PACC TECHNICAL REPORT 7

JULY 2014

Design for improved water supply and water management in Hihifo district, Tonga

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Design for improved water supply and water management in Hihifo district, Tonga. Apia, Samoa : SPREP, 2014.

p. cm. (PACC Technical Report No.7)

ISSN 2312-8224

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This publication is also available electronically from SPREP's website: www.sprep.org

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ACKNOWLEDGEMENTS

This report is an output of the Tonga PACC project. It was written by Quddus Fielea, and reviewed by a team that included Netatua Pelesikoti and Peniamina Leavai (SPREP), Ilisapeci Masivesi (Australian Department of Foreign Affairs and Trade), Gabor Vereczi (UNDP), and Paula Taufa (Tonga), Haden Talagi (Niue), Joseph Cain (Marshall Islands), Taiane Apelu (Tuvalu) and Jewel Toloa (Tokelau) (PACC Project Coordinators).

EXECUTIVE SUMMARY

This report provides design details and costs for the proposed long-term improvements to the water supply system at Hihifo on the island of Tongatapu, Kingdom of Tonga. This is part of the demonstration project under the Pacific Adaptation to Climate Change (PACC) programme. The proposed project provides an ideal opportunity for the Hihifo community to use local water resources sustainably and, hence, enhance the resilience of these water resources to the impacts of current climate variability and projected climate change.

The present public water (or 'town water') supply system at Hihifo is based on groundwater pumped directly into the distribution system and has shown a high level of unreliability and poor water quality for a number of years. This is due largely to operational problems associated with the current water supply system. The Hihifo Village Water Committee does not have the necessary funding and expertise to operate and maintain the current system.

Investigations by the PACC Technical Working Group have shown the potential for improvement in the operation of the existing system with appropriate design and construction techniques. The proposed water supply system improvements are primarily focused on the villages of Kolovai, 'Ahau, Kanokupolu and Ha'atafu. As Fo'ui and Ha'avakatolo villages already have separate water supply systems, they are not included in the improvement project except for provision of water meters for service connections, two solar pumps, some rainwater tanks and installation of isolating valves on the pipelines to these two villages to provide emergency water supply if required.

As part of the development of this report, a survey was conducted of around 88% of the Hihifo residents. The results highlighted that the future of Hihifo's water supply requires the integration of rainwater and public water supply system. The PACC project has therefore incorporated rainwater harvesting as a supplementary source to groundwater.

The following measures are proposed to improve the water supply for the residents of Hihifo in terms of water quality, pressure and reliability.

(a) Improve access to public water supply by:

i. Providing a 3.5 km long 150 mm diameter PVC transmission pipeline ('rising main') and a new pipe reticulation system for the four Hihifo villages of Kolovai, 'Ahau, Kanokupolu and Ha'atafu. The existing 100 mm PVC distribution pipeline to feed the water consumers at Ha'atafu.

ii. Increasing the water storage capacity to around 136 kL consisting of both an elevated storage ('high level tank' or HLT) and ground level storages ('low level tanks' or LLT).

iii. Feeding all water connections in the four villages using two water supply zones to water control pressures. To do this, the higher elevation parts of Kolovai and all of Ha'atafu will be fed from the HLT and most of Kolovai and all of 'Ahau and Kanokupolu villages will be fed from the LLT.

iv. Adopting a minimum residual water pressure of 5 m at peak hours in the highest areas of the reticulation systems in both water supply zones.

v. Installing transfer pumps to enable water to be pumped from the LLT to the HLT, if required.

vi. Installing hydrants for fire fighting purposes and for emergency use.

vii. Reducing unscheduled interruptions to public water supply by installation of flow control valves and training in system operation. These valves will also enable possible step testing for leakage detection purposes.

(b) Improve the quality of public water supply by:

i. Having a minimum of five production wells/boreholes and three monitoring wells to meet demand in the year 2031.

ii. Setting out the new wells/boreholes 150 m apart, and having a maximum pumping rate of 1.5 litres per second (L/s) per well/borehole compared to the current pumping rate per well of 3 L/s. This strategy will minimise the pumping impact on the groundwater salinity.

iii. Adopting a freshwater upper limit in terms of electrical conductivity (a measure of salinity) of 2,500 µS/cm.

iv. Carrying out regular monthly groundwater level and salinity measurements of pumped groundwater at all five production wells/boreholes.

v. Carrying out salinity monitoring at the three monitoring boreholes every 3 months.

vi. Carrying out bacteriological, chlorine residual and nitrate tests at each well/borehole.

(c) Improve the pumping systems from the wellfield by:

i. Installing three solar pumps and two diesel pumps at the five production wells/boreholes. This will also act to decrease operational costs and the risk of groundwater pollution from oil and diesel. A conservative estimate of 2/3 solar pumping and 1/3 diesel pumping is assumed.

ii. Provide electricity back-up to the solar pumps to enable pumping to occur on cloudy days.

(d) Implement demand management and leakage control strategies with set targets by:

i. Allowing for a per capita demand of 100 L/person/day.

ii. Further reducing demand to 80 L/person/day where rainwater harvesting systems are available.

iii. Allowing for a leakage rate equivalent to 7.5 L/property/hour.

iv. Installing district flow meters at strategic locations in the system.

v. Installing connection meters at all houses and other buildings.

vi. Using the meter data to monitor water usage and help identify the location and magnitude of leakages within the distribution system.

vii. Repairing household leaks prior to the new system being commissioned.

viii. Implementing a leakage control programme with trained staff. This is essential in order to maximise the benefits of the improved water supply infrastructure.

(e) Increase access to rainwater by providing 30 rainwater tanks with gutters, fittings, downpipes and concrete bases to selected houses.

(f) Increase the level of service provided by the Hihifo Village Water Committee (HVWC) by:

i. Offering a better maintenance service for all leaks by increasing the plumbing capability of HVWC personnel, re-training meter readers as plumbers, providing more transport, and improving fault reporting and responses, including car to base communications.

ii. Moving the office to the main town to make payments easier and provide a venue for other demand management activities.

iii. Conducting surveys of consumers to gauge response to the water supply improvements in terms of water quality, pressure and reliability.

iv. Becoming a provider of plumbing services. Consideration will be given to including gutter and downpipe maintenance and new plumbing.

(g) Contribute to the community by increasing public awareness on issues such as:

i. Health aspects of water.

ii. Water use efficiency.

iii. Maintenance of rainwater harvesting systems (gutters, downpipes and tanks).

iv. Potential impacts from climate change as well as current climate variability.

This aspect will be a component of the training and public awareness programme.

(h) Encourage economic growth by extending water supply service to all holiday resorts in Hihifo. This aspect is covered by the project.

It is recommended that the Hihifo water supply improvement project be implemented at an estimated cost of approximately TOP 1,712,000 within the next 12 months.

ABBREVIATIONS

AC	Asbestos cement
AusAID	Australian Agency for International Development
EC	Electrical conductivity
GEF	Global Environment Facility
HLT	High level tank (elevated water storage on a tankstand)
HVWC	Hihifo Village Water Committee
JICA	Japan International Cooperation Agency
kL	Kilolitres
kL/day	Kilolitres per day
L	Litre(s)
L/person/day	Litres per person per day
L/s	Litres per second (a measure of flow)
LLT	Low level tank (ground level water storage)
m^3	Cubic metre(s)
MECC	Ministry of Environment and Climate Change
MOH	Ministry of Health
PACC	Pacific Adaptation to Climate Change [programme]
PMU	Project Management Unit
PS	Pump station
PVC	Polyvinyl chloride
rpm	Revolutions per minute
RRJ	Rubber ring joint
SWJ	Solvent weld joint
TOP	Tongan Pa'anga
TWB	Tonga Water Board
VWC	Village Water Committee
µS/cm	Microsiemens per centimetre (measure of electrical conductivity, or salinity)

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.

This report provides design details and costs for the proposed long-term improvements to the water supply system at Hihifo on the island of Tongatapu, Kingdom of Tonga (Figures 1 and 2). This is part of the demonstration project under the Tonga PACC project. The proposed project provides an ideal opportunity for the Hihifo community to use local water resources sustainably and, hence, enhance the resilience of these water resources to the impacts of current climate variability and projected climate change.

Figure 1. Map of Tongatapu (source: Google Maps, 2011).

Figure 2. Hihifo district, PACC pilot site (source: Google Maps, 2011).

Hihifo is in a better position than a more industrialised community to move to sustainable use of water resources. It is not burdened with massive water supply infrastructure, rainwater use is part of the local culture, and there is no expensive reticulated sewerage system. Individual water usage is low, and the community can generate enough money to pay for the operation and maintenance of the water supply system. To take advantage of this situation, adaptation activities are proposed for implementation in water resources management to promote water conservation, water use efficiency, protection of groundwater, use of renewable energy for pumping and rainwater harvesting. Implementation of demand management strategies will also assist in enabling more sustainable use of local groundwater resources and rainwater for Hihifo residents.

The goal of the Tonga PACC project, as stated in PACC (2007), is to "increase the resilience of the water resources management sector and to enhance adaptive capacity of villages/communities and socio-economic activities to climate change and sea-level rise." PACC (2007) further states that this goal will be achieved through a project "piloting climate change adaptation in water resources management in Hihifo District, Tongatapu Island focusing on sustainable use and management of water resources."

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.

2. CURRENT WATER SUPPLY SYSTEM

2.1. Outline

The public water supply system for the district of Hihifo on the island of Tongatapu is operated by the Hihifo Village Water Committee (HVWC) under the jurisdiction of the Ministry of Health. Groundwater is 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 (AC) pipeline. No water storage is used in the system. The numbers and layout of consumer connections supplied from these two pipelines is not known at this stage. Further details are provided in section 2.4.1.

The village of Fo'ui has recently completed the construction of its own water supply system funded by the Japan International Cooperation Agency (JICA). The village of Ha'avakatolo runs its own water supply system and is currently under consideration by JICA for further upgrading and improvement. This leaves the four villages of Kolovai, 'Ahau, Kanokupolu and Ha'atafu under the control of the HVWC.

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

Water from the public water supply system is used primarily for flushing toilets, cleaning the house, cooking and watering animals (PACC, 2014). The present high salinity of the public water is a reason for its limited use. By comparison, rainwater is 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, 2014).

2.2. Water supply problems

The public water supply for Hihifo has suffered from problems of unreliability and high salinity for a number of years. These aspects are considered in more detail below.

2.2.1. Unreliability

Unreliability of the water supply in the past has been caused by a number of problems including:

- Failure of pumps and motors at wells and subsequent delays in repairing the problems;
- Large leakage rates in the system;
- Financial problems (e.g. lack of funds to ensure effective repair and maintenance is undertaken);
- Absence of storage capacity at appropriate elevation to generate water pressures and volumes to sustain the water demand within the specified area;
- Very high flow restriction when water is transferred from the newer 100 mm PVC pipeline to the old 80 mm AC pipeline.

One conclusion is that a concentrated leak reduction effort is required in order to maximise the benefits of any improved water supply infrastructure and improve both its reliability and the water quality.

2.2.2. High salinity

The average salinity of the groundwater (measured as electrical conductivity or EC) pumped from most of the previously used wells which fed the Hihifo water supply system during the period 1965–2007 (Table 1) was within the adopted limit for fresh groundwater of 2,500 µS/cm (Table 2). However, the well at Ha'avakatolo (well 155) has an average EC above this adopted freshwater limit. Also, the maximum EC values for all wells except well 153 were above the adopted freshwater limit.

Table 1. Summary of groundwater salinity in Hihifo wells, 1965 to 2007

Well No.	Average salinity (EC, µS/cm)	Monitoring period	Highest salinity (µS/cm)	Month, year
151 (Fo'ui)	2,400	1990–2005	5,000	December,1993
152 (Fo'ui)	1,600	1990–2007	2,900	May, 1990
153 (Fo'ui)	1,900	1965–2006	2,200	October, 2006
154 (Fo'ui)	2,000	1990–2004	2,900	May, 1990
155 (Ha'avakatolo)	3,400	1965–2007	6,700	November, 1996

Note: EC values are shown to the nearest 100 µS/cm

Table 2 lists some significant EC values for groundwater and describes these in terms of water quality and water use.

Table 2. Groundwater salinity (EC) values and description.

Electrical conductivity (µS/cm)	Description
500	The water would not taste salty, but is still difficult to lather due to calcium concentration from limestone coral
1,500	At this level chloride ion concentration is around 250 mg/L, which is the WHO drinking water guideline value based on taste considerations (WHO, 2011). This is the target freshwater maximum for Tonga.
2,500	Suggested limit of freshwater for water resources analyses

It is noted that the EC values of all the wells shown in Table 1, and hence the EC of the water supplied to Hihifo residents, are high compared with average EC value of approximately 1,000 µS/cm for groundwater supplied to Nuku'alofa consumers from the Mataki'eua-Tongamai wellfield. The most likely reason for the higher salinity groundwater being supplied to Hihifo residents 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 owing to the thin freshwater lens conditions if pumping continues at current rates. Another possible reason for some high EC readings is that the salinity meter was not properly calibrated.

2.3. Present water production

The water demand assessment, as presented in this report, is based on a number of flow estimates from logged flow measurement data at Hihifo in December 2010.

The present daily water production, as logged with an ultrasonic flow meter, is approximately 545 kL/day if the two operational pumps are running 24 hours a day. The two pumps produce water at the following rates: (a) pump at well 152: 3.35 L/s (approx 290 kL/day) and (b) pump at well 151: 2.95 L/s (255 kL/day). It is noted that these flows supply existing consumers but much of it is lost through leakage.

Future water demand and production is considered in section 4.2.

2.4. Previous improvement efforts

2.4.1. Installation of 100 mm PVC pipeline

A number of attempts have 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 AC distribution pipeline. The basis for this addition is not known as it would have been more sensible to relocate all service connections to the 100 mm PVC main. It is not known to date which connections are supplied from both pipelines. The set up and layout of the pipe connections from the 100 mm PVC pipeline to the 80 mm AC pipeline adds a lot of restrictions when the water is transferred between the two pipelines. Water is transferred from the 100 mm to the 80 mm pipeline via 50 mm pipes which reduce to 32 mm to make the final connection to the 80 mm pipes. It is expected that the majority of the service connections to all the villages is supplied from the 80 mm (secondary) distribution pipeline. The purpose of constructing the new 100 mm main to boost the delivery of water was defeated by continuing to use the 80 mm AC pipeline for distribution purposes.

2.4.2. Installation of elevated tank

The second attempt to rectify the low pressure problems in the Hihifo water supply system was the installation of an elevated tank to supply the villages of Kolovai, 'Ahau, Kanokupolu and Ha'atafu. The idea was to fill the elevated tank from the distribution system during the low demand hours when water pressure is high and use the stored water in times of peak demand hours to maintain water pressure. One 50 mm PVC pipeline was used as the combined inlet and outlet pipe to the tank. This type of elevated storage tank system (often called 'floating on the system') works well if the peak demand for water is satisfied with the stored water from the overhead tank. However, the installation of the elevated tank resulted in no improvement to water pressure in the Hihifo distribution system.

3. PROPOSED PROJECT

3.1. Overview

The investigations outlined above have now progressed to a stage where it is feasible to upgrade the water supply to the current settlement and tourist resort within the service area. Training will be provided to HVWC so that it will be able to operate and maintain the new system.

This project is intended to provide long-term benefits, particularly in terms of water quality and reliability. Achievement of the full potential benefits of the project depends on lowering operational costs due to the introduction of solar pumps, lowering of pumping rates from each well, and implementation of a strategic leakage minimisation programme.

3.2. Design objectives

Specific design objectives for the water supply improvements are presented below in terms of typical technical and financial parameters for water supply systems.

- 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. This EC value has been used as the limit of fresh groundwater in studies for Tonga and other Pacific islands (e.g. White et al., 2009) and is equivalent to about 5% of seawater EC. It is noted that there is no WHO drinking water quality guideline for EC; WHO drinking water guidelines (WHO, 2011) provide values for other measures of salinity such as chloride ion concentration.
  b. it meets required bacteriological quality at all times. Normally, this means that no faecal coliforms should be detected in the water supplied to consumers.
- 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.

3.3. Design strategy

The strategy to achieve the above design objectives has the following main features.

- Install three solar pumps with electricity backup to minimise operational costs of pumping. The electricity backup will enable these pumps to be operated during cloudy periods and possibly at night to keep up with demand. The use of solar pumps will assist in reducing operational costs.
- Replace existing diesel pumps with new pump sets to provide additional pumping at night time or during cloudy periods if solar pumping does not keep up with water demand.
- Install 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 (see Appendix 1) 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.

3.4. Project components

The proposed project consists of the following main components.

- Use of two existing operational dug wells at Hihifo equipped with diesel pumps.
- Drilling of three new boreholes to replace existing collapsed boreholes. The new boreholes are 150 m apart and will each pump at a rate of 1.5 L/s compared to the current 3 L/s.
- Installation of solar pumps at each of the three new boreholes.
- Construction of proper pump houses and security fences at all pumping sites.
- Installation of a chlorination unit to provide treated water.
- Construction of a new elevated tank (HLT) and ground level storage tanks (LLT) 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.
- Replacement of existing distribution pipelines and use of the existing 100 mm transmission pipeline 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.
- Construction of a new 150 mm main pipeline to transfer the water from the wellfield to the storage tanks at Kolovai.
- Extension of water supply services to all holiday resorts within the Hihifo water supply area.
- Installation of flow control valves and district meters for leak detection purposes.
- Training of HVWC personnel in basic plumbing, motor and pump maintenance, leak detection and administration.
- Establishment of an office at a central location for customer liaison, financial and administrative work of the HVWC.
- Establishment of a workshop (for repairs and maintenance) at the water storage site.
- Provision of 30 rainwater tanks with gutters, fittings, downpipes and concrete bases to selected houses.

4. DESIGN PARAMETERS

4.1. Overview

Table 3 summarises the main components of the proposed Hihifo water supply improvements. As previously mentioned, the villages to be supplied will be Kolovai, ‘Ahau, Kanokupolu and Ha’atafu.

The proposed water supply distribution system will be split into two pressure zones (Zones 1 and 2) due to the elevation difference between the higher and lower settlements in Hihifo. The two zones are required to ensure that all connections have adequate water pressure (not less than 5 m) but not excessive pressure (so as to minimise leakages from a demand management viewpoint).

The pumping strategy using solar pumps for the water supply system will provide significant energy savings and hence cost benefits rather than relying solely on diesel pumps. This project offers an ideal opportunity to reduce energy costs by the introduction of solar energy.

Table 3. Main components of the proposed Hihifo water supply improvements

Description	Pressure zone	Storage	Water source	Pumps
Supply to higher elevation parts of Kolovai and all of Ha’atafu	Zone 1	High level tank (HLT)	Wellfield on south-eastern margin of Hihifo township using existing wells and new boreholes	Combination solar and diesel (with capacity of each pump set to 1.5 L/s)
Supply to most of Kolovai and all of ‘Ahau and Kanokupolu	Zone 2	Low level tanks (LLT)		

4.2. Demand and production forecasts

The Hihifo water supply improvement project has been designed on the basis of the following population estimates and water supply design guidelines.

- Planning horizon: 2031 (20 years from 2011)
- Villages to be included: Kolovai, ‘Ahau, Kanokupolu and Ha’atafu, except for connection meters which will also be fitted in Fo’ui & Ha’avakatolo
- Total population: 1,534 (from 2006 census)
- Assumed growth rate: 0.4% (for population and connections)
- Design population (in 2031): 1,695
- Number of connections: 430 which allows for the 401 connections in all six villages (from Faka’osi and Takau, 2011) and 29 additional connections (see section 4.5.5).

The Tonga Water Board has adopted the following design guidelines for village water supply projects:

- Domestic demand: 100 L/person/day, reducing to 80 L/person/day (with rainwater)
- Non-domestic demand: 20% of domestic demand
- Unaccounted for water (mainly leakage): 25% of domestic plus non-domestic demand, reducing to 15% (using leak control strategies).

It is becoming increasingly common for western urban utilities to set demand targets and manage demand rather than simply supplying what might be used. In the USA, these targets are beginning to become law, and there is a whole industry built around the reduction of leakage and minimising of water use.

Adopting the same approach, the following targets have been applied to the proposed Hihifo water supply improvement project:

- Leakage capped at an average of 7.5 L/property/hour;
- Design domestic consumption of public water capped at 100 L/person/day reducing to 80 L/person/day where supplementary rainwater is available.

Table 4 summarises the key design figures for water demand and production. From this table, the design demand and required production in 2031 is 254 kL/day.

Table 4. Water demand and production forecasts

Identifier	Item	Notes	2006	2011	2031
[A]	Total population	Assumed AGR = 0.4%	1,534	1,565	1,695
[B]	No. of connections (for water demand calculations)	Assumed AGR = 0.4%	256	261	282
[C]	Per capita demand (L/person/day)	Assumed value	100	100	100
[D]	Domestic demand (kL/day)	[A] × [C]/1000	153	157	170
[E]	Domestic demand (L/s)	[D] / 86.4	1.78	1.81	1.96
[F]	Non-domestic demand (% of domestic)	Assumed %	20%	20%	20%
[G]	Non-domestic demand (kL/day)	[D] × [F]	30.7	31.3	33.9
[H]	Non-domestic demand (L/s)	[E] x [F]	0.36	0.36	0.39
[I]	Total domestic and non-domestic (kL/day)	[D] + [G]	184	188	203
[J]	Leakage (% of domestic and non-domestic)	Assumed %	25%	25%	25%
[K]	Leakage (kL/day)	[I] × [J]	46.0	47.0	50.9
[L]	Leakage (L/s)	[K] / 86.4	0.53	0.54	0.59
[M]	Leakage (L/property/hour)	[K] * 1000 / (24 x [B])	7.5	7.5	7.5
[N]	Total demand (kL/day)	[I] + [K]	230	235	254
[O]	Total demand (L/s)	[N] / 86.4	2.66	2.72	2.94
[P]	Daily average production (kL/day)	[N]	230	235	254
[Q]	Daily maximum production (kL/day)	[P] × 1.25	288	293	318
[R]	Daily maximum production (L/s)	[Q] / 86.4	3.3	3.4	3.7
[S]	Peak hourly flow (L/s)	[R] × 1.8	6.0	6.1	6.6

Notes:

- *AGR = annual growth rate.*
- *The 2006 population census reveals that the population of Hihifo is declining and is expected to be stable. A low AGR of 0.4% has been adopted for planning purposes.*
- *The number of connections shown is for the four villages Kolovai, 'Ahau, Kanokupolu and Ha'atafu. The total number of connections for ordering of connection meters is greater as it includes meters for connections in Fo'ui and Ha'avakatolo.*
- *Daily maximum production (L/s) is used for designing pumping facilities.*
- *Peak hourly flow (L/s) determines the sizing diameters of pipelines.*

4.3. Sources of supply

Options for the supply of water to Hihifo are:

- Rainwater via private tanks;
- Rainwater via community tanks;
- Groundwater via a public (town) water supply system;
- Groundwater from wells.

For the purposes of this report, groundwater from wells is not considered further as this source of water is subject to pollution from sanitation systems and animals.

4.3.1. Rainwater harvesting

This report is not based on any detailed investigation of the potential of rainwater to make a significant contribution to meeting the water needs of the residents of Hihifo. The socio-economic study (PACC, 2014) showed that all households used rainwater from household tanks as the only or main source of drinking water although no estimates were made of the quantity of rainwater used for drinking purposes. Given that Tongatapu has experienced significant droughts, there is a real need to have an alternative water supply in the project area which can be used to supplement rainwater when it is available and to be used instead of rainwater when rainwater is not available in sufficient quantity. Rainwater is more vulnerable than groundwater to the impacts of drought under current climate conditions. The vulnerability of rainwater to the impacts of drought could possibly increase with climate change.

Therefore, it is proposed that the planning and implementation of water supply improvements for Hihifo should consist of *improving residents' access to both rainwater and public water*. Although the recommendation for conjunctive use of rainwater and public water remains, the Hihifo water supply improvements focus on public water supply with only 11% of the budget being allocated to rainwater harvesting improvements due mainly to the limited budget. The project will provide thirty 10 kL rainwater tanks to be distributed to selected Hihifo residents with the necessary gutters, downpipes, concrete bases, outlet taps and fittings.

Additional rainwater harvesting improvements can be considered if more funding is made available. Guidelines should be prepared to assist the Hihifo people with best practices about the use of rainwater and maintenance of gutters, downpipes and tanks.

4.3.2. Groundwater development (existing wells and new boreholes)

The socio-economic study (PACC, 2014) clearly states the need to retain groundwater as the major source of additional water supply for Hihifo.

The wellfield layout at Hihifo is a line of wells and boreholes at 150 m spacings. All existing and new boreholes have been lined with new PVC casing and screen. The extraction rate from each well will be set at a maximum of 1.5 L/s. The current wells and new boreholes are designed to provide sufficient capacity to meet the total demand until the year 2031.

Details of wells, boreholes and pumps at the Hihifo wellfield are shown in Table 5 and Figure 3.

Table 5. Details of wells, boreholes and pumps at the Hihifo wellfield.

HIHIFO WATER PROJECT			
Well and boreholes	**Present condition and recent work**	**Proposed pump**	**Notes**
Well 1	Dug well and needs to be developed and cleaned	Diesel power (PACC)	Existing dug well
Well 2	Dug well; now operational	Diesel power (PACC)	Existing dug well
New borehole 1	Has been drilled, not yet operational	Solar power with Powerpaks (PACC)	
New borehole 2	Has been drilled, not yet operational	Solar power with Powerpaks (PACC)	
New borehole 3	Has been drilled, not yet operational	Solar power with Powerpaks (PACC)	
FO'UI WATER PROJECT			
Existing Borehole	Currently working		
New Borehole 4	Has been drilled, not yet operational	New solar power with Powerpaks (PACC)	
HA'AVAKATOLO WATER PROJECT			
Well 1 (in Ha'avakatolo, not shown in Figure 3)	Currently working (new helical rotor pump recently by JICA)	New solar power with Powerpaks (PACC)	Dual system (existing helical and new solar power with Powerpaks (PACC)

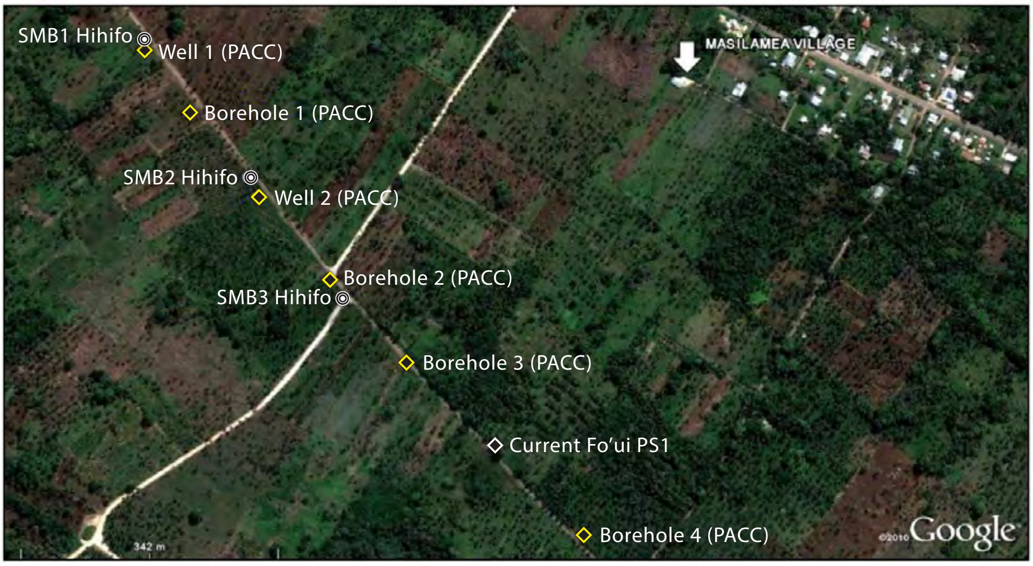


Figure 3. Well and borehole locations (source: Google Maps).

4.3.3. Water quality of groundwater

In June 2011, the average salinity (measured in electrical conductivity or EC units) of the groundwater at the wells and boreholes shown in Figure 3 was approximately 2,000 µS/cm. The new pumping strategy using more pumps and lowering individual pump rates from 3 L/s to 1.5 L/s is expected to result in lower average conductivity than 2,000 µS/cm.

Three salinity monitoring boreholes (HihiSMB1, HihiSMB1 and HihiSMB3) were drilled in the western and central part of the Hihifo wellfield (see Figure 3) in September 2011. The initial salinity monitoring test results from September 2012 (Figure 4) show 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 described in Table 2.

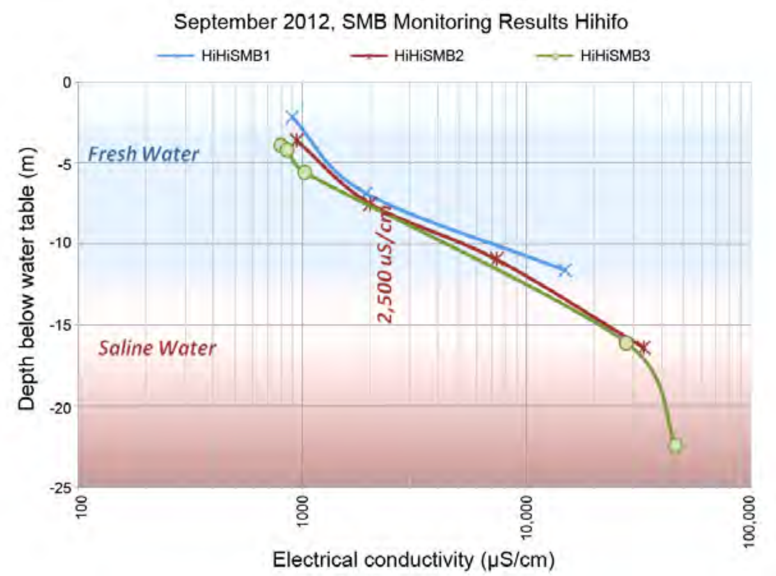


Figure 4. Salinity profiles for the Hihifo salinity monitoring boreholes, September 2012.

Regular monitoring of salinity and bacteriological water quality will be required. Because of the nature and recharge characteristics of the freshwater lens, over-pumping will cause deterioration in water quality due to rising salinity. Hence, the sustainable development of Hihifo's water resources will *always* require ongoing monitoring and demand management of the public water supply. In addition, maximising water from other sources, particularly rainwater, is most important.

4.3.4. Well heads and discharge pipes

The well heads will be covered with concrete slabs to prevent entry of foreign matter into the wells or boreholes. A number of tees and reducer couplings will be required to connect the discharge pipes from each pump to the main pipeline. In addition, a number of elbows and long radius bends will be required. Each discharge pipe will be fitted with an isolating valve, reflux valve (to avoid backflow into the well), flow meter, sampling tap, pressure gauge, and pressure relief valve.

4.3.5. Sustainable yield and pumping rates

To ensure that pumping (groundwater extraction) from the Hihifo wellfield at the western boundary of the Tongatapu freshwater lens does not adversely affect the sustainability of the lens, it is necessary to ensure that:

(a) the overall extraction (pumping) rate does not exceed the estimated sustainable yield of the lens; and

(b) pumping rates at each well or borehole are sufficiently low to minimise drawdown and, hence, avoid up-coning of the underlying transition zone.

A reasonably conservative average rate of pumping (1.5 L/s) was adopted for each well or borehole in the Hihifo wellfield. By comparison, the total current pumping has been approximately 2.5 to 3 L/s in recent months. Thus, the total current pumping is considerably greater than the proposed pumping. The long-term sustainable yield of the Hihifo wellfield will be confirmed once a reasonable amount of data is collected from the pumping wells and boreholes and the recently installed salinity monitoring bores. The salinity monitoring boreholes will enable the effects of pumping and recharge variations on the freshwater and transitions zones to be analysed.

The five pumps (three solar and two diesel) for the Hihifo water improvement project will be capable of supplying the design maximum daily production requirement of 318 kL/day in 2031 (see Table 4). The solar pump (2,100 watt) analysis in Table 6 reveals that each solar pump is capable of producing an average of 98 kL/day at 26 m (to the LLT) and 87 kL/day at 35 m (to the HLT).

Hence, the proposed three solar pumps would be able to supply 294 kL/day at 26 m head and 261 kL/day at 35 m head assuming good solar radiation. These combined solar pump flow rates are equivalent to 92% and 82%, respectively, of the maximum production requirement in 2031. For the maximum production requirement of 288 kL/day in 2011 (see Table 4), these combined solar pump flow rates are equivalent to 102% and 91%, respectively. The imbalance between demand and supply from the solar pumps would need to be supplemented by the use of the two diesel powered pumps.

It is noted that the average daily pumping rate of 98 kL/day for each solar pump is equivalent to an average pumping rate over 24 hours of about 1.13 L/s. This is less than the recommended average pumping rate of 1.5 L/s. The actual pumping rate for each solar pump during the daytime hours when solar radiation is good will obviously be higher than this average rate. On a day with good solar radiation over 8 hours, the average pumping rate would be about 3.4 L/s during these 8 hours. This higher flow rate over part of the day is not considered to be a problem for the freshwater lens as it will be in an undisturbed condition for approximately 16 hours each day.

4.3.6. Types of pumps

SOLAR PUMPS

It is recommended that solar pumps be used and backed up by diesel pump to save on energy costs.

There are two options for solar pumping. These are the direct solar pumping option requiring no batteries, and the solar pumping option using batteries which are charged by solar energy from the panels. For the direct solar pumping option, pumping can only occur during daylight hours when there is sufficient solar energy to enable pumping to occur.

The direct pumping option would be more cost effective than the battery storage pumping option. The direct pumping option also has much lower maintenance requirements, as batteries require continual maintenance. While it has a disadvantage in terms of the higher pumping rate for shorter periods than the battery storage option, the direct pumping option has the same average pumping rate as the battery storage option and is not considered to be detrimental to the freshwater lens. The direct pumping option is therefore recommended.

Additional pumping can occur using electricity supplied via Powerpaks to the solar pumps. It is important that such Powerpaks be used only on cloudy days when there is insufficient solar pumping. This method of pumping should not be used at night to supplement solar pumping on days of good solar radiation, otherwise sustainable pumping rates are likely to be exceeded. Training in the operation of the solar pumps with Powerpaks in conjunction with the diesel pumps will be required during the project.

Table 6 provides details of a potential solar pumping system which could be used for the proposed project.

Table 6. Mono solar pump system details and performance at 26 m and 35 m heads.

Item	Type	Performance	26 m (head)	35 m (head)
System type	Sun Sub	Average flow (kL/day)	98	87
System size (W)	2,100	Pump speed (rpm)	3,231	3,231
Array type	Tracking	Pump efficiency	89%	89%
MPPT size	Series 3000 SMC	Motor efficiency	88%	90%
Motor size	Series 3000	Cable loss	1%	1%
Pump size	SM151	System efficiency	45%	57%
Drive ratio	1.0			

DIESEL PUMPS

Helical rotor pumps powered by diesel engines should be used as back up to the solar pumps when necessary. They may be required during cyclones and other natural disasters, if the solar panels are removed and safely stored or if the solar panels are damaged. The diesel pumps may also be required to provide additional supply on days when the demand is at a maximum.

Mono 510 vertical rotor pumps are recommended for the two Hihifo wells. These are variable speed pumps that can pump at a rate of 1.5 L/s at motor speeds of approximately 1,100 rpm.

4.4. Design of pumping and reticulation system

Given the difference in elevation of the Hihifo area, it was considered necessary to separate the consumers within the four villages into two water supply zones to control water pressures, as mentioned in Section 4.1. As shown in Table 3, the higher elevation parts of Kolovai and all of Ha'atafu will be in one water supply zone (Zone 1) while most of Kolovai and all of 'Ahau and Kanokupolu villages will be in the other water supply zone (Zone 2).

Table 7 provides summary details of elevations and pumping heads for both water supply zones.

Table 7. Elevations and pumping heads for both water supply zones.

Pressure zone	Elevation of HLT inlet pipe (m)	Elevation of LLT inlet pipe (m)	Components of pumping head (m)			
			Bore static head	Static delivery head	Pipe friction	Total pumping head
Zone 1 (supplied from HLT)	33	–	8	25	2	35
Zone 2 (supplied from LLT)	–	24	8	16	2	26

4.4.1. Peak demand

As indicated in Table 4, an allowance has been made in the pipeline designs for an additional 80% flow to account for peak demand above average daily demand. Thus, the design flow for the pipelines is 1.8 times the average daily demand.

The peak demand factor of 1.8 was estimated as part of the pre-design study (Fielea and Fakakovikaetau, 2010).

4.5. System hydraulic performance

4.5.1. Hihifo distribution system

The Hihifo water supply system was designed using the program Epanet. It is not practical to list all the demand and pipe assumptions made in the design model in this report. For each demand case, a set of Epanet outputs was generated. Each output set includes a table of the pipe diameters and node numbers used for that case plus the pressures and flows for peak and off-peak times. The design outputs which meet all the design criteria adopted are reported in Appendixes 2 and 3.

Daily demand variations were modelled using the demand patterns of most rural villages in Tongatapu.

The pipe layouts for the whole Hihifo system including pumps and storage tanks are shown in Figure 5 and Appendix 4. Details of pipe layouts for each village are shown in Appendixes 5 to 9.

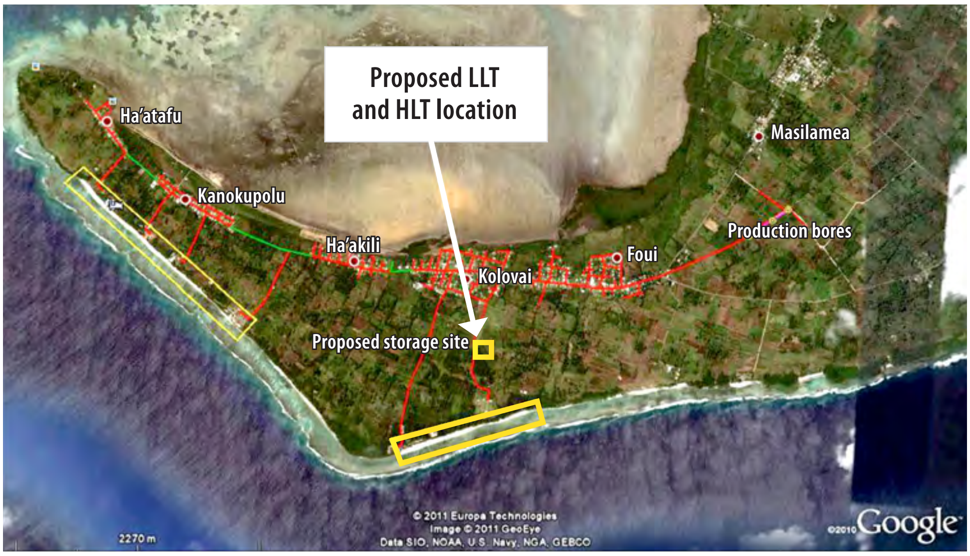


Figure 5. Layout of Hihifo pipe network and proposed location of high and low level tanks (source: Google Maps).

4.5.2. Location of ground storage and elevated tanks

The site selected for the ground storage tanks (LLT) and elevated tank (HLT) is located at 22 m above mean sea level at Kolovai (Figure 5). This is the best possible location for the LLT and HLT given its relatively high elevation and central location to supply the whole of Hihifo using the force of gravity. This will keep operation costs to a minimum and will better enable the HVWC to provide its service to the community.

Details of the HLT and LLT are as follows:

- HLT: a 22.7 kL tank on a 9 m high tankstand to serve the Zone 1 consumers;
- LLT: three 45.5 kL ground level storage tanks with a total capacity of 136 kL close to the location of the HLT to serve the Zone 2 consumers.

The total storage will be equivalent to about 58% of the estimated daily demand in 2011 and 54% of the estimated daily demand in 2031 (Table 4).

The arrangement of the pipework to the LLT and HLT will enable both storages to be utilised using different operational scenarios.

4.5.3. Pumping strategy and transfer pump

The normal pumping strategy will be to pump groundwater from the wellfield to the HLT with excess water being gravity fed via the HLT's overflow pipe to the LLT for distribution to the consumers in Zone 2. This pumping strategy is considered preferable as it saves the energy costs of re-pumping from the LLT to the HLT most of the time.

A transfer pump will be installed to enable water to be pumped from the LLT to the HLT at times when there is possible loss of pumping pressure in the pipeline from the wellfield to the HLT, and when it is still possible to fill the LLT. The transfer pump will be equipped with an electric diesel motor with float control switches (two in the HLT for low level start and high level stop and one in the LLT to prevent the pump from operating if the water level is too low). A backup diesel powered transfer pump is proposed to be installed to enable pumping to occur if the electricity supply is not available.

The arrangement of pipework allows for switching the flow between the LLT, HLT and the main distribution pipelines.

4.5.4. Pipelines

Details of the proposed transmission pipeline from the wellfield to the proposed location of the storage tanks are:

- Approximately 3.5 km in length from the wellfield to the storage tanks at Kolovai;
- Constructed from 150 mm diameter class 9 PVC pipe;
- The pipeline will have a capacity of 15 L/s, equivalent to pumping from 10 wells, each pumping at 1.5 L/s. By comparison a 100 mm diameter class 9 PVC pipe has capacity of about 9 L/s, equivalent to six wells, each pumping at 1.5 L/s. The 150 mm diameter option is recommended as it would allow for a reasonable increase in flow in the future, if required;
- The pipeline is expected to cost in the order of TOP 71,000.

In addition to the 150 mm transmission pipeline above, other PVC pipes in the proposed distribution networks vary in diameter from 100 mm to 80 mm, 50 mm, 40 mm, 32 mm, 25 mm and 20 mm. Service connections to houses will be 15 mm PVC pipes.

4.5.5. Water metering

The need for water meters on connections to monitor flow is a crucial element of demand management. This will enable the monitoring of system leakage as well as enabling water charges to consumers to be based on actual water usage as opposed to a flat fee.

Monitoring of flows using meters at all pumps, outflows from tanks and other key locations in the distribution system and at connections will enable a 'water balance' of the hydraulic system to be calculated each month. This is essential to monitor leakage in the whole hydraulic system from water sources to consumer meters. The following metering arrangement will be located at various strategic points in the water systems as follows:

- Five 50 mm flow meters at the outlet pipes from each of the proposed five pumping wells/boreholes. These meters are necessary to monitor the amount of groundwater pumped from each well;
- Two 100 mm flow meters will be installed on the outlets of the HLT and LLT;
- Five 100 mm flow meters at the upstream side of each village within the pipe system for water balance and leakage detection purpose;
- 430 x 15 mm flow meters at each service connection in all six villages. This allows for a total of 401 connections with an additional 29 meters (about 6% of total) for additional households and/or other buildings with water connections. These meters are necessary for water balance/leakage detection and for charging for water based on usage.

4.5.6. Water treatment

A chlorination system to disinfect the water will be installed at the downstream side of the bulk distribution meter to ensure the safety of the supply of water to the residents of Hihifo given the scale of the system. The following calculation reveals the operating costs for chlorination of the Hihifo water supply system (see also Table 8).

Calculation of dose rate using calcium hypochlorite powder for Hihifo water supply system:

- Daily flow = 0.32 ML/day
- Assume no correction for manganese, iron or hydrogen sulphide (reported concentrations are low)
- Assume dose rate of 1 ppm (= 1 mg chlorine per litre of water and available chlorine of 65%)

1 mg/L for 0.32 ML/day = 1 mg/L x 0.32 ML/day x 106 L/ML x 10-6 kg/mg

= 0.32 kg of chlorine /day

= 0.32 / 0.65 kg/day of powder

= 0.5 kg/day of powder.

The dosing rate is subject to adjustment after a few tests run in the initial stages of the system in stable operation mode. Chlorine residual test kits will also be provided by the project.

Table 8. Chlorination cost per year.

Chemicals	Daily usage (kg/day)	Annual usage (kg/year)	Annual cost
Calcium hypochlorite	0.5	182.5	TOP 860

4.6. Estimated costs and tariffs

4.6.1. Capital costs

Appendix 10 provides details of the project items and the estimated capital costs. The total estimated capital cost is approximately TOP 1,712,000.

The HVWC therefore depends on government contributions and international development aid for expanding and replacing infrastructure to maintain service standards.

4.6.2. Recurrent costs

The HVWC currently collects insufficient revenue to cover recurrent operating costs and has no funds for capital works. It is expected that the recurrent costs will be lower than at present mainly due to the use of solar pumps for most of the pumping rather than the current sole use of diesel pumps. It is expected that the HVWC will manage recurrent costs of the new water supply system with funding derived from collection of fees from customers.

Estimated annual recurrent costs for the improved water supply system will include:

- Operation and maintenance of pumps (e.g. diesel and oil for diesel pumps, grass cutting at pump stations, etc.): TOP 4,000;
- Repairs and maintenance of other water supply infrastructure (e.g. pipe fittings to repair breakages, maintenance of valves, meters, painting of tankstand): TOP 2,400;
- Operation and maintenance costs for chlorination system (purchase of chlorine, maintenance of equipment): TOP 1,000;
- Salaries for HVWC water staff: TOP 33,000;

- Vehicle running costs: TOP 6,200;
- Office costs: TOP 2,200;
- Workshop costs (e.g. repairs and replacements of tools): TOP 1,200;
- Miscellaneous costs: TOP 1,000.

From the above, the total annual recurrent costs are estimated to be TOP 51,000.

These estimates will need to be updated once more accurate data are available.

4.6.3. Water tariff structure

An appropriate tariff structure will be determined after commissioning of the project and when more accurate data about recurrent costs are available.

Based on the estimated annual recurrent costs of TOP 51,000, and the 261 connections in 2011 (see Table 4), the average tariff per connection would be approximately TOP 195 per year or TOP 16 per month.

5. PROJECT RECORDS

5.1. As-constructed drawings

As the project progresses, as-constructed drawings should be made of completed components. These would include, but not be limited to:

- Plan view and details of the pumps, solar panels and fittings (meters, valves, etc.). Use should be made of the design drawings to be supplied by the solar pump and panel contractor.
- Plan views and selected cross sections of the pipelines from pumps to the low level tanks showing pipe diameters, fittings and offsets from key points (e.g. houses, fences, poles, etc.).

The preparation of as-constructed drawings will require the collection of data on locations and depths during the construction process. This should be recorded by the contractor and/or the supervisor at appropriate stages of the construction work.

The as-constructed drawings should be implemented on either AutoCAD or MAPINFO. Drawing numbers and appropriate titles should be attached to each drawing. The numbers and titles should be entered into the HVWC drawing database.

Copies of drawings should be sent to the HVWC to be checked. After adjustments, as necessary, copies of drawings should be kept at the HVWC, TWB, MECC and MOH.

5.2. Operation and maintenance manuals

Copies of operation and maintenance manuals, obtained from equipment suppliers, should be kept at both the VWC and in the MECC office in Nuku'alofa. These manuals should include:

- Operation and maintenance of solar pumps and panels;
- Operation and maintenance of electric pumps;
- Operation and maintenance of transfer pump and float switch controls;
- Operation and maintenance of valves, flow meters, fire hydrants and other hydraulic fittings;
- Maintenance of tank stand and tank.

6. OPERATIONS, MONITORING AND CONSUMER SURVEYS

6.1. Pump and tank operation

There will be a 'settling-in' period with the solar pumps to see how they perform and how the high level tank levels respond to inflows from both solar and diesel pumps. It will also be necessary to monitor how the low level tanks respond to overflows from the high level tank. It will take some time to finetune the new system to the mix of pumps.

On cloudy days, when solar pumping is low, the AC Powerpaks at the solar pumps will need to be used and, if necessary, the diesel pumps will be required to make up any shortfall.

6.2. Monitoring

The following monitoring requirements are identified at this stage. These will need to be reviewed and modified as necessary after construction.

- Flow meters at pumps and tanks: daily and ongoing.
- Flow test on selected solar pump: special test for approximately 1 month to identify actual pumping period, peak outflows and total flows per day. Continuation of this special test at other solar pumping sites will then need to be determined after review of data collected.
- Water level and salinity monitoring (using calibrated salinity-water level meters) at all production (pumped) wells/boreholes: every month, ongoing. These data will need to be analysed in conjunction with pump flow results.
- Water level and salinity monitoring (using calibrated salinity-water level meters) at all monitoring boreholes every 3 months. This will provide useful data about the freshwater lens storage. In conjunction with available rainfall data, it will also provide valuable information about the groundwater recharge which is required to sustain the freshwater lens.
- Salinity monitoring at sample taps on outflow pipelines from low level and high level tanks: conduct on a daily basis after commissioning the new system to assess variations in the mixed water from multiple pumps. Review results after 1 month and modify monitoring frequency based on results.
- Bacteriological, chlorine residual and nitrate testing at each pump station: every month for the first 6 months. Review results and modify monitoring frequency based on results.

The total estimated cost of equipment for the above monitoring programmes is in the order of AUD 10,500 and is included in the budget.

It is important to note that monitoring of water resources and water supply system is of fundamental importance to this project. Without effective monitoring, the water resources and water supply system cannot be sustainably managed. If sustainable management of both the water resources and water supply does not occur then the overall project objective and goal cannot be achieved.

6.3. Consumer education and surveys

Advance notification of the proposed water supply improvements including the aims, summary of the works and the timetable should be provided to HVWC consumers. This could be done be a number of means including presentations, displays and radio segments.

Approximately 1 month after the water supply improvements have been completed, a survey of HVWC consumers should be undertaken to gauge consumer response to any water quality changes. Other aspects such as reliability, pressure and use of HVWC water and rainwater should also be covered in the survey.

The survey should be repeated after another 6 months and the two sets of results reviewed and a report written.

REFERENCES

Fielea Q. (2012) Technical specifications. Water Supply Improvement Project, Hihifo, Tongatapu, November 2012.

Fielea Q. and Fakakovikaetau N. (2010) Study of the water distribution report, Hihifo, Tongatapu, Water Supply Improvement Project, Final Draft. Pacific Adaptation to Climate Change Project, December 2010.

PACC (2007) Report of In-country consultations. Pacific Adaptation to Climate Change Project, Kingdom of Tonga.

PACC (2014) Socio-economic assessment of Hihifo district, the pilot site for the Pacific Adaptation to Climate Change project in Tonga. PACC Technical Report No. 6. SPREP, Samoa.

White I., Falkland A. and Fatai T. (2009) Groundwater evaluation and monitoring assessment, vulnerability of groundwater in Tongatapu, Kingdom of Tonga. Report to Pacific Islands Applied Geoscience Commission (SOPAC) by Australian National University, Canberra Australia European Union EDF8 project, Reducing the Vulnerability of Pacific APC States, September 2009.

WHO (2011) Guidelines for drinking-water quality. 4th edition, World Health Organization, Geneva, Switzerland.

APPENDIX 1. MINIMUM HYDRAULIC STANDARDS USED BY TONGA WATER BOARD

MINIMUM PRESSURE

The minimum pressure in the reticulation system is 5 metres. This is considered to be the minimum head that should be maintained in the reticulation mains to be sure that infiltration does not occur and which provides sufficient pressure for use inside most houses. In those few cases where this minimum pressure is insufficient, a local break tank and pressure pump will be required to be operated by the homeowner.

Operating at these minimum pressures is recommended on the basis of saving energy for pumping and reducing the capital cost of high towers for head tanks. Lower pressures also reduce the demand for water by lowering wastage, lower leakage rates and increase the service life of valves and fittings.

RANGE OF PIPE SIZES

So that an excessive range of pipes and fittings is not required, the pipelines should be restricted to 40, 50, 80, 100 and 150 mm. The minimum diameter of pipe laid in the street should be 40 mm.

PIPE MATERIALS

PVC, Class 9, rubber ringed pipe (Australian/New Zealand Standard 1477) is proposed to be used for the range of pipes for which they are available (50 mm to 150 mm at present). The use of polyethylene pipe (Australian/New Zealand Standard 4130) should also be considered where this is appropriate.

DEMAND CRITERIA

Residential demand should be designed for 100 L/person/day. In areas where rainwater tanks are provided to the majority of the population, this rate should be reduced to 80 L/person/day if all houses have access to rainwater. A further reduction by up to 20% should apply to areas which do not use water flushed toilets.

An allowance of 25% unaccounted for water should be added.

The peak hourly demand is assumed to be twice the average demand.

Because of the coincidence of peak flows from a small number of households and considering that small diameter pipes can cause a significant head loss, the length of small diameter pipes should be limited. As a guide, it is suggested that single-ended 50 mm pipes should not be longer than 150 metres or serve more than 12 houses while a 50 mm main fed from both ends should not exceed 350 metres in length or serve more than 25 houses. Similarly, an 80 mm pipe should not be longer than 400 metres or serve more than 30 houses if single ended or longer than 1000 metres or serve more than 70 houses if fed from both ends.

PROVISION OF FIRE FLOWS

It is recommended at this stage that no special provision for fire flows be made.

WATER QUALITY STANDARDS

The quality of the water supplied should meet the WHO guidelines for drinking-water quality wherever possible.

SECURITY OF SUPPLY

The water supply should be designed so as to maximise security of supply without significantly increasing the overall cost of the system. Generally, mains should be looped, not only to improve the hydraulic characteristics, but also to increase reliability by providing an alternative supply route. An exception to this would be when a long supply main is required to supply an area and a substantial cost penalty would be incurred if a duplicate main needed to be provided.

When designing pumping installations, consideration should be given to splitting the demand between two or more pumps (and also the supply) so as to increase the overall reliability of the water supply to the area in the event of a mechanical failure.

Similarly, the need to take tanks or reservoirs out of service for maintenance should also be considered, either by providing additional tanks or by installing a suitable by-pass.

LOCATION OF ISOLATING VALVES

Valves should be located so that areas can be isolated for repairs or for leakage determination. The number of valves required to achieve this should be kept to a minimum and preferably below five. Generally, the maximum number of houses without water when a section of main needs to be isolated should not exceed 10.

AIR RELEASE FROM MAINS

Normally in the reticulation system, air would be released from the system via consumer connections and no special provision needs to be made. On long supply mains, the grading of the pipe should be such as to minimise the number of high points relative to the hydraulic grade line and a method should be provided for releasing air from the main at these points. This could be achieved by using an air valve (single or double depending on the situation) or by installing a hydrant at this point for manual release of any air.

MINIMUM COVER OVER PIPES

The minimum cover over any new pipes to be installed should be:

- Where no vehicle loading could occur: 300 mm
- Where vehicle loading could occur:
  - not in roadway: 450 mm
  - under the roadways: 600 mm.

This depth of main is regarded as the minimum that is required to install valves and thrust blocks and to protect the pipe. It is roughly in accordance with the minimum cover requirements recommended by the pipe suppliers.

LOCATION OF MAINS AND VALVES

Generally water mains should be located 300 mm in front of block boundaries to conform to the present standard. However, excavating a trench this close to the boundary using mechanical equipment may pose a problem. If this is the case, a new alignment closer to the road should be determined in conjunction with Telecom and Tonga Power.

Valves are normally provided on branch lines and should be bolted to the flanged branch if this is possible. Valves should not be placed under road pavements.

INSTALLATION OF PUMPS

Normally, direct connection of private booster pumps to a service is not allowed without specific permission from the relevant authority (e.g. Tonga Water Board, Village Water Committee). For larger commercial services, direct connection may be possible but the specific installation would need to be approved by the relevant authority. As a minimum, the installation would need to be fitted with a pressure sensor which switched off the pump when the residual pressure in the suction main dropped below one metre of head. See section on 'Separation of network from private water supplies' below for the preferred arrangement for installation of private booster pumps.

DETAILS OF STANDARD METER SERVICE

Normally only one metered service is provided to a block and, where possible, it should be located 1 m from the side boundary so that it can be readily located. The meter should be securely mounted at least 30 mm clear of the ground and adequately protected against being knocked or broken. The house connection should contain at least one reflux valve. If the meter or isolating valve does not provide this action, then a separate reflux valve should be installed. A reflux valve is required to reduce the possibility of contaminated water flowing back into the reticulation system when mains pressure is lost.

The standard size of a house service main is 15 mm PVC and is connected to a 15 mm water meter. A main cock is provided at the connection to the main and a second isolating valve is located upstream of the meter.

SEPARATION OF NETWORK FROM PRIVATE WATER SUPPLIES

The use of rainwater tanks by residents to supplement the network supply should be encouraged. However, the network supply needs to be separated from any private water supply by an air gap of at least 50 mm. The preferred arrangement when both rainwater and network water are to be reticulated around a house is for the service main to be connected to a buffer tank of at least 300 litres capacity and the outlet of this tank connected to a booster pump via an isolating gate valve. The outlet from the rainwater tank could also be connected to the suction side of the booster pump.

APPENDIX 2. HYDRAULIC DESIGN OUTPUTS FOR PIPES (HIHIFO AT 07:00 PEAK HOUR)

Link ID	Length (m)	Diameter (mm)	Flow (L/s)	Velocity (m/s)	Headloss (m/km)	Status
Pipe INL1	53.69	150	9.31	0.53	2.02	Open
Pipe KVP28	70.46	100	5.31	0.68	5.14	Open
Pipe KVP15	97.27	50	0.38	0.19	1.12	Open
Pipe KVP29	84.11	100	5.23	0.67	4.99	Open
Pipe KP7	56.46	50	0.29	0.15	0.69	Open
Pipe KP8	13.82	50	-0.02	0.01	0.01	Open
Pipe HP12	156.34	50	0.07	0.04	0.05	Open
Pipe HP9	60.22	50	0.22	0.11	0.43	Open
Pipe HP5	95.89	50	0.11	0.05	0.11	Open
Pipe HP6	54.11	80	0.94	0.19	0.62	Open
Pipe HP11	71.63	80	0.61	0.12	0.28	Open
Pipe HP10	168	50	0.03	0.02	0.01	Open
Pipe HP7	22.58	50	0.13	0.07	0.16	Open
Pipe HP17	62.99	50	0.11	0.05	0.11	Open
Pipe HP16	131.12	50	0.11	0.05	0.11	Open
Pipe HP15	153.2	50	0.11	0.05	0.11	Open
Pipe HP14	79.73	50	0.11	0.05	0.11	Open
Pipe HP13	133.11	80	0.43	0.09	0.14	Open
Pipe HP4	60.32	50	0.35	0.18	0.96	Open
Pipe HP3	352.54	80	1.39	0.28	1.28	Open
Pipe HP2	512.26	80	0.11	0.02	0.01	Open
Pipe KP22	79.6	50	0.13	0.07	0.16	Open
Pipe KP21	59.35	100	0.27	0.03	0.02	Open
Pipe KP20	54.99	50	0.13	0.07	0.16	Open
Pipe KP19	46.79	100	0.53	0.07	0.07	Open
Pipe KP17	504.48	80	0.14	0.03	0.02	Open
Pipe KP18	63.57	50	-0.01	0	0	Open
Pipe KP14	348.09	100	0.82	0.1	0.16	Open
Pipe KP12	56.99	50	0.13	0.06	0.15	Open

Link ID	Length (m)	Diameter (mm)	Flow (L/s)	Velocity (m/s)	Headloss (m/km)	Status
Pipe KP10	106.3	50	0.13	0.07	0.16	Open
Pipe KP11	108.75	100	1.41	0.18	0.44	Open
Pipe KP9	78.71	25	0.13	0.27	4.81	Open
Pipe KP6	171.91	50	0.24	0.12	0.5	Open
Pipe KP4	69.59	50	0.38	0.19	1.13	Open
Pipe KP5	175.76	100	1.83	0.23	0.72	Open
Pipe KP3	278.71	100	2.34	0.30	1.13	Open
Pipe KP2	346.58	50	0.06	0.03	0.04	Open
Pipe KP1	221.9	100	2.40	0.31	1.19	Open
Pipe AP39	147.31	50	0.06	0.03	0.04	Open
Pipe AP38	31.46	100	2.52	0.32	1.30	Open
Pipe AP36	34.39	100	2.64	0.34	1.41	Open
Pipe AP37	69.41	50	0.06	0.03	0.04	Open
Pipe AP35	138.82	50	0.06	0.03	0.04	Open
Pipe AP34	99.94	100	2.76	0.35	1.53	Open
Pipe AP31	85.43	50	0.08	0.04	0.06	Open
Pipe AP33	67.58	50	0.06	0.03	0.04	Open
Pipe AP28	46.95	25	0.06	0.12	2.00	Open
Pipe AP25	112.81	50	0.32	0.16	0.82	Open
Pipe AP26	31.82	50	0.06	0.03	0.04	Open
Pipe AP30	26.08	25	0.06	0.12	1.07	Open
Pipe AP29	38.66	100	2.80	0.36	1.57	Open
Pipe AP27	46.18	100	2.92	0.37	1.70	Open
Pipe AP24	80.71	100	3.29	0.42	2.13	Open
Pipe AP23	135.23	50	0.06	0.03	0.04	Open
Pipe AP22	35.89	100	3.41	0.43	2.27	Open
Pipe AP20	46.06	100	3.53	0.45	2.42	Open
Pipe AP21	43.5	25	0.06	0.12	1.07	Open
Pipe AP19	137.12	40	0.06	0.05	0.11	Open
Pipe AP18	50.35	100	3.65	0.46	2.57	Open
Pipe AP16	27.3	100	3.77	0.48	2.73	Open

Link ID	Length (m)	Diameter (mm)	Flow (L/s)	Velocity (m/s)	Headloss (m/km)	Status
Pipe AP17	144.45	50	0.06	0.03	0.04	Open
Pipe AP13	80	50	0.18	0.09	0.28	Open
Pipe AP14	25.88	25	0.06	0.12	1.07	Open
Pipe AP15	75.5	50	0.06	0.03	0.04	Open
Pipe AP12	80.15	100	4.01	0.51	3.05	Open
Pipe AP10	128.61	50	0.12	0.06	0.13	Open
Pipe AP11	32.75	25	0.06	0.12	1.07	Open
Pipe AP9	86.15	100	4.19	0.53	3.31	Open
Pipe AP6	78.56	50	0.18	0.09	0.28	Open
Pipe AP8	45.46	40	0.06	0.05	0.11	Open
Pipe AP7	35.32	25	0.06	0.12	1.07	Open
Pipe AP4	108.42	100	4.48	0.57	3.76	Open
Pipe AP3	107.42	50	0.06	0.03	0.04	Open
Pipe AP2	83.28	50	0.06	0.03	0.04	Open
Pipe KVP31	129.48	50	0.09	0.05	0.09	Open
Pipe KVP30	73.91	100	5.04	0.64	4.67	Open
Pipe KVP32	143.5	50	0.09	0.05	0.09	Open
Pipe KVP33	193.64	50	0.39	0.20	1.17	Open
Pipe KVP36	94.78	50	0.48	0.24	1.75	Open
Pipe KVP37	191.68	50	0.13	0.07	0.15	Open
Pipe KVP27	70.39	100	5.56	0.71	5.6	Open
Pipe KVP38	166.84	50	0.70	0.36	3.55	Open
Pipe KVP46	79.06	40	0.09	0.07	0.25	Open
Pipe KVP45	44.43	50	0.89	0.45	5.51	Open
Pipe KVP43	43.86	25	0.09	0.19	2.51	Open
Pipe KVP42	89.71	50	0.42	0.22	1.40	Open
Pipe KVP44	58.04	50	0.24	0.12	0.47	Open
Pipe KVP49	116.47	50	0.09	0.05	0.09	Open
Pipe KVP48	131.5	50	0.44	0.23	1.51	Open
Pipe KVP53	111.33	40	0.09	0.07	0.25	Open
Pipe KVP52	119.69	50	0.28	0.14	0.66	Open

Link ID	Length (m)	Diameter (mm)	Flow (L/s)	Velocity (m/s)	Headloss (m/km)	Status
Pipe KVP54	68	25	0.09	0.19	2.51	Open
Pipe KVP19	50.33	100	5.64	0.72	5.75	Open
Pipe KVP23	82.69	100	5.19	0.66	4.94	Open
Pipe KVP24	109.28	100	4.58	0.58	3.90	Open
Pipe KVP22	60.69	40	0.09	0.07	0.25	Open
Pipe KVP20	44.78	40	0.09	0.07	0.25	Open
Pipe KVP8	104	50	1.05	0.53	7.45	Open
Pipe KVP7	175.32	80	2.93	0.58	5.06	Open
Pipe KVP12	200.83	80	1.79	0.36	2.03	Open
Pipe KVP10	47.81	25	0.09	0.19	2.51	Open
Pipe KVP16	80.55	50	0.09	0.05	0.09	Open
Pipe KVP17	83.51	50	0.19	0.10	0.31	Open
Pipe KVP18	76.16	50	0.09	0.05	0.09	Open
Pipe KVP14	154.12	50	0.09	0.05	0.09	Open
Pipe KVP39	42.9	50	0.28	0.14	0.66	Open
Pipe KVP40	75.01	40	0.09	0.07	0.25	Open
Pipe KVP41	44.36	25	0.09	0.19	2.51	Open
Pipe GSIP1	1214.67	80	0.38	0.07	0.11	Open
Pipe KVP1	341.64	50	0.09	0.05	0.09	Open
Pipe KVP3	144.55	150	8.71	0.49	3.33	Open
Pipe KVP4	43.98	25	0.09	0.19	4.68	Open
Pipe KVP6	42.8	40	0.09	0.07	0.25	Open
Pipe KVP5	122.59	150	8.43	0.48	1.68	Open
Pipe CMain2	143.76	100	3.71	0.47	2.65	Open
Pipe CMain3	142.19	100	5.58	0.71	5.63	Open
Pipe CMain4	151.46	150	7.44	0.42	1.33	Open
Pipe CMain5	3515.71	150	9.31	0.53	2.02	Open
Pipe INL2	11.73	150	9.31	0.53	2.02	Open
Pipe AP5	150.36	50	0.06	0.03	0.04	Open
Pipe KP16	514.28	80	0.14	0.03	0.02	Open
Pipe INL3	10	150	9.31	0.53	2.02	Open

Link ID	Length (m)	Diameter (mm)	Flow (L/s)	Velocity (m/s)	Headloss (m/km)	Status
Pipe P2CM	10	80	1.86	0.37	2.18	Open
Pipe P3CM	10	80	1.86	0.37	2.19	Open
Pipe P4CM	10	80	1.87	0.37	2.20	Open
Pipe P5CM	10	80	1.87	0.37	2.21	Open
Pipe P1CM	10	80	1.85	0.37	2.17	Open
Pipe CMain1	150	80	1.85	0.37	2.17	Open
Pipe Outlet1	87.35	150	11.83	0.67	3.15	Open
Pipe KVP2	756.93	150	11.73	0.66	3.10	Open
Pipe KVP25	84.3	100	4.90	0.62	4.44	Open
Pipe KVP11	89.67	50	-0.08	0.04	0.07	Open
Pipe KVP9	71.8	50	0.11	0.05	0.11	Open
Pipe KVP8-2	85	50	0.85	0.43	5.04	Open
Pipe KVP50	196.06	50	0.49	0.25	1.85	Open
Pipe KVP47	95.64	50	0.75	0.38	3.99	Open
Pipe KVP13	166.99	50	1.13	0.57	8.51	Open
Pipe AP40	122.17	50	0.20	0.10	0.34	Open
Pipe HP8	25.55	50	0.08	0.04	0.07	Open
Pipe KVP26	65.55	100	4.53	0.58	3.83	Open
Pipe KVP56	34.32	100	5.45	0.69	5.40	Open
Pipe KVP55	17.57	100	5.38	0.69	5.27	Open
Pipe KVP58	56.06	50	1.08	0.55	7.89	Open
Pipe KVP59	69.99	50	0.87	0.44	5.28	Open
Pipe PI18	83.67	40	0.12	0.09	0.38	Open
Pipe PI19	61.13	40	-0.02	0.02	0.02	Open
Pipe KVP57	73.57	100	4.85	0.62	4.35	Open
Pipe KVP60	107.87	50	0.09	0.05	0.09	Open
Pipe AP1	205	100	4.66	0.59	4.04	Open
Pipe KP15	333.08	50	0.12	0.06	0.14	Open
Supply to Ha’atafu	3687.29	100	1.61	0.21	0.57	Open
Pipe HTF1	49.61	100	1.61	0.21	0.57	Open

APPENDIX 3. HYDRAULIC DESIGN OUTPUTS AT NODES (HIHIFO AT 07:00 PEAK HOUR)

Node ID	Demand in litres	Head in metres	Pressure in metres
Junc P1	0	38.70	31.70
Junc JU2	0	31.60	12.10
Junc JU3	0	31.49	11.99
Junc JU4	0	31.47	11.47
Junc KV2	0.09	28.82	23.82
Junc KV1	0	31.17	11.67
Junc KV6	0.09	28.14	25.14
Junc KV7	0.09	27.85	24.85
Junc KV9	0.09	27.57	24.57
Junc KV11	0.09	27.16	24.16
Junc KV13	0.09	27.16	22.66
Junc KV14	0.09	27.94	23.44
Junc KV17	0.28	27.53	23.03
Junc KVC1	0.38	27.39	23.39
Junc KV15	0.09	26.73	23.73
Junc KV16	0.09	26.11	23.11
Junc KV18	0.28	25.71	22.71
Junc KV19	0.09	25.70	21.20
Junc KV20	0.09	25.35	22.35
Junc KV21	0.09	25.24	20.74
Junc KV22	0.09	25.24	21.24
Junc KV23	0.09	25.22	20.22
Junc KV24	0.09	25.21	20.21
Junc KV25	0.09	24.93	21.93
Junc KV26	0.09	24.59	21.59
Junc KV27	0.09	24.58	23.08

Node ID	Demand in litres	Head in metres	Pressure in metres
Junc KV28	0.09	24.92	22.92
Junc KV29	0.09	25.58	24.08
Junc KV30	0.09	25.74	24.24
Junc KV38	0.09	26.34	24.34
Junc KV39	0.09	26.32	24.82
Junc KV37	0.09	26.58	24.58
Junc KV35	0.09	26.61	24.11
Junc KV36	0.09	26.5	24
Junc KV40	0.09	26.96	24.96
Junc KV41	0.09	26.95	25.45
Junc KV42	0.09	27.33	25.33
Junc KV43	0.09	27.25	25.25
Junc KV44	0.09	27.22	25.72
Junc KV45	0.09	27.08	25.58
Junc AR1	0.06	23.44	20.44
Junc AR3	0.06	23.44	21.94
Junc AR2	0.06	23.44	19.44
Junc AR4	0.06	23.03	20.03
Junc AR5	0.06	23.03	19.03
Junc AR6	0.06	23.01	21.01
Junc AR9	0.06	22.75	19.75
Junc AR10	0.06	22.73	21.23
Junc AR12	0.06	22.5	19.5
Junc AR13	0.06	22.48	20.48
Junc AR15	0.06	22.48	20.98
Junc AR16	0.06	22.43	19.43

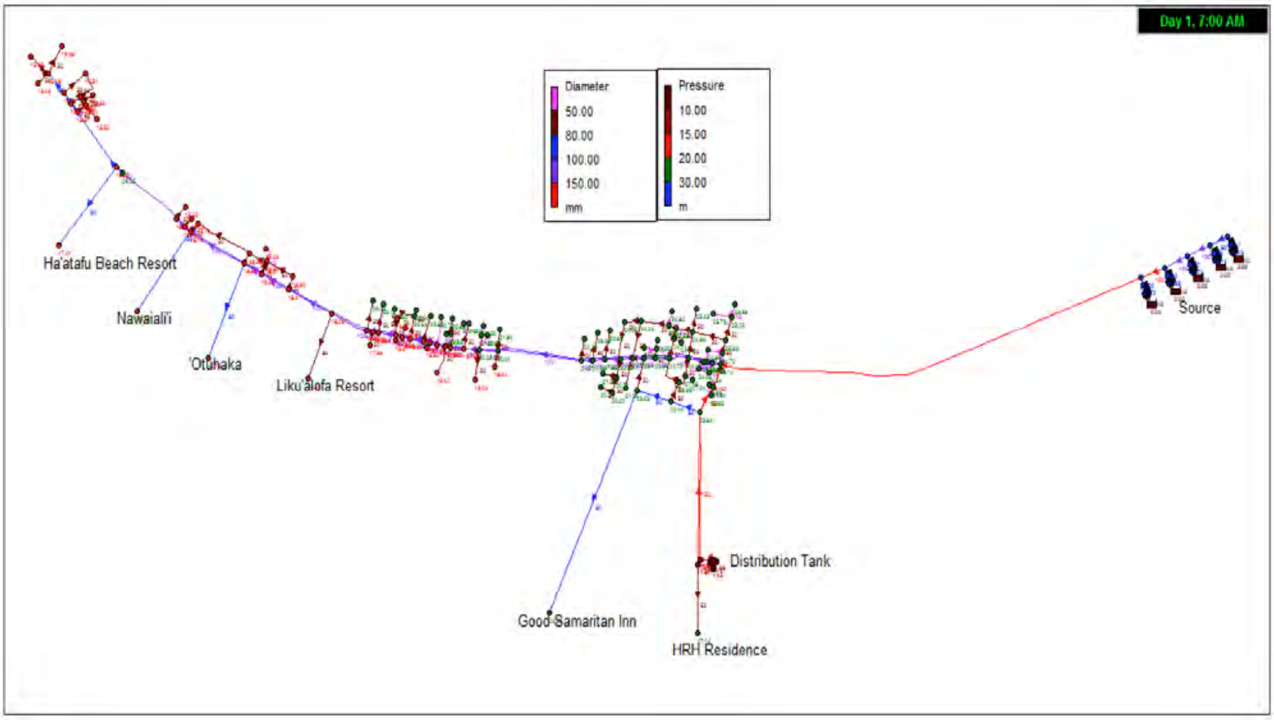
Node ID	Demand in litres	Head in metres	Pressure in metres
Junc AR18	0.06	22.30	19.3
Junc AR22	0.06	22.11	19.11
Junc AR19	0.06	22.28	20.78
Junc AR23	0.06	22.10	20.6
Junc AR24	0.06	21.93	18.93
Junc AR25	0.06	21.84	20.34
Junc AR26	0.06	21.84	20.34
Junc AR29	0.06	21.79	18.79
Junc AR32	0.06	21.80	20.30
Junc AR33	0.06	21.64	18.64
Junc AR34	0.06	21.64	20.14
Junc AR35	0.06	21.59	18.59
Junc AR36	0.06	21.59	17.59
Junc AR37	0.06	21.55	18.55
Junc AR38	0.06	21.55	20.05
Junc KR2	0.13	20.97	18.47
Junc KR3	0.13	20.90	19.90
Junc KR4	0.13	20.85	18.35
Junc KR5	0.13	20.81	19.31
Junc KR6	0.13	20.81	19.81
Junc KR9	0.13	20.79	19.29
Junc KR8	0.32	20.80	18.80
Junc KR11	0.13	20.74	18.74
Junc KR12	0.13	20.74	19.74
Junc KR13	0.13	20.74	18.74
Junc KR14	0.13	20.73	19.23
Junc KR15	0.13	20.74	18.74
Junc KR16	0.13	20.73	19.23
Junc KC3	0.14	20.74	15.74

Node ID	Demand in litres	Head in metres	Pressure in metres
Junc H1	0.11	26.02	16.02
Junc HR2	0.11	25.57	15.57
Junc HR3	0.11	25.51	15.51
Junc HR9	0.11	25.51	15.51
Junc HR10	0.11	25.51	15.51
Junc HR11	0.11	25.49	15.49
Junc HR13	0.11	25.48	16.48
Junc HR14	0.11	25.48	15.48
Junc KV10	0.09	27.55	24.05
Junc KV8	0.09	27.84	24.34
Junc AR8	0.06	23.00	21.50
Junc AR7	0.06	22.97	20.97
Junc AR11	0.06	22.69	21.19
Junc AR14	0.06	22.45	20.45
Junc AR17	0.06	22.42	18.42
Junc AR27	0.06	21.86	18.86
Junc AR28	0.06	21.76	19.26
Junc AR30	0.06	21.77	18.27
Junc AR31	0.06	21.80	19.30
Junc AR20	0.06	22.19	19.19
Junc AR21	0.06	22.14	18.64
Junc KR7	0.13	20.43	19.43
Junc P2	0	38.90	31.90
Junc P3	0	39.71	32.71
Junc P4	0	40.09	33.09
Junc HR12	0.11	25.49	15.49
Junc HRHR	0.09	31.14	27.14
Junc HC1	0.11	26.01	17.01
Junc KC2	0.14	20.79	15.79

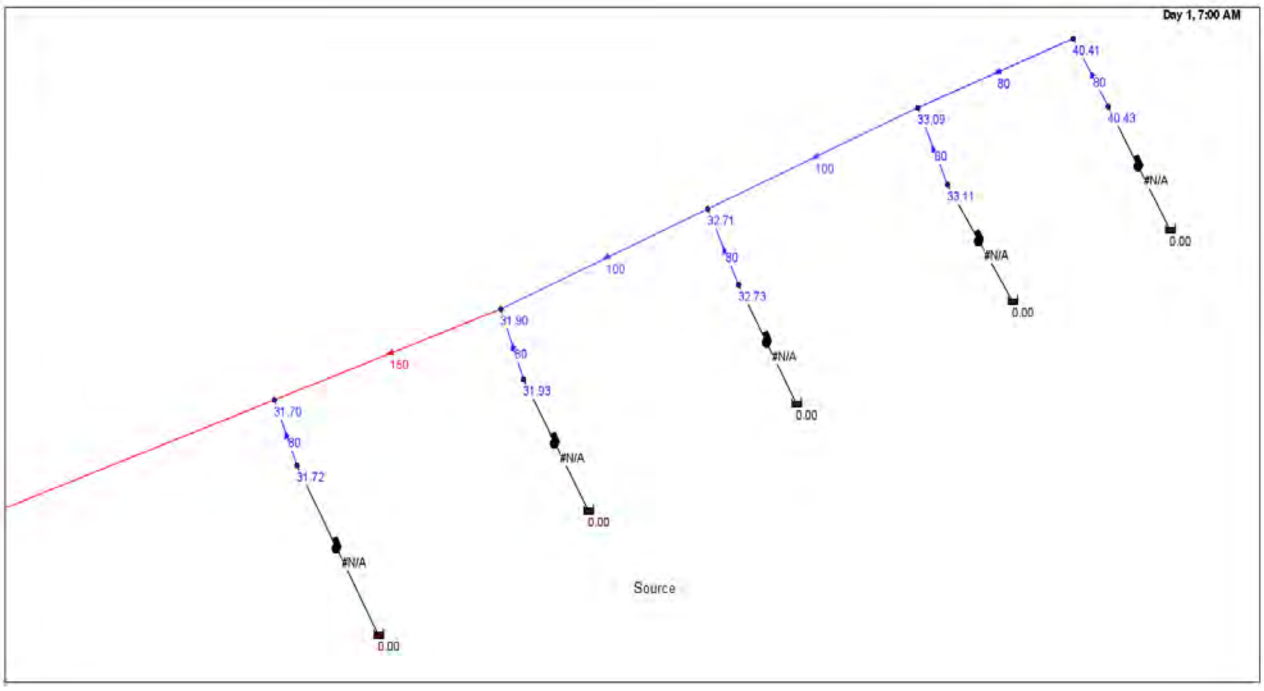
Node ID	Demand in litres	Head in metres	Pressure in metres
Junc KR1	0	21.29	18.29
Junc KC1	0.06	21.28	16.28
Junc HR7	0.11	25.51	15.51
Junc HR4	0.11	25.50	15.50
Junc HR8	0.11	25.53	15.53
Junc HR5	0.11	25.51	15.51
Junc HR6	0.11	25.50	15.50
Junc KV46	0.09	27.04	27.04
Junc KV12	0.09	27.16	27.16
Junc KV31	0.09	26.36	23.36
Junc KV32	0.09	26.33	24.33
Junc KV34	0.09	26.22	24.22
Junc KV33	0.09	26.31	24.31
Junc KV3	0.09	28.34	24.84
Junc KV5	0.09	28.14	24.64
Junc KV4	0.09	28.33	23.33
Junc JU1	0	38.72	31.72

Node ID	Demand in litres	Head in metres	Pressure in metres
Junc JU5	0	38.93	31.93
Junc JU6	0	39.73	32.73
Junc JU8	0	40.11	33.11
Junc P5	0	40.41	40.41
Junc JU10	0	40.43	40.43
Junc KV7-1	0.09	27.66	24.66
Junc KV6-1	0.09	27.70	24.70
Junc KV47	0.09	27.66	24.66
Junc KV48	0.09	24.27	21.27
Junc KV49	0.09	24.26	22.26
Junc JU7	0	26.05	26.05
Resvr RE1	-1.87	0	0
Resvr RE2	-1.87	0	0
Resvr RE3	-1.86	0	0
Resvr RE4	-1.86	0	0
Resvr RE5	-1.85	0	0
Tank TA1	-2.51	31.45	1.45

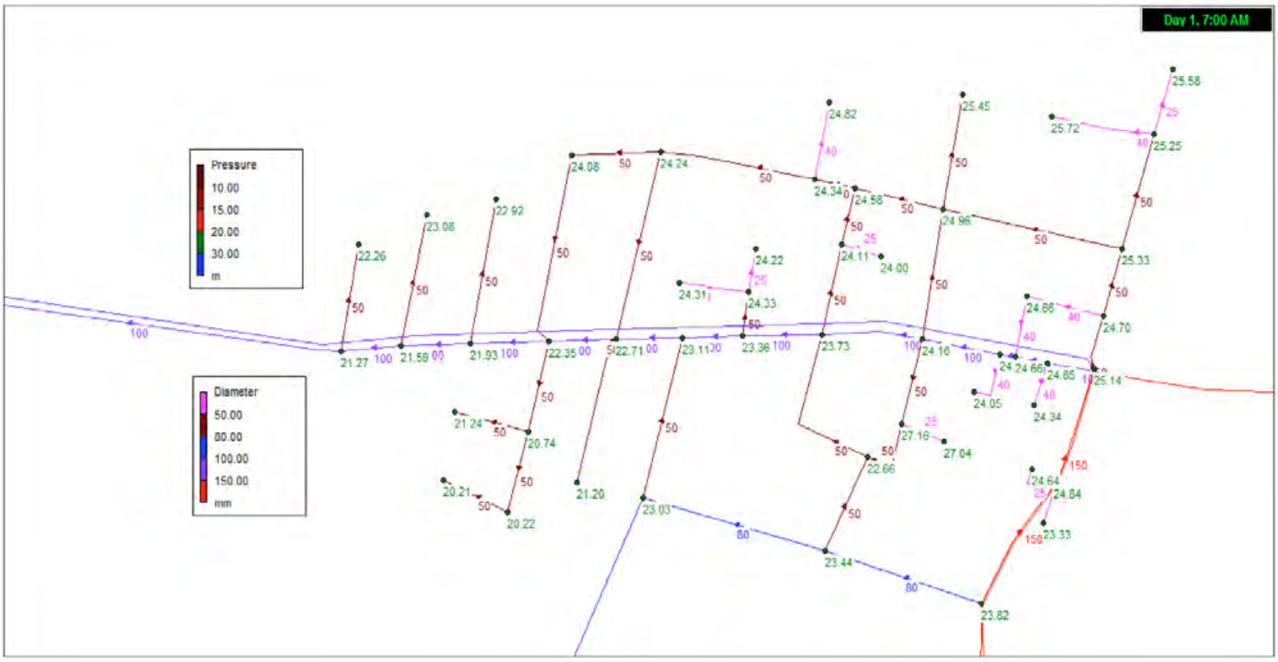
APPENDIX 4. DETAILED HIHIFO WATER SUPPLY SYSTEM (SYSTEM LAYOUT)



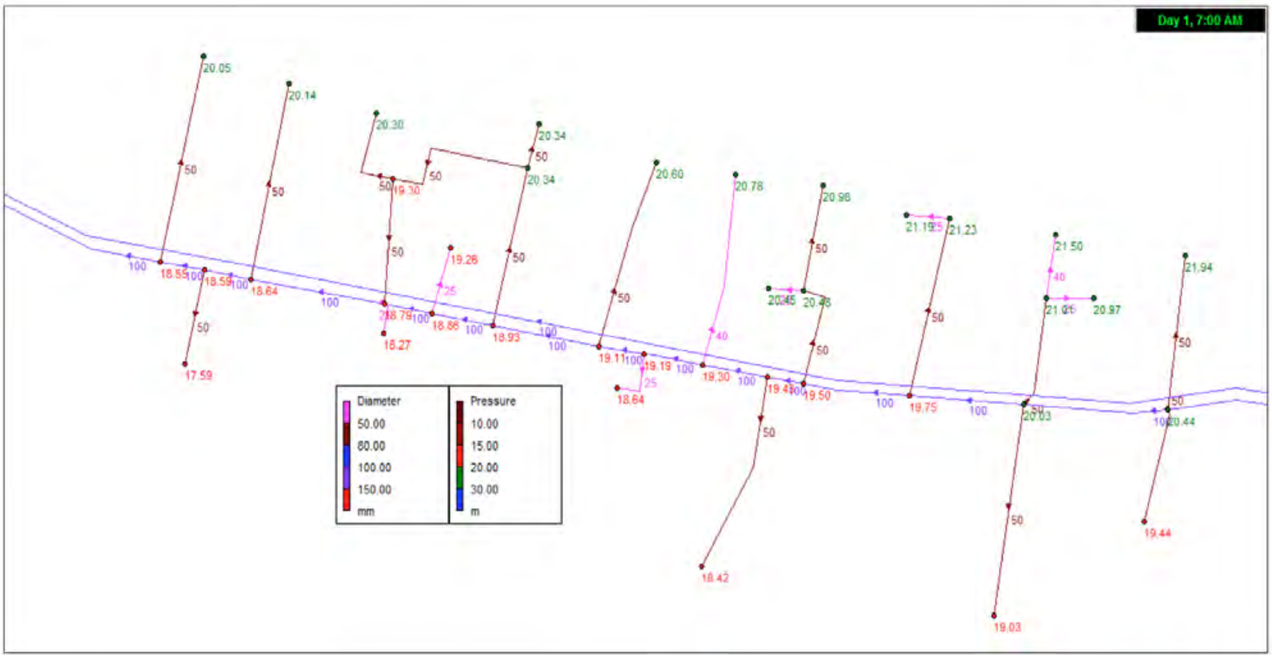
APPENDIX 5. DETAILED PRODUCTION PIPE LAYOUT AT FO'UI (PRESSURES AT 7:00 AM AND DIAMETER)



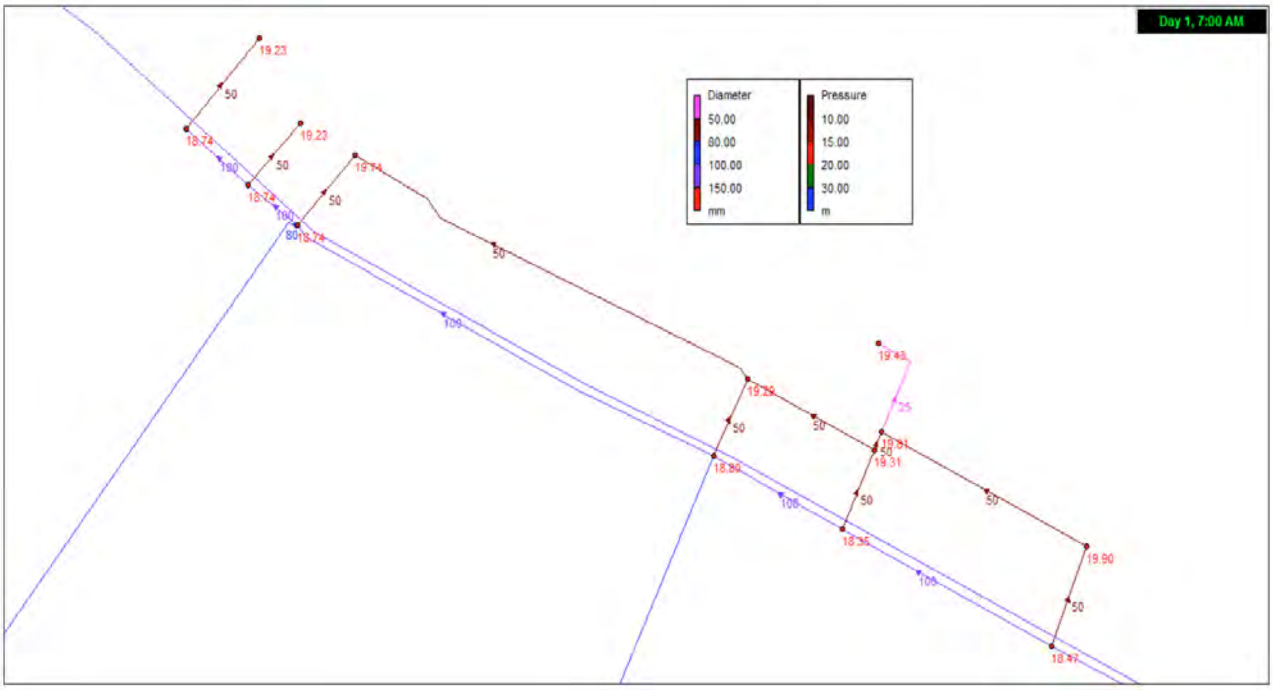
APPENDIX 6. DETAILED DISTRIBUTION PIPE DRAWING OF KOLOVAI (PRESSURES AT 7:00 AM AND DIAMETER)



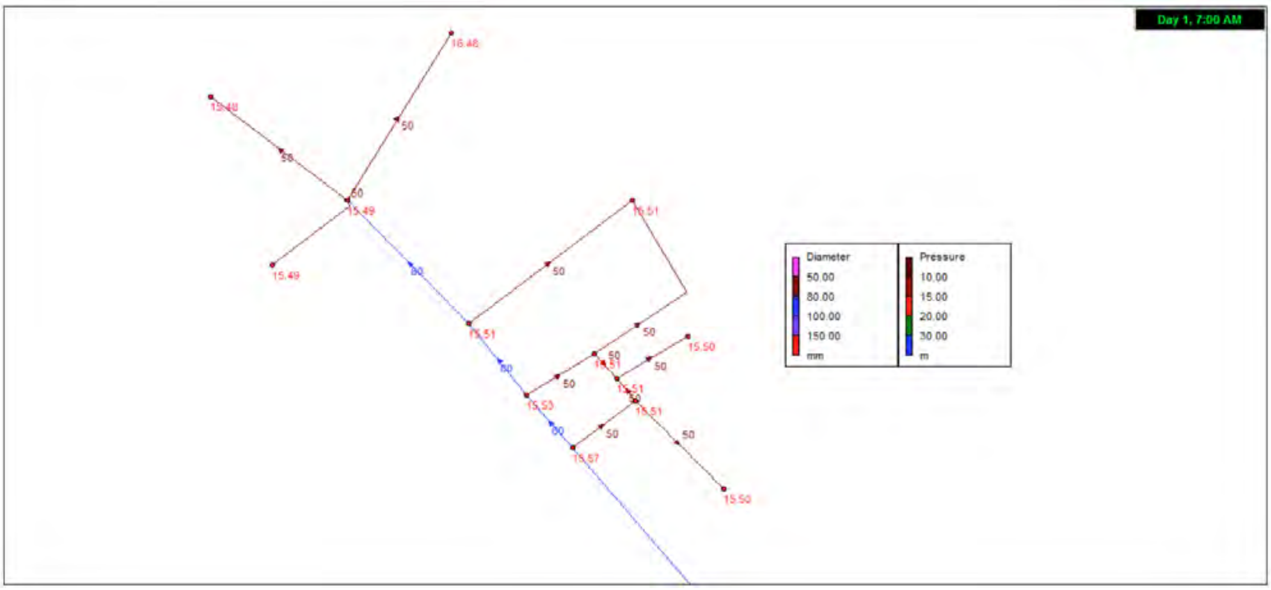
APPENDIX 7. DETAILED DISTRIBUTION PIPE DRAWING OF ʻAHAU (PRESSURES AT 7:00 AM AND DIAMETER)



APPENDIX 8. DETAILED DISTRIBUTION PIPE DRAWING OF KANOKUPOLU (PRESSURES AT 7:00 AM AND DIAMETER)



APPENDIX 9. DETAILED DISTRIBUTION PIPE DRAWING OF HA'ATAFU (PRESSURES AT 7:00 AM AND DIAMETER)



APPENDIX 10. DETAILED PROCUREMENT LIST AND ESTIMATED COSTS

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
Fittings for Storage Tank Inlet						
1	PVC	100mm	Kent Helix 4000 Water Meter	1	$2,829.34	$2,829.34
2	PVC	100mm	Dressing Set (Stub Flange, Backing Ring, Gasket, Bolt and Nuts) to suit meter above	2	$158.78	$317.57
3	PVC	100mm	Plain Elbow	18	$64.28	$1,157.08
4	PVC	80mm	Plain Elbow	5	$11.25	$56.25
5	PVC	150mm	Plain Tee	2	$130.01	$260.03
6	PVC	80mm	Plain Tee	2	$14.24	$28.48
7	PVC	150mm	150DN SLUICE VALVE (FI-FI)	3	$780.46	$2,341.38
8	PVC	150mm	Dressing Set (Stub Flange, Backing Ring, Gasket, Bolt and Nuts) to suit S/ Valve above	6	$158.78	$952.71
9	PVC	80mm	80DN SLUICE VALVE (FI-FI)	5	$436.02	$2,180.10
10	PVC	80mm	Dressing Set (Stub Flange, Backing Ring, Gasket, Bolt and Nuts) to suit S/ Valve above	10	$65.53	$655.26
11	PVC	150 × 100mm	Reduce Socket	2	$33.53	$67.06
12	PVC	100 × 80mm	Reduce Bush	2	$11.62	$23.24
Sub Total						**$10,868.48**
Fittings for Storage Tank Outlet						
13	PVC	150mm	150DN SLUICE VALVE	2	$780.46	$1,560.92
14	PVC	150mm	Dressing Set (Stub Flange, Backing Ring, Gasket, Bolt and Nuts) to suit S/ Valve above	6	$158.55	$951.31
15	PVC	100mm	100DN SLUICE VALVE	2	$436.02	$872.04
16	PVC	100mm	Dressing Set (Stub Flange, Backing Ring, Gasket, Bolt and Nuts) to suit S/ Valve above	4	$76.82	$307.26
17		80mm	80DN SLUICE VALVE	2	$436.02	$872.04
18		80mm	Dressing Set (Stub Flange, Backing Ring, Gasket, Bolt and Nuts) to suit S/ Valve above	5	$65.53	$327.63

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
19	PVC	100mm	Valve Socket	6	$15.29	$91.77
20	PVC	150mm	Valve Socket	3	$27.34	$82.01
21		80mm	Valve Socket	2	$6.57	$13.15
22	PVC	150mm	Plain Elbow	10	$64.28	$642.82
23	PVC	150 × 100mm	Reduce Socket	1	$33.53	$33.53
24	PVC	100 × 80mm	Reduce Bush	1	$11.62	$11.62
25	PVC	80mm	Plain Tee	2	$14.24	$28.48
26	PVC	80mm	Plain Elbow	9	$11.25	$101.24
27	PVC	150 × 15mm	Tapping Band	1	$225.53	$225.53
28	PVC	100mm	Kent Helix 4000 Water Meter	1	$2,829.34	$2,829.34
29	PVC	150mm	Dressing Set (Stub Flange, Backing Ring, Gasket, Bolt and Nuts) to suit meter above	1	$159.51	$159.51
30		150mm	PIPE CLAMPS (to hold 150mm PVC to Tank Stand and Tank)	8	$20.50	$164.02
Sub Total						**$9,274.23**

Fittings for Pump Outlets & Connection to Collector Mains						
31	GALV.	50mm	Galvanised Screwed Flanges to Table C	30	$46.03	$1,381.05
32		50mm	Neoprene Gasket	30	$2.84	$85.29
33	GALV.	50mm	Galvanised Union (f-f) 50DN	5	$89.12	$445.59
34		50mm	Galvanised Hexagon Nipple 50DN	5	$47.84	$239.20
35		50x50x25	Galvanised Reduce Tee 50DN	5	$34.44	$172.22
36	GALV.	50x50x15	Galvanised Reduce Tee 50DN	10	$33.65	$336.51
37		15mm	Pressure Gauge 15DN Direct Mounted 50DN Face	5	$102.92	$514.61
38		50mm	Dirt Box Davies Shephard in line Filter 50DN	5	$342.02	$1,710.11
39		50mm	Kent Helix 4000 Meter 50DN	5	$1,214.95	$6,074.75
40		25mm	Bronze Spring Relief Valve 25DN	5	$102.87	$514.34
41	GALV.	50mm	Galvanised 45˚ BEND BSP Parallel Thread - 50DN	10	$12.21	$122.06
42	GALV.	50mm	Sluice Valve 50DN	10	$436.02	$4,360.19

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
43	GALV.	50mm	Threaded Galvanised Pipes (medium duty) - 500mm length	5	$76.54	$382.71
44	GALV.	50mm	Threaded Galvanised Pipes (medium duty) - 100mm length	5	$91.56	$457.82
45	GALV.	50mm	Threaded Galvanised Pipes (medium duty) - 80mm length	5	$46.47	$232.36
46	GALV.	50mm	Threaded Galvanised Pipes (medium duty) - 1500mm length	5	$61.51	$307.54
47	PVC	150 × 50mm	Reduce Y-Junction	3	$170.85	$512.56
48	PVC	100 × 50mm	Reduce Y-Junction	3	$150.35	$451.05
49	PVC	80 × 50mm	Reduce Y-Junction	2	$136.16	$272.33
50	PVC	50mm	Stub Flange	10	$26.26	$262.57
51		50mm	Metal Backing Ring	10	$42.54	$425.36
52		50mm	Neoprene Gasket	10	$2.84	$28.43
Sub Total						**$19,288.64**
PVC Pressure Pipe Metric Pipe Series 1,AS/NZS 1477						
53	PVC	150	DN 150 PN9 Pressure Pipe x 6M RRJ	826	$123.83	$102,287.66
54	PVC	100	DN 100 PN6 Pressure Pipe x 6M RRJ	627	$60.03	$37,639.59
55	PVC	80	DN 80 PN6 Pressure Pipe x 6M RRJ	684	$53.29	$36,452.25
56	PVC	50	DN 50 PN6 Pressure Pipe x 6M RRJ	1,296	$25.71	$33,320.29
57	PVC	40	DN 40 PN6 Pressure Pipe x 6M SWJ	135	$20.05	$2,706.94
58	PVC	32	DN 32 PN6 Pressure Pipe x 6M SWJ	20	$12.59	$251.77
59	PVC	25	DN 25 PN6 Pressure Pipe x 6M SWJ	105	$12.11	$1,271.56
60	PVC	20	DN 20 PN6 Pressure Pipe x 6M SWJ	50	$8.45	$422.35
61	PVC	15	DN 15 PN6 Pressure Pipe x 6M SWJ	690	$5.88	$4,055.39
62	GAL	50	Medium Duty 50mm Galvanised Pipe	10	$61.51	$615.07
Sub Total						**$219,022.88**
Sluice Valves and Cover (Resilient Seated)						
63		150	Resilient Seated (Double Flange to Table D)	2	$1,560.92	$3,121.84
64		100	Resilient Seated (Double Flange to Table D)	6	$654.03	$3,924.17

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
65		150	Stub Flange	4	$67.45	$269.81
66		100	Stub Flange	12	$57.77	$693.19
67		150	Metal Backing Ring with Nuts & Bolts to Table D	4	$154.92	$619.67
68		100	Metal Backing Ring with Nuts & Bolts to Table D	12	$20.78	$249.31
69		150	Neoprene Gasket	4	$173.42	$693.67
70		100	Neoprene Gasket	12	$7.15	$85.78
71		100	Resilient Seated (Soc-Soc)	4	$436.02	$1,744.08
72		80	Resilient Seated (Soc-Soc)	9	$242.23	$2,180.10
73		50	Resilient Seated (Soc-Soc)	4	$1.42	$5.69
74		50	Gate Valve	35	$158.12	$5,534.30
75		40	Gate Valve	8	$4.77	$38.15
76		25	Gate Valve	5	$3.64	$18.22
77			Valve Cover and Frame	50	$156.58	$7,829.21
Sub Total						**$27,007.18**
Pumps						
78		2100watts	Mono Sun Sub - 2100watts pump with Gen Back Up(Include 1 each for Haavakatolo & Fo'ui)	5	$43,000.00	$215,000.00
79			Mono 520 pump & TR1 Lister Engine	2	$25,000.00	$50,000.00
80			Transfer Pump (Electric) with Float Switch	1	$6,500.00	$6,500.00
81			Transfer Pump (Diesel)	1	$9,500.00	$9,500.00
82			Pulsa Diapharam Pump (Chlorination)	1	$5,000.00	$5,000.00
Sub Total						**$286,000.00**
Flow Meters(Leak Detection Works)						
83		100	Kent Helix 4000 Water Meters	5	$1,729.04	$8,645.21
84		100	Stub Flange	10	$19.81	$198.05
85		100	Metal Backing Ring with Nuts & Bolts to Table D	10	$49.86	$498.62
86		100	Neoprene Gasket	10	$7.15	$71.49
Sub Total						**$9,413.37**

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
Plain Tees (mm)						
87	PVC	150x150x150	Plain Tees	9	$130.01	$1,170.12
88	PVC	100x100x100	Plain Tees	5	$37.27	$186.37
89	PVC	80x80x80	Plain Tees	5	$14.24	$71.21
90	PVC	50x50x50	Plain Tees	20	$3.73	$74.63
Sub Total						**$1,502.33**
Reduce Tees (mm)						
91	PVC	100x80	Reduce Tees	11	$11.62	$127.80
92	PVC	100x50	Reduce Tees	40	$35.58	$1,423.15
93	PVC	80x50	Reduce Tees	5	$21.39	$106.95
94	PVC	50x40	Reduce Tees	8	$4.40	$35.21
95	PVC	40x25	Reduce Tees	5	$6.48	$32.39
Sub Total						**$1,725.50**
Reduce Socket (mm)						
96	PVC	150x100	Reducing Socket	8	$33.53	$268.23
97	PVC	100x80	Reducing Socket	5	$11.48	$57.41
98	PVC	100x50	Reducing Socket	5	$11.48	$57.41
99	PVC	80x50	Reducing Socket	5	$6.16	$30.82
100	PVC	50x40	Reducing Socket	10	$3.13	$31.30
101	PVC	40x32	Reducing Socket	10	$3.02	$30.21
102	PVC	32x25	Reducing Socket	15	$2.73	$41.00
103	PVC	25x20	Reducing Socket	15	$1.38	$20.71
104	PVC	20x15	Reducing Socket	15	$0.86	$12.92
Sub Total						**$550.00**
Reducing Bush (mm)						
105	PVC	150x100	Reducing Bush	5	$22.13	$110.65
106	PVC	100x80	Reducing Bush	5	$11.62	$58.09
107	PVC	80x50	Reducing Bush	11	$4.17	$45.86

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
108	PVC	50x40	Reducing Bush	12	$1.67	$20.01
109	PVC	40x32	Reducing Bush	12	$1.20	$14.43
110	PVC	32x25	Reducing Bush	21	$0.78	$16.36
111	PVC	25x20	Reducing Bush	21	$0.53	$11.19
112	PVC	20x15	Reducing Bush	20	$0.53	$10.66
Sub Total						**$287.25**
Valve Socket (mm)						
113	PVC	80	Valve Socket	6	$6.57	$39.45
114	PVC	50	Valve Socket	74	$7.52	$556.30
115	PVC	40	Valve Socket	10	$3.21	$32.12
116	PVC	32	Valve Socket	10	$2.80	$28.02
117	PVC	25	Valve Socket	16	$2.71	$43.30
118	PVC	20	Valve Socket	40	$1.57	$62.87
119	PVC	15	Valve Socket	40	$1.53	$61.23
Sub Total						**$823.30**
Automatic Air Release						
120	PVC	32	Air release PVC 25mm	10	$170.85	$1,708.54
121		100 × 25	Tapping Band(gun Metal)	4	$170.85	$683.42
122		80 × 25	Tapping Band(gun Metal)	7	$148.98	$1,042.89
123		50 × 25	Tapping Band(gun Metal)	5	$129.85	$649.24
Sub Total						**$4,084.09**
End Cap						
124	PVC	80	End Cap	6	$7.30	$43.79
125	PVC	50	End Cap	28	$2.26	$63.15
126	PVC	40	End Cap	14	$1.18	$16.46
127	PVC	25	End Cap	20	$1.00	$19.96
Sub Total						**$143.35**

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
Plain Elbow						
128	PVC	50	Plain Elbow	15	$9.21	$138.19
Sub Total						**$138.19**

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
Bend 45˚						
129	PVC	150	Bend 90˚	2	$64.28	$128.56
130	PVC	150	Bend 45˚	7	$266.27	$1,863.91
131	PVC	100	Bend 45˚	10	$64.86	$648.56
132	PVC	80	Bend 45˚	3	$36.22	$108.66
Sub Total						**$2,749.70**

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
Tapping Band						
133	PVC	150×25	Tapping Band(gun Metal)	4	$170.85	$683.42
Sub Total						**$683.42**

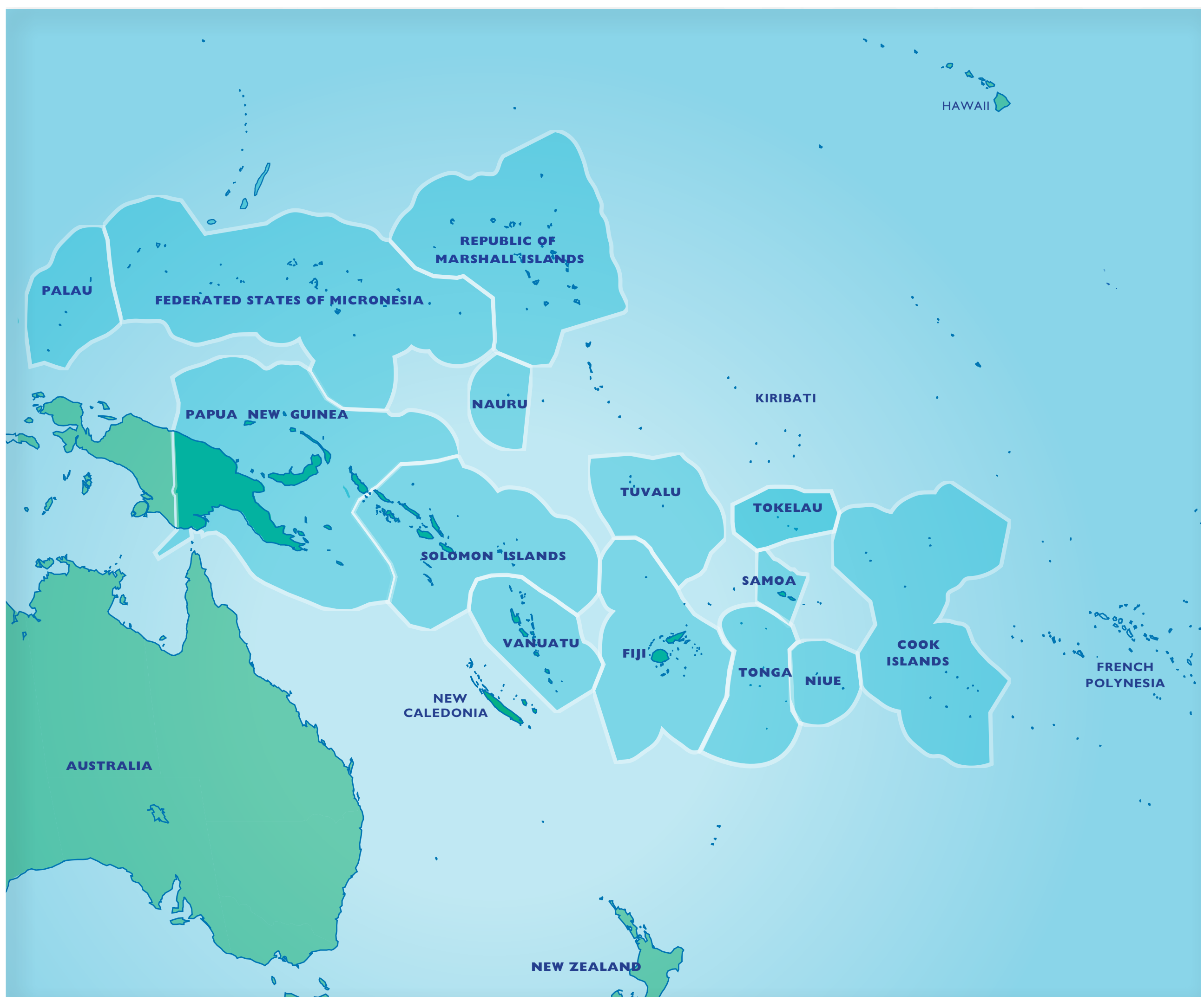
Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
House Connection Meter						
134	Brass	15mm	Kent PSM - T Water Meters	430	$95.61	$41,112.24
135	PVC	15mm	Valve Socket	430	$1.39	$599.49
136	PVC	15mm	Plain Elbow	1290	$0.25	$317.38
137	PVC	15mm	Faucet Elbow	430	$0.89	$382.03
138	Brass	15mm	Stop Cock	430	$8.67	$3,726.26
139			Meter Box (Polyethylene)	430	$62.19	$26,742.06
Sub Total						**$72,879.46**

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
Fire Hydrant						
140		100mm	Fire Hydrant (HTAL-C)	4	$780.46	$3,121.84
141		100mm	Hydrant Riser (HR600-C)	4	$351.28	$1,405.10
142		100mm	Hydrant Tees (RRJ suits Series 1 PVC and Hydrant Riser)	4	$481.12	$1,924.50
143		100mm	Fire Hydrant Dressing Set to suit Fire Hydrant and FH Tee	8	$158.55	$1,268.42
144		100mm	Fire Hydrant Box	4	$184.52	$738.09
145	PVC	100mm	Fire Hydrant Marker	4	$71.08	$284.30
Sub Total						**$8,742.25**

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
Miscellaneous						
146			Hacksaw Blade	10	$5.07	$50.71
147		500 ml	Marley Solvent Joint Primer	60	$22.06	$1,323.64
148		500 ml	Marley "Gold" Solvent Cement	60	$24.41	$1,464.70
149		501 ml	RRJ Lubricant (Jointing Crease)	60	$25.81	$1,548.35
150			Threading Tape	500	$1.23	$615.07
151		19904m	Marking Tapes	19904	$0.68	$13,602.71
Sub Total						**$18,605.17**
Repairs						
152			Toilet Cistern Rubber (Flat)	75	$1.71	$128.14
153			Toilet Cistern Rubber (Taper)	75	$1.85	$138.39
154		20mm	Valve Tap Jumper	50	$3.76	$187.94
155		15mm	Valve Tap Jumper	75	$3.54	$265.51
156			Hose Tap	100	$20.67	$2,066.65
Sub Total						**$2,786.63**
Ocean Freight						
157		4	Sea Freight Containers	4	$6,000.00	$24,000.00
Sub Total						**$24,000.00**
New Bores						
158		12m	Drilling and Casing (150mm) including 1 for Fo'ui	4	$4,070.00	$16,280.00
159			Pump House	6	$14,000.00	$84,000.00
160			Security Fence	6	$3,000.00	$18,000.00
Sub Total						**$118,280.00**
Ground & Elevated Level Storage, Pump Shed, Workshop, Chlorination Shed						
161	Fibreglass	45 kL	Fibreglass Tank (Ground Level)	3	$16,056.00	$48,168.00
162	Fibreglass	22.7 kL	Fibreglass Tank (Elevated Level)	1	$7,267.00	$7,267.00
163	Steel	9m	Steel Tankstand	1	$42,000.00	$42,000.00

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
164			Concrete Foundation(Ground Level Storage)	1	$14,000.00	$14,000.00
165			Chlorination Shed	1	$3,000.00	$3,000.00
167			Transfer Pump Shed	2	$4,000.00	$4,000.00
168			Workshop & Maintenance Tools & Equipment	1	$45,000.00	$45,000.00
Sub Total						**$163,435.00**
Roading and Site Access Preparation						
167			Site Clearance & Reservoir site preparation		$5,000.00	$5,000.00
168		200m	Access Road Construction		$20,000.00	$20,000.00
169			Reservoir Site Security fencing & Drainage		$7,500.00	$7,500.00
170			Fencing 1.8m high galv link mesh		$5,250.00	$5,250.00
171			Power Line Extension		$6,500.00	$6,500.00
172			Land Lease		$10,000.00	$10,000.00
Sub Total						**$54,250.00**
Pipe Trenching, Road Reinstatement and Fee						
173		548 cubic yard	Gravel (Pipe bedding material)	549	$19,215.00	$19,215.00
174		549 cubic yard	Sand (Pipe bedding material)	549	$23,497.20	$23,497.20
175		21183m	Excavation and trenching (212 hrs)	212	$39,220.00	$39,220.00
176			Road Cutting, Reinstatement and Administration Fee		$27,500.00	$27,500.00
177			Concrete works-m^3(Anchor Blocks & Chambers etc)		$15,000.00	$15,000.00
Sub Total						**$124,432.20**
Rain Water Tanks						
178		10 m^3	Fibreglass Tank	30	$3,550.00	$106,500.00
179		20 m	Spouting	20	$5,000.00	$5,000.00
180			Concrete slab and fittings for tank	30	$1,500.00	$45,000.00
Sub Total						**$156,500.00**

Item No.	Material	Size (mm)	Description	QTY	Unit price (TOP)	Total price (TOP)
Monitoring Equipment						
181			Monitoring Equipment	1	$18,865.00	$18,865.00
Sub Total						**$18,865.00**
Office & Transport						
182		1	Office	1	$15,000.00	$15,000.00
183		1	Pick up trucks	1	$20,000.00	$20,000.00
184			Furniture		$3,000.00	$3,000.00
185		1	Computers & Printers	1	$6,000.00	$6,000.00
Sub Total						**$44,000.00**
Training						
186			Training on Basic Plumbing, Leak Detection, Pump & Engine maintenance etc		$17,600.00	$17,600.00
Sub Total						**$17,600.00**
Sub Total						**$1,417,937.62**
Contingencies					5%	$70,896.88
Sub Total + TWB DDST						**$1,488,834.50**
Project Supervision & Quality Assurance					15%	$223,325.18
Total Project Cost						**$1,712,159.68**



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

PACC

Building Resilience to Climate Change in Pacific Communities

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 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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PACC TECHNICAL REPORTS

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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ISSN 2312-8224