat (very high confidence) and rainfall (high confidence);
3. Increased wet season rainfall and decreased dry season rainfall (moderate confidence);
4. Less frequent tropical cyclones (moderate confidence) but they may be more intense;
5. Sea level rise and ocean acidification will continue (very high confidence).

2.4. The water sector

2.4.1. Institutional framework

Water resources in Tonga are currently managed by a number of government agencies, some with specific and some with general monitoring responsibilities. Details are given in Table 1.

Table 1. Agencies and their water resources responsibilities

Agency	Water resources responsibilities
Geology Section, Natural Resources and Environment Division, MLECCNR	Designated national lead water agency. Responsible for water quality, licensing of water wells, ensuring sustainable pumping rates
Environment Section, Natural Resources and Environment Division, MLECCNR	Environmental impacts of development and extraction, lagoon water quality, biodiversity impacts, climate change impacts
GIS Section, Land Information and GIS Division, MLECCNR	Spatial representation and interpretation of data, mapping
Tonga Water Board (TWB)	Water quality of urban water supply in Nuku'alofa, Neiafu on Vava'u and Pangai-Hihifo on Ha'apai and to villages on 'Eua and selected villages on Tongatapu; water production volumes, water consumption data, payment for water
Public Health Section, Ministry of Health	Quality of village water supply, management of village water supply, coordination of village water committees, monitoring disease rates
Tonga Meteorological Service (TMS)	Weather and climate monitoring, forecasting
Tonga Waste Authority	Coordinates a multi-agency team to monitor groundwater quality around the Tapuhia Waste Management Facility
Village water committees	Water use and consumption, payment for water
Ministry of Agriculture, Forestry, Food and Fisheries (MAFFF)	Responsible for promoting agricultural production and supervising use of fertilisers, pesticides and irrigation (they have no facilities for monitoring contamination of groundwater by pesticides and fertilisers, or records of who is using irrigation systems)
Ministry of Finance and National Planning	Responsible for the coordination and monitoring of aid projects, including those affecting the water sector. Also oversees capital and recurrent funding of water supply and water resource programmes

2.4.2. Climate risks, vulnerabilities and impacts

The following climate change impacts will contribute to vulnerability of the Tongan water sector.

- Changes in rainfall: The main climate change impacts to the year 2030 are likely to be caused by changes in rainfall patterns. Changed rainfall will affect recharge to groundwater and groundwater in storage. Extended dry periods will lead to groundwater depletion, and saltwater intrusion into the groundwater supplies.
- Sea level rise: Mean sea level rise beyond 2030 has the potential to impact on groundwater resources in low-lying parts of high islands (coastal aquifers) and low lying islands (freshwater lenses). The reduction in water availability due to mean sea level rise is hard to quantify. If the assumption made for Tarawa of a 20% reduction in groundwater sustainable yield is applied to Tongatapu, the impact of this projected climate change is significant but relatively small compared to the large demand on water resources due to population increase and leakages.
- Tropical cyclones: If tropical cyclone severity was to increase, this could also impact on storm surge and lead to erosion and inundation of parts of low-lying islands and coastal areas of high islands, as well as damage to infrastructure.
- Extreme events: Recent climate change scenarios are projecting a possible reduction of drought events for Tonga, however an increase in drought intensity (duration and reduction in average rainfall) will seriously threaten Tonga. Heavy rainfall events, although an opportunity to harvest more water, bring the risk of floods, with related socio-economic and environmental issues.

2.4.3. Non-climate drivers of risk

In addition to potential climate impacts, there are also increasing stresses placed on water resources from anthropogenic factors. These non-climate factors currently pose the greater risk to Tonga's water sector.

- Population: Increasing water demand due to increasing population.
- Poorly maintained water system: Leakage from pipe systems poses the greatest risks to water availability. Leakage from pipe distribution systems was 50% or higher prior to the improvements to the Hihifo water supply system.
- Over-pumping of groundwater: Seawater intrusion due to over-pumping from fragile groundwater resources may lead to the depletion of groundwater resources at Hihifo.
- Pollution: Water contamination from urban centres, and agricultural and industrial activities (e.g. leaching of fertiliser and pesticide into underground water) is an increasing problem.
- Poor governance and management of the water sector: While this does not directly lead to a loss of water resources, it can lead to poor decisions about water resources development and protection.

The PACC project aimed to address both climate and non-climate related risks to the water sector. Strengthening the water sector and building resilience into the water supply system for Hihifo is no-regrets development that will reduce the vulnerability of the communities to all risks, including those linked to climate.

3. THE DEMONSTRATION PROJECT

3.1. Goal, objectives and outcomes

The goal of the Tonga PACC project is 'to contribute to reduced vulnerability and increased adaptive capacity to adverse effects of climate change in Tonga'.

Project objectives, which are based partly on PACC (2007) and partly on subsequent discussion about the specific nature of the water improvements for Hihifo since PACC (2007) was prepared, are:

- Improve the water supply system to provide Hihifo residents with better access to water in terms of reliability and pressure and better water quality than at present;
- Enhance the capacity of the residents of the Hihifo villages to sustainably manage their water resources and to effectively operate and maintain the improved water supply system for the benefit of all;
- Make use of renewable energy for pumping (solar pumps) to lower operating costs, decrease dependency on carbon-producing fossil fuel (diesel) and to minimise pollution of groundwater.

The project has three intended outcomes:

Outcome 1: Policy/plans mainstreamed to build resilience in the context of emerging climate risks in Tonga's water sector;

Outcome 2: Water security increased in Tongatapu Hihifo District through demonstration measures;

Outcome 3: Increased understanding of climate change impacts and awareness of how to adapt and build resilience (at community level).

This technical report focuses on Outcome 2, the demonstration project, but also includes relevant information on climate change mainstreaming (Outcome 1) and building of awareness and knowledge on climate change (Outcome 3).

3.2. Preparatory phase

3.2.1. Sector, project and pilot site selection

A PACC project mission was undertaken to Tonga in September 2006. One of the objectives was to hold consultations and carry out situation, institutional and stakeholder analyses to decide on sector focus and the demonstration project. The stakeholder consultations resulted in the selection of the water sector as priority for the project. Stakeholders also agreed on the demonstration project 'Piloting climate change adaptation in water resources management in Hihifo District, Tongatapu', with objectives to enhance and where necessary, develop water infrastructure for the six communities of Hihifo.

3.2.2. Linkages with strategic plans and processes

The Tonga PACC project is aligned with existing policies, strategies and action plans and builds on, adds value to, and implements many of the adaptation actions identified in other national documents. For example, it is aligned with the Tonga Strategic Development Framework 2011–2014 (TSDF), Tonga's National Climate Change Policy, the Joint National Action Plan for Disaster Risk Management and Adaptation to Climate Change (JNAP) as well as sector-specific documents such as the National Water Policy (NWP) as shown in Table 2.

Table 2. Linkages of the Tonga PACC project with existing policies, strategies and action plans.

Strategy/policy	PACC project is contributing to:
Tonga Strategic Development Framework 2011–2014	Outcome objective 7. Cultural awareness, environmental sustainability, disaster risk management and climate change adaptation, integrated into all planning and implementation of programs, by establishing and adhering to appropriate procedures and consultation mechanisms Strategy 23: Implementing the JNAP to reduce vulnerability and risks; and to enhance resilience to the impacts of climate change and natural hazards
Joint National Action Plan on Climate Change Adaptation and Disaster Risk Management (2010–2015)	Goal 1: Improved good governance for climate change adaptation and disaster risk management Objectives: Develop enabling policy and capacity to strengthen planning and decision making processes with the incorporation of relevant climate change and disaster risk management consideration
	Goal 3: Analysis and assessment of vulnerability to climate change impacts and disaster risk Objectives: Assess water resources and supply capacity in capitals, villages and outer islands
	Goal 4: Enhanced community preparedness and resilience to impacts of all disasters Objectives: Ensure food and water security after disaster events
	Goal 5: Technically reliable, economically affordable and environmentally sound energy to support the sustainable development of the Kingdom
National Climate Change Policy, 2006	Objective 2: To mainstream climate change issues into all environmental, social and economic processes including enactment and amending existing legislations Strategy 2.1: Strengthen Government, Non-Government Organisations, and private sectors networking capacity in the implementation of climate change policy/initiatives
	Objective 5: To protect the populations, resources and assets, vulnerable areas at risk from climate change impacts Strategy 5.1: Identify vulnerable areas and develop adaptation options that are cost effective and culturally sensitive to reduce vulnerabilities (foreshore construction, tree planting) Strategy 5.2: Extensive consultation and cooperation amongst government ministries, local communities and all relevant stakeholders in prioritising adaptation options that can be implemented to reduce vulnerability Strategy 5.3: Encourage the participation of communities in the planning, management and implementation of adaptation measures within their communities

3.2.3. Institutional framework for the project

The PACC project in Tonga is implemented by a Project Management Unit (PMU) and is housed in the Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR), and more specifically within the Climate Change Department. The PMU was established in January 2010, and the CEO of MLECCNR is the National Project Director.

The PMU is supported by a Technical Working Group, comprising staff from the Ministry of Health (rural water supply, environmental health and link to water committees), Natural Resources (groundwater management), Australia's Department of Foreign Affairs and Trade (DFAT, formerly AusAID), Tonga Water Board, Tonga Community Development Trust and the Joint National Adaptation Plan (JNAP) Secretariat. The PACC Tonga team (PACC coordinator and assistant) is also supported by PACC regional implementing agency the Secretariat of the Pacific Regional Environment Programme (SPREP), as well as regional and local consultants.

The PMU is linked directly to the demonstration project target communities through the Hihifo–PACC Water Committee (HPWC). The HPWC members include the District Officer, the six Town Officers (who liaise with the village committees), and the Chair of each Village Development Committee. The main function of the HPWC is sharing of information and knowledge, overseeing the smooth running of the project, decision making and ensuring the six villages remain actively engaged. Meetings are scheduled quarterly to advise on the last quarter's progress and the next quarter's work programme, including reasons for delays, problems and variations.

The PMU organises project activities through contracts and MoUs with the implementation partners and local private contractors. The implementation partners are the same as the members of the Technical Working Group. Wherever possible procurement of services and goods has been undertaken using Tongan government procurement processes. Later in the project however, the PMU started using SPREP to undertake procurement in an attempt to accelerate project activities.

3.2.4. Community engagement

In the early stages of the project, a communications strategy was developed that provided a framework for community engagement and involvement in the project. The purpose of the communications activities detailed in the strategy was to raise awareness of climate change generally, of the need for adaptation, and also specifically about the PACC project. As the project progressed, the strategy also guided community participation in developing and implementing the project (see Section 3.4.1).

The main community engagement activities carried out by the project were:

- National inception meeting;
- Hihifo community meetings and workshops;
- Monthly meetings with the Hihifo Village Water Committee (HVWC) on project progress;
- Door to door socio-economic survey carried out in Hihifo;
- Quarterly newsletter;
- Weekly radio broadcasting;
- A TV programme, and a video documentary on the project, produced;
- Training on basic plumbing and mechanics.

Successful engagement of the community was demonstrated during project implementation. For example, on the delivery of three 45,000 litre water tanks, the tanks were too large to be moved into place by vehicle. The community arrived at the solution that the local rugby team would assist, and the men carried the tanks over 300 metres to the waiting concrete bases.

3.2.5. Addressing gender

Ideally, a gender perspective would have been included from the very beginning of the project, and carried through all stages to final M&E. There are clearly gender issues in water resources use and management, and these should have been analysed for the Hihifo community during the early stages of the project. In fact, gender issues were mostly overlooked until midway through the project. At this point, efforts were made by the Regional Programme Management Unit to increase gender awareness within the PACC project teams, and to build capacity for integrating gender into project activities.

The project team is now collecting sex-disaggregated data for M&E purposes, which should give an indication the benefits of the project for women and for men.

3.3. Situation and problem analysis

3.3.1. Socio-economic assessment

A socio-economic assessment (SEA) was carried out in Hihifo district by the PACC project team in late 2010 and early 2011 (PACC, 2014a). The purpose of the assessment was to examine the current socio-economic situation in Hihifo, the situation regarding water supply, the health situation, as well as capturing the attitudes and experiences of people with regard to climate change impacts. Data were collected through a household survey and a focus group discussion.

The results of the household survey indicated that the communities in Hihifo are disadvantaged socially and economically. It was found that about 50% of households earn wages but these are mostly low. Most households said that their income often falls short of meeting basic needs because of the high cost of living.

The assessment found the following factors contributing to the unreliable water supply in Hihifo. First, the fragile and thin water lens and high water table, resulting in saltwater contamination. Second, increasing demand on the system due to an increasing population of Hihifo District. Third, a lack of community participation in the management of village water systems due to a disconnect between the water committee and the community. Fourth, the water committees lack capacity and resources to maintain the system and breakdown of water pumps and leakages are common.

Even though the PACC pilot project was focusing on groundwater, the project management team felt that it was important to also gather information on the use of rainwater. It was clear from the survey that the majority of households drink rainwater collected in water tanks. However, the survey also found that many households do not own a water tank and they have to collect their drinking water from water tanks belonging to neighbours or the community hall.

It was also apparent from the focus group discussions that communities are not informed and well aware of activities and decisions from the water committee.

The following ways forward were identified by the focus group to address the priority issues:

- Install a water meter in every household;
- Establish solar water pumps for village water supply;
- Construct additional water tanks;
- Improve governance of the water committees; and
- Improve transparency and communications between the water consumer and the water committee.

The full SEA report is published as PACC Technical Report No. 6 (PACC, 2014a).

3.3.2. Analysis of the existing water supply system

An analysis of the existing water supply system was carried out. In summary, the public water supply uses groundwater pumped from a number of dug and drilled wells on the south-eastern margin of the district. Pumps on the dug wells were commissioned in the early 1960s, while pumps on selected drilled bores were commissioned in the 1990s. Water is pumped to consumer connections via a 100 mm PVC pipeline and an older 80 mm asbestos cement pipeline. No water storage is used in the system.

Because of its high salinity, water use from the public water supply system was limited to flushing toilets, cleaning the house, cooking and watering animals (PACC, 2014a). Rainwater was used by many households for most purposes during rainy periods, but in dry periods the use of rainwater contracts to drinking, cooking and sometimes washing (PACC, 2014a).

WATER SUPPLY PROBLEMS

The public water supply for Hihifo had suffered from problems of unreliability and high salinity for a number of years. Unreliability of the water supply was caused by a number of problems including:

- Failure of pumps and motors at wells, and delays in repairing them;
- Leakages in the system;
- Financial problems (e.g. lack of funds for effective repair and maintenance);
- Absence of storage capacity at appropriate elevation to generate water pressures and volumes to sustain the water demand;
- Very high flow restriction when water transferred from the newer 100 mm PVC pipeline to the old 80 mm asbestos cement pipeline.

The most likely reason for the high salinity is that the fresh groundwater is thinner near the narrow western end of the island and the pumping rates are high for a thin freshwater lens. The salinity is likely to become worse in drought periods if pumping continues at current rates.

PREVIOUS IMPROVEMENT EFFORTS

A number of attempts had been made to improve the distribution of water in the Hihifo water supply system. The first attempt was the addition of a 100 mm PVC distribution pipeline to the existing 80 mm asbestos cement distribution pipeline. However, the purpose of constructing the new 100 mm main to boost the delivery of water was defeated by continuing to use the 80 mm pipeline for distribution purposes.

The second attempt was to rectify the low pressure problems in the Hihifo water supply system and involved the installation of an elevated tank to supply the villages of Kolovai, 'Ahau, Kanokupolu and Ha'atafu. However, the installation of the elevated tank resulted in no improvement to water pressure in the distribution system.

3.4. Design phase

3.4.1. Community consultations

A series of training activities and workshops was held to gather community knowledge on water, climate change and explain the PACC adaptation project. All community members in Hihifo were invited to participate to discuss the issues and put forward their views on solutions.

Community consultations were supported by a communications strategy. All communication and training materials were produced in Tongan. A newsletter was part of the strategy and was produced every quarter to inform both local and regional stakeholders on the progress of the project.

As a community-based adaptation project, the involvement of the Hihifo community in the design, implementation and evaluation phases of the project was crucial.

3.4.2. Technical design

Full details of the improvements to the Hihifo water supply system are published as PACC Technical Report No. 7 (PACC, 2014b). The main features of the design are summarised here. The system was designed with a timeframe of 30 years.

DESIGN OBJECTIVES

The objectives for the water supply improvements were:

- Quantity: pumping capacity at not more than 1.5 L/s per borehole;
- Quality: improve water quality such that (a) it has salinity (EC) level below the adopted limit for fresh groundwater of 2,500 µS/cm in each production borehole; (b) it meets required bacteriological quality at all times;
- Reliability: supply water on a 24 hour basis to consumers;
- Pressure: supply water at pressure not lower than 5 m at the highest point in the distribution system;
- Infrastructure costs: implement measures within the project budget;
- Operational costs: supply water at reduced operational cost compared to the present.

DESIGN STRATEGY

The strategy to achieve the above objectives included:

- Install three solar pumps with electricity backup to minimise operational costs of pumping;
- Replace existing diesel pumps with new pumps to provide additional pumping at night time or during cloudy periods when solar pumping does not keep up with water demand;

- Install a high level tank and low level tanks to supply consumers with water at adequate pressure, especially for Ha'atafu, by the use of an effective zoning system;
- Adopt the minimum hydraulic standards used by the Tonga Water Board as the basis for design;
- Adopt the technical specifications outlined in Fielea (2012) for the implementation of the project components;
- Minimise costs of implementation to fit within the PACC budget;
- Minimise recurrent costs.

3.5. Implementation phase

3.5.1. Timeframe

Implementation of the demonstration project started in January 2011. In November 2012, with the detail design completed, PACC started to work on the procurement of construction materials and a bid for tender was advertised using the Government of Tonga procurement procedures. The project took a total of 40 months to be finished. Procurement and tendering were identified as the main issues causing delay. Delays in the disbursement of funds also meant that PACC had to stop the work for a few months until a solution was found.

Figure 4 shows the timing of the main phases of the construction work.

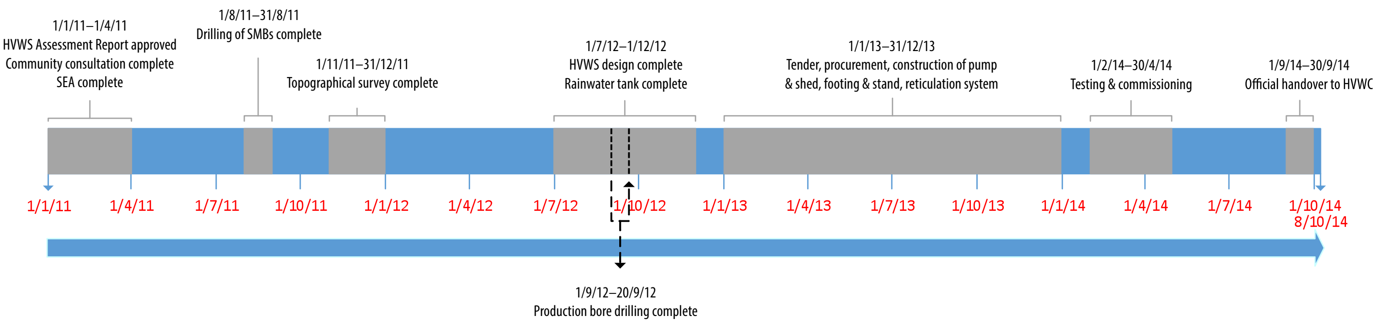

Figure 4. Project Implementation process.

Table 3 details some of the issues that caused delay, and how they were managed.

Table 3. Project implementation issues and responses.

Issues	PACC team response
Heavy rainfall	Delays on outdoor activities
Compliance with tendering and bidding process	Rebidding and evaluation
Government procurement process	Direct payment from SPREP to contractors
Land issues	Relocation to new site and redesign
Lack of support from HVWC	Issues discussed and resolved through meetings
Lack of timely financial disbursement	PACC resolved with SPREP
Initial failure of SPREP to negotiate customs exemptions with the Government of Tonga	PACC resolved with SPREP

3.5.2. Activities

The following activities were carried out during the construction phase:

- Two existing operational dug wells at Hihifo were equipped with diesel pumps.
- Three new boreholes were drilled to replace collapsed boreholes. The new boreholes are 150 m apart and each pump at a rate of 1.5 L/s.
- Solar pumps were installed at each of the three new boreholes.
- Pump houses and security fences were constructed at all pumping sites (Figure 5).
- A chlorination unit was installed to provide treated water.
- A new elevated tank (HLT) and ground level storage tanks (LLT) were installed at Kolovai to provide sufficient storage capacity to store water from the pumps equivalent to about half a day's demand and to provide sufficient water pressure to two water supply zones within the distribution system (Figure 6).
- Distribution pipelines were replaced to supply Ha'atafu. The existing 100 mm pipelines to Ha'avakatolo and Fo'ui will be used for emergency supply to both villages, if required.
- A new 150 mm main pipeline was constructed to transfer water from the well field to the storage tanks at Kolovai.
- Water supply services were extended to all holiday resorts within the Hihifo water supply area.
- Flow control valves and district meters were installed for leak detection purposes.
- HVWC personnel were trained in basic plumbing, motor and pump maintenance, leak detection and administration.
- An office was set up for customer liaison, financial and administrative work of the HVWC.
- A workshop (for repairs and maintenance) was set up at the water storage site.
- Thirty rainwater tanks with gutters, fittings, downpipes and concrete bases were provided to selected houses (Figure 7). Tanks were 10,000 litre capacity; total capacity of the rainwater storage of 300,000 litres is enough to reduce the load on the water supply system by approximately 25% (80–100 litres/person/day) under normal conditions.

Following completion, management and maintenance of the water supply system and associated infrastructure is under the responsibility of the HVWC.

Appendix 1 gives details on demand management and pumping strategies for the new system.

Figure 5. Securing one of the new pump houses.

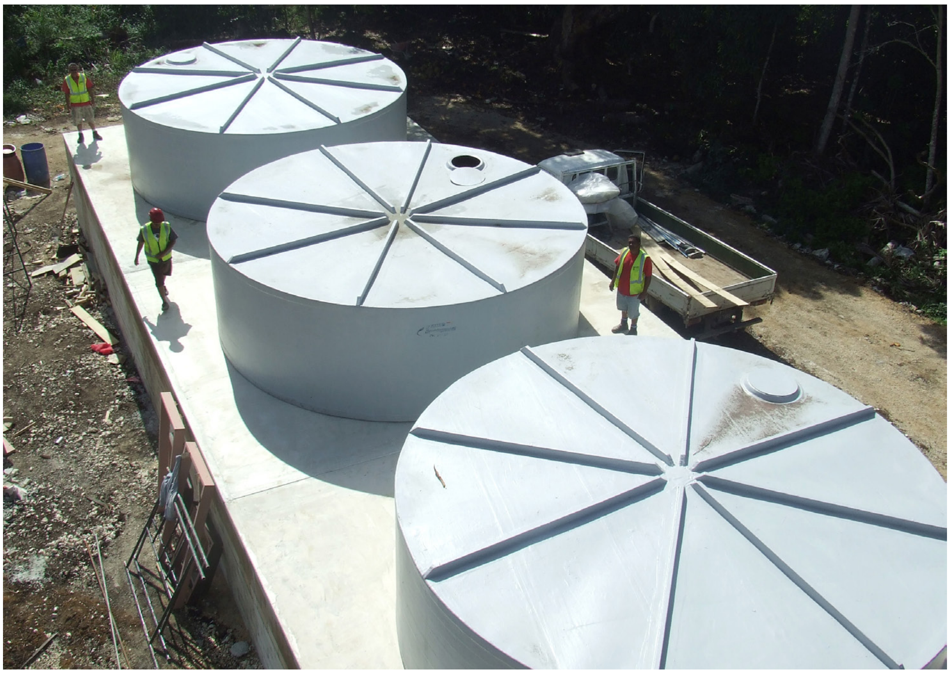

Figure 6. The ground level water tanks each with capacity of 45,000 litres.

Figure 7. A 10,000 litre water tank supplied to a household.

3.6. Monitoring and evaluation

Monitoring and evaluation (M&E) ensures that outputs are delivered and outcomes achieved by setting targets and measuring appropriate performance indicators. The M&E process has been continuous through the project process, with quarterly reports on progress, issues and lesson learned.

The PACC project used a logical framework (logframe) as an M&E tool. An extract from the Tonga PACC logframe is given in Table 4.

Key results from the evaluation are outlined in Section 4.

Table 4. Outcomes, targets and indicators for the PACC Tonga demonstration project (excerpt from the project logframe).

Outcome/output	Indicator	Source	Baseline	Target
Outcome 2: Water security increased in Tongatapu, Hihifo District through demonstration measures	% of water samples meeting Ministry of Health (or WHO) standards	The Geology Section Water test results	In 2011, results of underground water testing did not meet WHO Standard	By 2014 all households in Hihifo are supplied by WHO standard water (WHO, 2011)
	% of households with sufficient water supply (gender disaggregated)	Socio-economic survey Post-project impact survey report Water S Build map	60% access to sufficient water supply system	100% of household with sufficient water supply
	Reduction of household water use	Design report	100 L/person/day	Normal: Reduce to 80 L/person/day with the use of rain water tank. This measure only applies to drought periods
	Number of days with access to water during drought period	Consultation report Design and estimate report	During drought very few households have access to water	100% of households have access to water during drought period
	Water loss due to pipe leakage	PACC project report Tonga Water Report Household readings from meters	30% leakage	By end of 2014 less than 15% leakage
	Total number of people and communities benefiting from project (gender disaggregated)	PACC and SEA reports Impact survey	65% of the pilot communities benefitted	By the end of the project at least 90% of the population benefitted from the adaptation measures
	Community satisfaction with PACC project (gender disaggregated)	Impact survey	All villages are not satisfied with existing water supply system	By the end of 2013 at least 430 vulnerable households perceive benefits from the demo project 100% of the demo communities benefitted from the project
Output 2.1: Guidelines developed	(Gender-sensitive) technical guidelines developed	Guideline	No guidelines exist	By 2014 sectoral technical guidelines are prepared, capturing all phases of the demonstration project

Outcome/output	Indicator	Source	Baseline	Target
Output 2.2: Demonstration project delivered to increase resilience of Hihifo water supply	# of boreholes drilled	PACC and contractor's report	No monitoring boreholes exist	Installation of 3 new monitoring boreholes (completed 2010) Drilling and installing of 4 new production boreholes (completed 2012)
	% of water treated	Design report (shows provision for water treatment)	2010 0% of the underground water extracted was treated	By 2014, 100% of underground water extracted is treated
	# of households supplied with rainwater tanks	Contractor's implementation reports	30 households out of the 430 households have no water tank	Installation of 30 x 10,000 L household water tank completed 2012
	# of community reservoir tanks installed	Project implementation document Water supply improvement project	Tanks exist but are not accessible	By the end of Quarter 1 2013 three x 45,000 L and 2 x 25,500 L overhead tanks, new additional storage fibreglass tanks added
	meters of road constructed	Contractor report	200 meters bush road	By the end of 2014 a tar seal road for reservoir is implemented
	# of water pumps installed	Progress report	Only one pump running	By the end of the project 2 new diesel pumps installed
	# of solar electric systems installed	Progress report	No solar pump	By the end of the project 4 new solar pumps installed
	km of pipes fixed	Progress report	Leakage happened along 21.18 km pipes need to be replaced	By the end of the project 21.18 km of pipeline replaced to avoid leakages
	Number of household meters installed	Map of reticulation system Contractor	In 2010, no households meters	By the end of the project in 2014, 404 households will have meters
	Technical capacity of the members of the Hihifo Water Committee Efficient use of water monitoring equipment	Workshop report Water monitoring records	In 2010 the Hihifo water committee has very limited capacity and no equipment available to monitor and manage	By 2014, all members of the Hihifo water committee have increased technical and administration capacity By 2014, the Hihifo District Water Committee is able to monitor and manage their water supply system efficiently
	Gender issues considered in project (both genders benefit)	Gender toolkit used		Gender toolkit used Women and men benefit equally from the project

3.6.1. Community impact assessment

Following completion of the main demonstration activities, a community survey was carried out in May 2014 to assess impacts of the project as perceived by the community. Thirty representatives of the Hihifo community, including household residents, resort owners and town officers in the Hihifo District, were interviewed.

A key finding was that the water security component of the Tonga PACC project has delivered some immediate positive benefits to households in the six target villages of Hihifo. The main benefit noticed was that the water supply was now more reliable and this led to high levels of satisfaction with the village water supply and the PACC project as a whole. However, whilst the reliability of the village water supply was improved, there was room for further improvement to ensure a constant supply of water is delivered all day, every day to every household.

The analysis found evidence that the improved village water supply has also resulted in improvements to sanitation in homes and shared community facilities. Tourist resorts also acknowledged the future benefits (reduced costs) they would experience during drought events as a result of not having to cart in large volumes of water. Future cost savings and improved revenue collection were also noted as future anticipated benefits from the town officers.

Recipients of rainwater tanks were extremely grateful and noticed the immediate benefits of more convenient access to drinking water. These households and the neighbouring households they would normally borrow water from have also increased their resilience to drought events. The analysis found no major gender imbalances in the distribution of benefits and impacts delivered by the PACC project.

3.7. Adjustments

Throughout the implementation and M&E phase, adjustments were necessary to overcome unexpected issues or to adapt features of the demonstration project as requested by the community.

Necessary adjustments made during the building phase are given above in Table 3.

In addition, a land issue arose prior to the installation of one of the storage tanks, as the landowner had not been informed or advised by the Hihifo Village Water Committee of the proposal. To overcome this issue, the PACC team took over the negotiation and agreed with the owner of the land opposite to the original site for a relocation of the construction site. The relocation of the storage needed a design modification with an additional raised footing of 2 metres to allow for the loss in elevation at the new site.

3.8. Communications and knowledge management

The project addressed communications and knowledge management at different levels, and both formally and informally.

Community engagement was a critical part of the project, and was guided by the national communications strategy, as described in Sections 3.2.4 and 3.4.1.

Other key target audiences were identified by the project, at both national and regional levels, and communications products were developed and disseminated. Examples include news stories published on the PACC webpages (www.sprep.org/pacc), and further circulated in the online newsletter Climate Change Matters; a 'country brief' describing the project and targeting decision makers across the region; and technical reports targeting primarily other climate change practitioners in the region, specifically a report of the SEA carried out by the project (PACC, 2014a) and the technical design report (PACC, 2014b). Information and case studies were also drawn from the Tonga PACC project in synthesis publications, in particular the PACC Experiences series (see for example PACC Experiences No. 4: Building resilient freshwater systems).

For communications and knowledge management targeting audiences beyond Tonga, the PACC webpages (www.sprep.org/pacc), and in particular the Tonga project webpage (www.sprep.org/pacc/tonga), has been the main dissemination tool used to share information and knowledge generated by the project. Outputs are also being shared through the Pacific Climate Change Portal, and other online information hubs, such as the Climate & Development Knowledge Network (CDKN), Eldis and ReliefWeb.

3.9. Coastal zone management works

Following successful implementation of the water supply improvement project in Hihifo, Tonga was given additional funding in the next phase of PACC (called PACC+) for coastal zone management adaptation. The implementation of coastal protection measures aims to reduce inundation and infiltration of salty water into freshwater lenses and boreholes.

At time of writing (November 2014), the PACC team had undertaken assessments including a coastal vulnerability and adaptation assessment, a socio-economic assessment and an environmental impact assessment.

Planned activities include carrying out lagoon entrance construction revetment at 'Ahau, revetment remediation at Kanokupolu, installing culverts at Kanokupolu, and a detached breakwater at Ahau. A 2 km seawall is also planned, which will withstand waves up to 2 metres height.

4. MAINSTREAMING CLIMATE CHANGE AT THE STRATEGIC LEVEL

Recognising that 'top-down' adaptation is also needed, to support on-the-ground adaptation, the Tonga PACC team also devoted time and effort to the mainstreaming of climate change into national policy for the water sector.

The project team contributed to the development of a climate-responsive National Water Policy (NWP). The process included a review of the current legislative framework for water management, existing national plans, institutional mandates and the draft National Water Resources Management Bill. The draft Policy was approved by both the PACC TWG and the National Water Committee. The Policy has been ratified and approved by Cabinet. After formal NWP endorsement was secured, the National Water Resources Management Bill, prepared in 2006, was reviewed and has been amended to reflect the revised structure and focus on the NWP. The Bill has now passed through the Attorney-General's Office and is with the Law Review Committee ahead of its final passage to Parliament for approval.

5. SUSTAINABILITY, RELEVANCE, EFFECTIVENESS AND EFFICIENCIES

5.1. Sustainability

The policy changes supported by the PACC project will enhance the sustainability of the project, by providing an appropriate climate-responsive framework for operation of the water supply system.

Capacity building carried out by the project will also significantly enhance sustainability of the project, in particular training of members of the Village Water Committee in basic plumbing, motor and pump maintenance, and leak detection.

Other factors contributing to sustainability are given in Table 5.

Table 5. Sustainability indicators for the PACC demonstration project.

Domain	Parameter	Sustainability indicators
Socio-cultural	Water demand	The new water supply system is designed to deliver 100 L/person/day and has a storage capacity 159.1 m^3 which represents 67% of the day's demand. The additional 300 000 L of rainwater tanks represents an increase of 189% Further community engagement will focus on demand-side measures to reduce water consumption from behavioural response and infrastructure changes (fixing leaks, low flow taps etc.) and this will enhance sustainability of the system
	Cultural compatibility	The project results are compatible with the expectations of the community
		The water system is operated and maintained by an already existing and respected community organisation (HVWC)
Infrastructure	Life span	Life span of pumps is 5–10 years, other installations 40–60 years
	Required maintenance	Maintenance is low due to use of solar pumps with fewer moving parts
Political	Political support/in line with public policy/political agenda	The project is in line with TSDF objectives, National Water Policy and Climate Change Policy
Economic	Energy consumption	Low energy consumption due to the introduction of solar power, and additional 300,000 L of rainwater tank capacity reducing need for pumping
	Net benefit/return on investment	This is a community project and no expected return on investment is expected
Environmental	Impact on groundwater resource	The lowering of pumping rate to half of the previous pumping rate of 3 L/s, and the additional rainwater tanks, is expected to lower demands and groundwater abstraction
	Adverse effect on environment	None identified at this stage
	Climate resilience	The new water system is resilient to climate impacts anticipated for the next 30 years

5.2. Relevance

The project was aligned to the needs and plans of Tonga. The country adopted a National Water Policy in 2012 which mandated the mainstreaming of climate change into its development plans and processes. It also created the Joint National Action Plan on Climate Change Adaptation and Disaster Risk Management. The PACC project is aligned with these national policies.

The project also responded to the needs of the Hihifo District communities, as expressed during community consultations. Reliable and good quality water supply is a basic need for all communities, and the Hihifo villages had struggled for many years with an inadequate supply system.

Project results that contribute to water security for the Hihifo community include:

- Residual water pressure at the highest point was measured above the minimum of 5 m;
- Salinity was measured at an average of 948 µS/cm (38% of the upper limit (2,500 µS/cm) for freshwater);
- Leakage rate was measured at an average of 6.1 L/person/hour compared to the design figure of 7.5 L/person/hour;
- Operation costs have been reduced;
- The additional 30 x 10,000 L rainwater tanks have reduced the demand on the system;
- The introduction of the metered system provides the foundation for water conservation measures within the community.

5.3. Effectiveness

The new water supply system provides the residents of Hihifo with better access to water in terms of reliability and pressure and better water quality than previously. Reliability has been improved through groundwater extraction and distribution infrastructure improvements. Improved water quality has been achieved through the addition of a chlorination unit and reduced extraction rates of groundwater from the top of the water lens to reduce salinity. The new system has low energy consumption due the introduction of renewable energy and additional rainwater tanks. The introduction of the HLT and LLT system has greatly improved distribution of water to high elevation consumers at the extremities of the system.

The setting up of demand management areas (DMAs) (see Appendix 1) makes the water system of Hihifo manageable in terms of leakages and water balance. The training of the HVWC has also enhanced the capacity of the residents of the Hihifo villages to sustainably manage their water resources and to effectively operate and maintain the improved water supply system for the benefit of all.

5.4. Efficiency

The project has improved efficiency of the Hihifo water system as follows:

- Reduction of non-revenue water through system improvements;
- Training of Village Water Committees;
- Metering: 100% coverage for revenue collection;
- The introduction of free renewable energy to the system;
- Improvements to the system have reduced production costs from $0.34 to $0.21 per kilolitre of water for the diesel driven pumps and to almost nil for the solar powered pumps.

6. LESSONS LEARNED AND RECOMMENDED BEST PRACTICES

6.1. Stakeholder lessons learned workshop

Thirty project stakeholders from Government departments, Hihifo villages, the private sector and NGOs attended a lessons learned workshop for the Tonga PACC project in May 2014. The purpose of the workshop was to document lessons learned from the design, planning and implementation of the project. These lessons come from a reflection of the project activities and asking three key questions: what worked well?, what can be improved?, and what would the project team and stakeholders do differently next time?

The main lessons were on the themes of participatory project management, collaboration and communication. Participatory project management involved engaging deeply with the target group and beneficiaries to help uncover the core problem to be solved, alternative solutions, selection of the best solution and in some cases involvement in implementation, monitoring and evaluation. This helps ensure buy-in and support for the project and sustainability of project benefits. Collaboration both at the regional Pacific level and Government department country level was shown to yield good outcomes for projects.

Effective, regular communication between key project stakeholders was noted as a strength of the Tonga PACC project. However, it was identified that there was a need for more communication between implementing contractors, the PACC project team and the communities in the Hihifo villages.

The key lessons identified at the workshop were:

- Concept notes are useful documents to attract donor funding;
- Collaborations can cost-effectively scale up or expand interventions;
- Involve town officers (village leaders) in survey implementation;
- Community consultations can help resource managers become more aware of the scope and scale of issues faced by households;
- Establish a procurement committee to select contractors;
- Closer contractor supervision to ensure quality of work;
- Clear and continuous communication is the key;
- Participatory project management and community engagement from the start is the key to getting buy-in and ownership from the community;
- Ensure project scope is documented, signed off and communicated;
- Cross-sector project coordination can avoid problems;
- Demonstration measures should now be replicated to remote needy communities.

6.2. Lessons learned by the Project Management Unit

During the five years of the PACC project, the PMU learned lessons along the way. Some of these are described briefly here.

The project team found that it is not easy to regulate common resources used by everyone, i.e. water in this case. People fear that their use will be restricted. The team addressed this by raising awareness of good water resources management, for fair use and sustainability, as provided by the National Water Policy.

The lessons learned workshop was an extremely useful exercise for the project team. Bringing together diverse project stakeholders, it provided the opportunity to have open and honest discussions on what had worked and what could have been done better or differently. The lessons learned workshop is recommended as a best practice for similar projects.

The use of renewable energy for pumping (solar pumps) to lower operating costs, decrease dependency on carbon-producing fossil fuel (diesel) and to minimise pollution of groundwater has been a success in the new water system. Even though the capital cost of solar technology is expensive, the benefits outweigh the cost and the technology will pay for itself in approximately three years.

Community engagement was an essential part of the project. The development of a communication strategy early in the project provided a useful framework for meaningful engagement, which contributed to successful outcomes and an effective project. The raising of awareness, building community involvement and ownership, and capacity building to manage their water resources over the longer term has greatly empowered the Hihifo community and built its resilience to climate change impacts.

Further community engagement will focus on demand-side measures to reduce water consumption. It is important for the community to understand that quality water is a limited resource, and that households need to take action to reduce their demand through behavioural (e.g. shorter showers) and infrastructure improvements (e.g. fixing leaking taps, installing low-flow taps) to complement supply-side improvements.

A gender perspective should have been included from the start of the project. This is because men and women are affected differently by climate change, and are differently vulnerable. There are also clear gender implications in water resources use and management, which should have been analysed early in the project. Although gender was overlooked at the beginning of the project, efforts were later made to introduce gender-sensitive approaches and collect gender-sensitive data for M&E.

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APPENDIX 1. PUMPING RATES, DEMAND MANAGEMENT AND PUMPING STRATEGIES

Salinity levels and pumping rates

Three salinity monitoring boreholes (Hihifo SMB1, Hihifo SMB2 and Hihifo SMB3) were drilled in the western and central part of the Hihifo well field in September 2011. The initial salinity monitoring test results from September 2012 shows that the freshwater lens thickness at these boreholes at the western boundary of the Tongatapu freshwater lens was about 6–7 m. The freshwater lens thickness is defined by an EC of 2,500 µS/cm, as the upper limit.

The data from the salinity monitoring boreholes do not cover a period of extreme drought as occurred in the 1980s, so the effect of severely reduced recharge on groundwater aquifer thickness is not known. During such periods, there may be enhanced mixing between the fresh groundwater and underlying saline groundwater leading to a further reduction in the thickness of the aquifer. This factor can only be assessed after monitoring salinity profiles during significant periods of nil or negative recharge.

The initial measurement of salinity at the five production wells at Hihifo was compared to the salinity of the production wells at the TWB well field at Mataki'eau. The TWB production well was measured at an average of 1236 µS/cm, while the five productions well at Hihifo were measured at an average of 948 µS/cm. The thickness of the water lens at Mataki'eua well field was in the range of 10–15 m while Hihifo was measured at 6–7 m. The pumping rate at Hihifo was set at a maximum of 1.5 L/s while the TWB was at 3 L/s. The three salinity monitoring boreholes have been handed over to the Geology Unit of the Ministry of Lands and Survey for maintenance and further monitoring.

Demand management area and leakages

Figure A1 shows the demand management areas (DMAs) for the villages of Hihifo. The zoning is separated by district water meters at approximately the boundaries of each village. Individual flow meters were installed at each pump station with a bulk supply meter at the inlet to the storage tank. A second bulk flow meter was installed at the outlet from the distribution tank to monitor the actual water delivered to the consumer. This will enable a water balance assessment of non-revenue water using the customer meter readings and bulk meter or district meter.

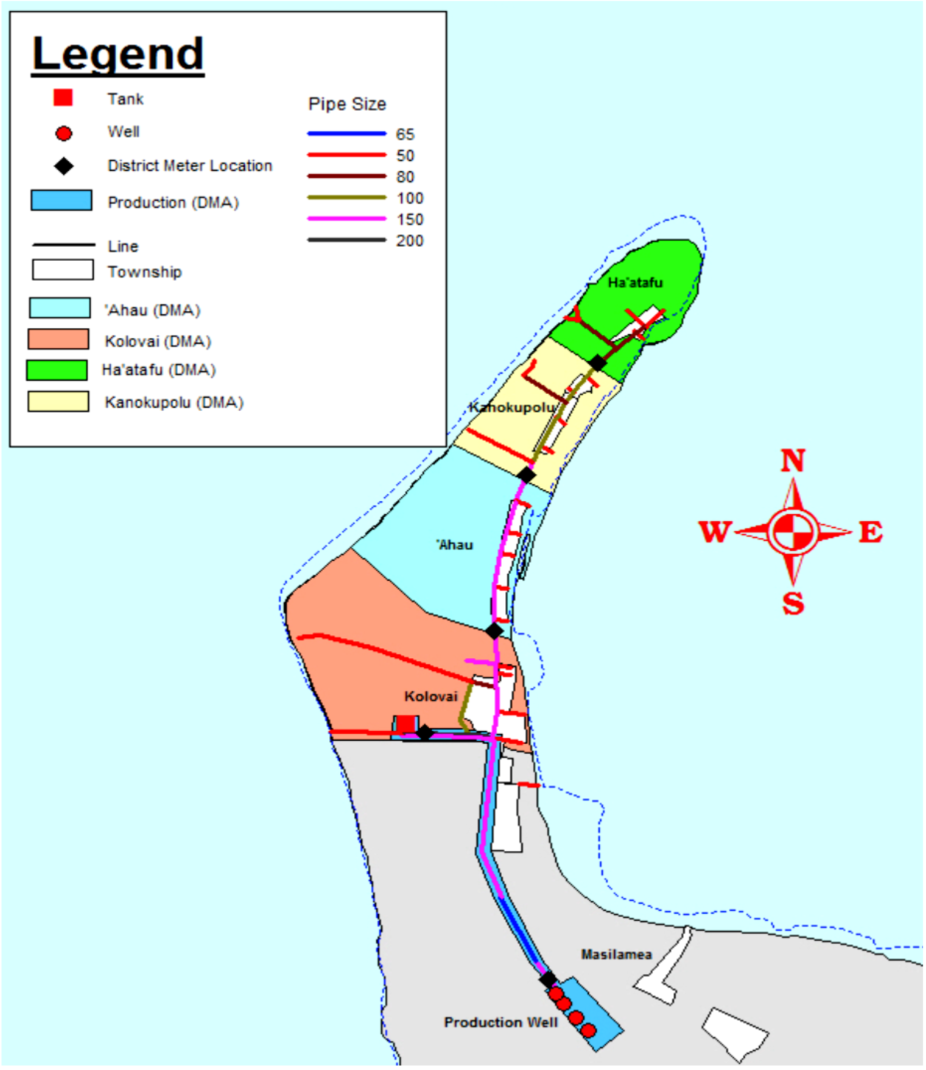


Figure A1. Demand management areas for the Hihifo water system.

The minimum night flow shows the volume of water that is delivered during the morning hours of the night which is the most exact method of estimating the leakage rate of a water system. Night time water users need to be identified and accounted for in the calculation of net night flows.

Table A1 shows the initial measurement of leakages through the DMAs of the new Hihifo water system.

Table A1. Initial measurement of leakages through the DMAs.

DMA zone	Leakage rate (L/property/h)	Design (target)
Kolovai	6.4	7.5
‘Ahau	7.1	7.5
Kanokupolu	4.5	7.5
Ha’atafu	6	7.5
Production	0	0

The net night flow measured was 0.46 L/s (5.9 L/property/h) compared to the designed leakage rate of 0.59 L/s (20% of domestic demand or 7.5 L/property/h). It is crucial to understand that there is no watertight system and to undertake leakage works beyond this level is uneconomical.

Demand management and pumping strategies

The following demand management scenarios have been considered for the system:

- Normal;
- Rainwater as a supplementary source;
- Drought.

Scenario 1 – Normal conditions

The design allows 100 L/person/day under normal conditions. Daily average production of 236.6 kL/day can be supplied by 50% of the pumps at a total intake capacity of 259.2 kL/day. Domestic + non-domestic (20%) + leakage (25%).

Scenario 2 – Rainwater as a supplementary source

Assuming that rainwater usage will reduce demand to 80 L/person/day. Daily average production of 189.3 kL/day, a reduction of 25%, and can still be supplied by 50% of the pumps at a total intake capacity of 259.2 kL/day. Domestic + Non-domestic (20%) + Leakage (25%)

Scenario 3 – Under drought conditions

Assuming no supplementary rainwater usage which will get back to 100% reliance on underground water. Flow is restricted to 70 L/person/day. Under this condition water conservation measures are required to be strictly undertaken including restriction on non-domestic usage (reduce to 10% as in Table A2). The same strategy needs to be duplicated on reducing the leakage rate from 25% to 15% as in Table A2. Daily average production of 139.7 kL/day, a reduction of 69%, and can still be supplied by approximately 25% of pumps at a total intake capacity of 129.6 kL/day. Domestic + Non domestic (10%) + Leakage (15%)

The daily average production was the appropriate figure to use as the daily maximum was only used for the calculation of the capacity of the reticulation system (Table A2). In the worst case scenario the demand can be restricted to 40 L/person/day, i.e. the figure used in the analysis was very conservative.

Table A2. Demand scenario (normal, rainwater, drought conditions).

Code	Details/years	AGR	2013	2013	2013
[A]	Total population	0.40%	1577	1577	1577
[B]	No. of connections		263	263	263
[C]	Per capita demand (l/c/d)		100	80	70
[D]	Domestic demand	[A] x [C]/1000	157.7	126.2	110.4
[E]	Domestic demand	[D]/86.4	1.8	1.5	1.3
[F]	Non-domestic demand (kl/d)	[D] x [H]	31.55	25.24	11.04
[G]	Non-domestic demand (l/sec)	[F]/86.4	0.37	0.29	0.13
[H]	% of domestic (kl/day)		20%	20%	10%
[I]	Leakage (kl/d)	[L x M]	47.32	37.86	18.22
[J]	Leakage (l/sec)	[I]/86.4	0.55	0.44	0.21
[K]	Leakage (l/prop/hr)	[I] x 1000/24*[B]	7.5	6	2.8875
[L]	Total domestic and non-domestic (kl/d)	[F] + [D]	189.30	151.44	121.47
[M]	% of domestic and non-domestic		25%	25%	15%
[N]	Total demand (kl/day)	[L+1]	236.6	189.3	139.7
[O]	Total demand (l/sec)		2.7	2.7	2.7
	Design capacity				
[P]	Daily average demand (kl/day)	[F] + [D]	189.3	151.4	121.5
[Q]	Daily average production (m^3/d)	[L+1]	236.6	189.3	139.7
[R]	Daily maximum production (m^3/d)	[Q x 1.25]	295.8	236.6	174.6
[S]	Daily maximum production (l/s)	[R/86.4]	3.4	2.7	2.0
[T]	Peak hourly flow (l/sec)	[R/86.4 x 1.8]	6.2	4.9	3.6
		Percentage reduction	**100%**	**25%**	**69%**

Table A3. Pumping strategies (intake capacity).

Balance between design and intake capacity	Pump operation rate	25%	50%	75%	100%
Average pumping rate: 1.5 l/sec/well	No. of pump operation	1	2	3	4
Current no. of operational wells: 4	Average pump rate	1.5	1.5	1.5	1.5
Maximum intake capacity	Intake capacity (l/sec)	1.5	3	4.5	6
Maximum intake capacity	Intake capacity (kl/day)	129.6	259.2	388.8	518.4

Hydraulic water pressure

Figure A2 below shows the result of pressure logging at Ha'atafu, the highest point at the extremities of the reticulation system, as part of the assessment after the augmentation of the new system. The minimum pressure when supplied from the LLT tank was 2.1 m with a maximum pressure of 6.9 m. The same parameters were also measured when the supply switched to the HLT, with a minimum of 9.0 m and a maximum of 9.7 m.

The result confirms that the hydraulic performance of the new system meets the design objectives of having a minimum of 5 m at the highest point in the system. The village of Ha'atafu can be supplied from both the LLT and HLT.

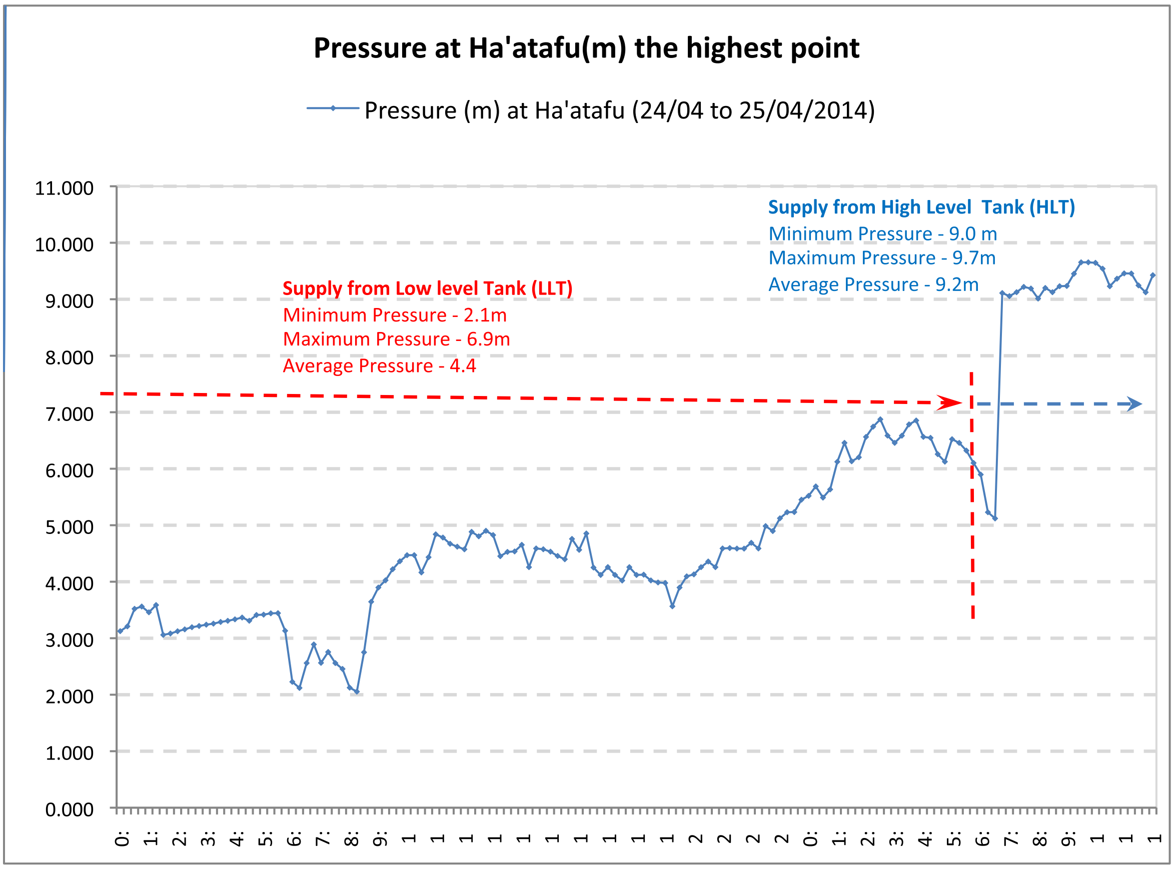
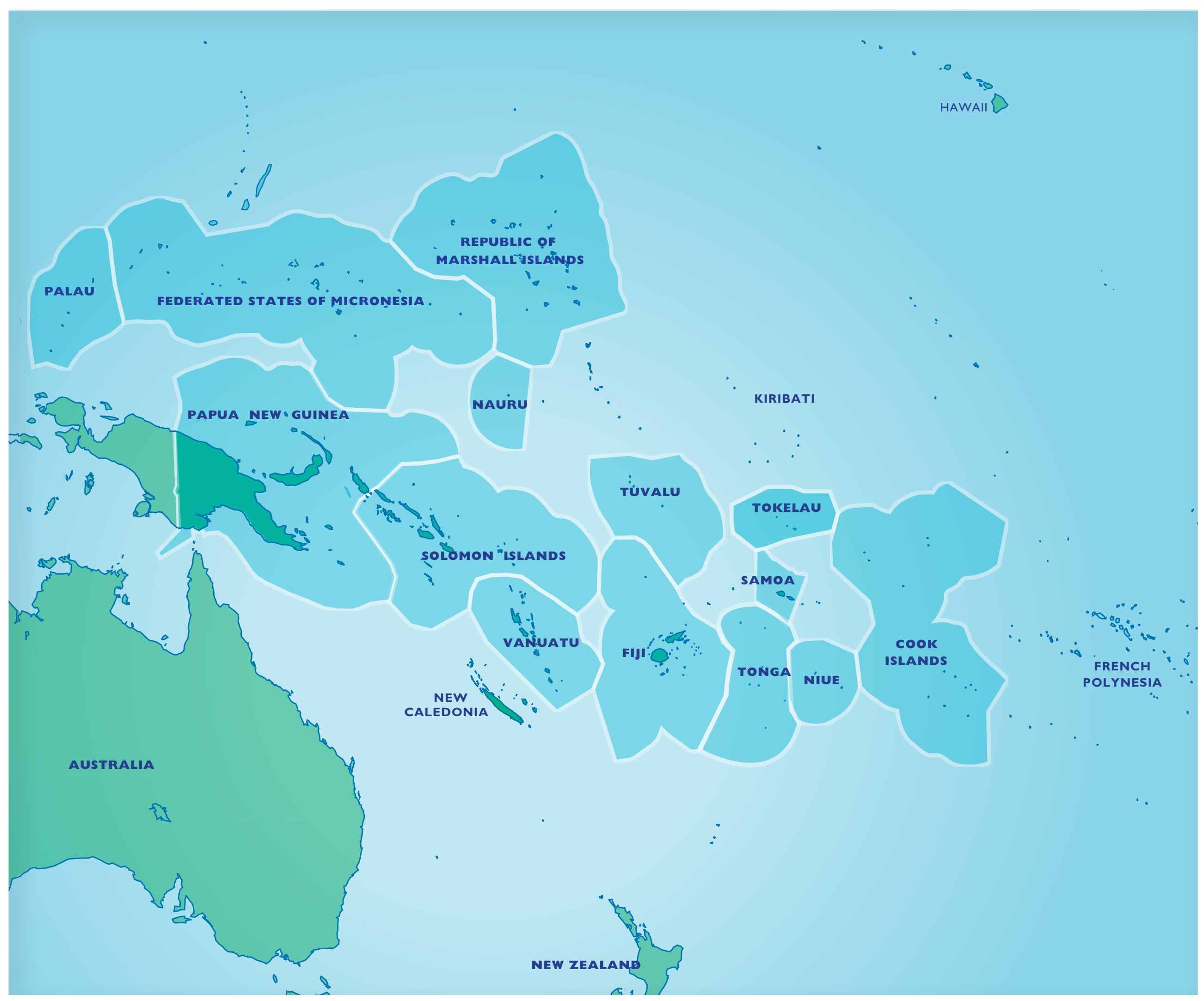


Figure A2. Pressure logging at Ha'atafu.



PACC – building adaptation capacity in 14 Pacific island countries and territories

PACIFIC ADAPTATION TO CLIMATE CHANGE (PACC) PROGRAMME

The PACC programme is the largest climate change adaptation initiative in the Pacific region, with activities in 14 countries and territories. PACC is building a coordinated and integrated approach to the climate change challenge through three main areas of activity: practical demonstrations of adaptation measures, driving the mainstreaming of climate risks into national development planning and activities, and sharing knowledge in order to build adaptive capacity. The goal of the programme is to reduce vulnerability and to increase adaptive capacity to the adverse effects of climate change in three key climate-sensitive development sectors: coastal zone management, food security and food production, and water resources management. PACC began in 2009 and is scheduled to end in December 2014.

The PACC programme is funded by the Global Environment Facility (GEF)'s Special Climate Change Fund (SCCF) and the Australian Government with support from the United Nations Institute for Training and Research (UNITAR) Climate Change Capacity Development (C3D+). The Secretariat of the Pacific Regional Environment Programme (SPREP) is the implementing agency, with technical and implementing support from the United Nations Development Programme (UNDP).

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The PACC Technical Report series is a collection of the technical knowledge generated by the various PACC activities at both national and regional level. The reports are aimed at climate change adaptation practitioners in the Pacific region and beyond, with the intention of sharing experiences and lessons learned from the diverse components of the PACC programme. The technical knowledge is also feeding into and informing policy processes within the region.

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