AECOM

Te Mato Vai

Water Supply Master Plan for Rarotonga

Government of the Cook Islands

Ministry of Finance and Economic Management

Te Mato Vai - Water Supply Master Plan for Rarotonga

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Executive Summary

The Government of the Cook Islands are committed to supplying reliable potable water to all properties connected to the water network by 2015 / 2016. The reliable supply of potable water affords an important opportunity to provide for population and economic growth and the continuing health of local communities.

The Government of the Cook Islands have recognised that the current system will need a Master Plan to realise this opportunity and have secured funds through a grant from the New Zealand Government and a loan from the People's Republic of China.

This commitment is substantial. It is the largest single infrastructure project in the Cook Islands since the international airport construction in 1974. As a legacy project it is important that the potable water system is designed to fulfil its obligations now, and for future generations.

The overriding purpose of the Master Plan is to implement the Government of the Cook Islands policy of delivering potable water, reliably, to all properties connected to the existing water supply network, by 2015/16.

The Master Plan is intended to:

- identify the deficiencies in the water supply network caused by deterioration of the existing network, changes in population growth and legislation; and
- analyse the deficiencies under current peak conditions and future peak water demand conditions, to determine appropriate solutions and associated costs.

This will enable a financial plan to be developed that identifies the costs of the required network upgrades and options for cost recovery.

The Master Plan will provide immediate tangible benefits for the local community:

- An asset which is optimal in design so that it provides a reliable water source to all connected properties and continues to be economic to maintain and operate over the design life;
- Reliable treatment facilities that keep the local communities safe from pathogens, protozoa and viruses such as crypto, giardia and campylobacter within their drinking water; and
- Governance of the water network structured so that the Cook Islands are in a position to best manage this asset economically, politically, socially and environmentally.

This project also harbours considerable opportunity to leave a legacy of education within the Cook Islands:

- Up-skilling of local people to operate and maintain the asset, so that more local jobs are created and reliance on outside resource is minimal; and
- Education of the local community on the importance of potable water, its preciousness as a resource and how, at a community level, they can seek to sustain it.

Governance

A review was undertaken of the current governance and management arrangements for water services on Rarotonga.

As part ADB TA7287-COO "Improving the Delivery of Infrastructure Services", a national policy for water was drafted and issued for comment on the 30th July 2010. The draft policy proposes the establishment of a Public Utilities Authority (PUA) by first transferring responsibility to the SOE Te Aponga Uria (TAU) who is currently responsible for electricity, and then enacting legislation to transform into a PUA that would be responsible for the delivery of power, water supply, sanitation and solid waste services on Rarotonga.

This approach would make good sense, especially when the practicalities of introducing a cost recovery regime for water are considered. The systems, processes and customer interaction requirements will be very similar for water billing to those already in place at TAU and these could be extended to water customers.

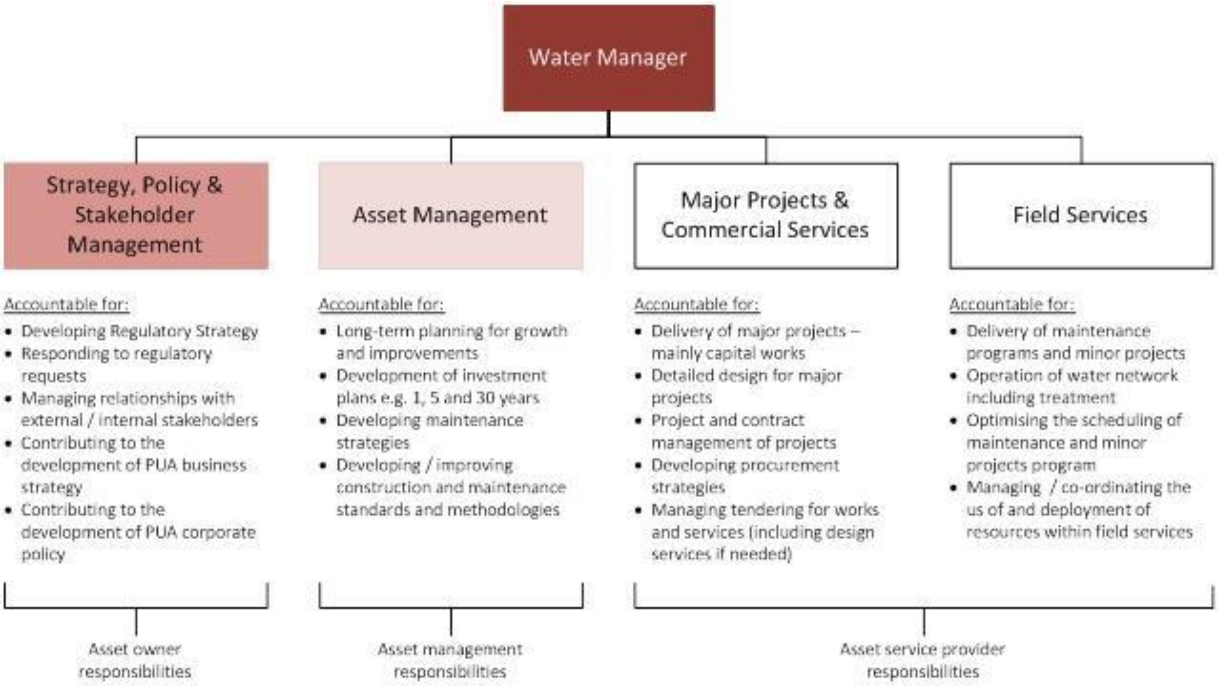
NSDP 2011 – 2015 states that for Priority Area 2: Infrastructure Strategy No. 5 involves strengthening Asset Management and "*We [the Cook Islands] will strengthen the management of our public assets. As a matter of priority we will develop and implement Asset Management planning frameworks in 2011-2015.*"

The implication of this strategy is that Asset Management needs to be embedded within the organisation and closely aligned with planning and development.

The adoption of Asset Management principles into the organisation design will internally separate the roles of:

1) The 'Asset Owner' role which sets the short and long term investment objectives for the assets.
2) The 'Asset Management' role which makes decisions to satisfy the Asset Owner objectives whilst managing the balance between asset life, levels of service and capital and operational expenditure.
3) The 'Asset Service Provider' which provides services to satisfy the decisions made by the Asset Manager

This translates into the suggested organisation chart for water supply services below.



While these roles are separated out they should be linked so that there is alignment across the organisation. Asset Management is a function that should be embedded across the entire organisation. The roles or functions are not necessarily attributable to individual persons and are likely to be spread across multiple persons.

The move towards a PUA that will charge for water and upgrading the water system to a potable standard will require legislation to be enacted to protect public health, prevent water wastage and manage Rarotonga's groundwater resources.

Water Network Recommendations

Through hydraulic analysis to the design horizon of 2031, and after consultation with the different stakeholder groups of Te Mato Vai, AECOM has identified 64 projects as part of the renewal and upgrade of Rarotonga's water distribution network. Identified projects include the ringmain upgrades proposed by CCECC and subsequent network upgrade projects as follows:

- All of Rarotonga's intakes and trunkmains have been recommended for refurbishment and replacement with the exception of the Takuvaine intake which was completed as part of the Project City upgrades;
- Treatment works and storage reservoirs are required at each of the intakes; and

- The installation of PRVs on the intake lines, flow meters and backflow prevention devices is recommended to facilitate effective management of the network.

A number of smaller and peripheral projects have been identified including:

- The continuation of the subsidised private water tanks project;
- The installation of local booster pumps to supply properties over 30m above mean sea level;
- Initiatives to address customer side leakage across Rarotonga; and
- The implementation of Supervisory Control and Data Acquisition Systems (SCADA).

Project Prioritisation

Upon the completion of the proposed ringmain upgrades, the order in which subsequent upgrades are undertaken has significant impacts regarding the level of service the network has the capacity to provide. The works should be scheduled in such a way that the projects delivering the greatest hydraulic benefit are prioritised. From the initial hydraulic analysis AECOM recommends the following projects as a high priority:

- The installation of raw water storage at Avana and Turangi due to the consistent yield and high elevation of these sources.
- Upgrades to the Kia Orana reservoir at Takuvaine due to the intakes location as the primary source serving the Project City area and the reportedly poor condition of the existing Takuvaine reservoir which sits at a relatively low elevation.
- Installation of raw water storage at Taipara intake to improve the security of supply and pressures in the South Western region of the network.

Water Treatment

Recommendations are given for water treatment unit processes, distribution system infrastructure and operations strategies to provide and maintain drinking water quality in the Rarotonga water supply system.

The proposed treatment strategies offer a multi-barrier approach to remove contaminants from the water source and maintain quality after treatment and prior to delivery to consumers. The proposed treatment processes aim at the following objectives, and are further detailed below:

- Particle removal that can withstand storm events which cause highly turbid water,
- Removal (by filtration) and inactivation (by primary disinfection) of microorganisms, and most importantly, pathogens,
- Residual disinfection to protect the treated water against pathogen introduction into the network during water distribution and also inhibit microbial regrowth,
- Distribution system control and water quality monitoring to ensure compliance with water quality goals and the ability for operations staff to know when quality degrades,
- Water storage to ensure that peak demand is met, but also to stop treatment during storm events that bring overly turbid water that may compromise the treatment steps.

Options are proposed for both mechanical filtration and disinfection. These options are categorised as the minimum requirement (that which should be installed to meet minimum water quality needs) and the recommended option (that which should be installed to allow for a more robust level of treatment and more stable protection of water quality).

Further considerations which are presented include treatment waste residual management, backflow prevention, network system operation, water quality monitoring and operator training.

Non-revenue Water Losses

Over the last 10 years MOIP has systematically replaced the reticulation mains on Rarotonga; the final sections in Avarua have been completed as part of Project City. Following the water system renewals, as seen recently in Avana, there are issues with leakage on private pipework. Much of the customer side pipework is old and its condition is unknown.

Therefore, non-revenue water has been primarily associated with residential properties. Based on previous work it has been assumed that leakage at the point of supply accounts for the majority of water loss from the system, estimated at anywhere between 40 – 70 % losses.

Recommendations have been presented for non-revenue water loss management, including the commencement of a customer-side leakage programme.

Cost Estimates

The Master Plan for Rarotonga has reviewed the cost estimates for the project based on the outputs from the hydraulic modelling and unit rates based on those provide by MOIP (Project City) and from other unit rate models, where applicable. A summary of the estimates is shown below (no allowance has been made for inflation).

Table 1 Summary of project costs

Project type	Total project cost ($NZ)
Trunkmains	11,302,000
Treatment Plants - minimum	1,681,000
Water Storage	14,121,000
Inlet Refurbishment	1,782,000
PRV	504,000
Meters and Backflow	4,251,000
Ringmain	23,161,000
Other	2,555,000
	59,357,000

The estimates also include extra costs for additional storage, upsized trunkmains and further definition of the meter costs resulting in a higher estimate.

The estimates produced are a class 5 estimate and are plus or minus 50%. Further project definition and scoping will allow the accuracy of these estimates to be better defined. The Master Plan also sets out prioritised programmes which can be amended if funding constraints dictate.

Quality and Standards

The Te Mato Vai project is a significant investment for the Cook Islands and material components should be to a high quality, correct specification and installed correctly. The ringmain has been designed by CCECC and has been designed to Chinese material specifications and the construction standards proposed are Chinese. The Government of the Cook Islands uses Australian and New Zealand Standards.

MOIP has undertaken substantial work during and after Project City to ensure quality and standards have been produced for the water supply.

The Master Plan includes standards which are complementary to the existing standards and should be read in conjunction with those outlined above.

1.0 Introduction

AECOM New Zealand Ltd (AECOM) was engaged by the Ministry of Finance and Economic Management (MFEM) of the Government of the Cook Islands (GoCI).

The GoCI is committed to supplying reliable potable water to all properties connected to the water network by 2015 / 2016. The benefits of a reticulated and treated water supply with storage are that public health is improved, especially for the young, elderly and those with a medical condition, there is water available for use during dry periods and that water is available for fire-fighting. The reliable supply of potable water engenders great opportunity to secure this resource to cater for population and economic growth and the continuing health of local communities.

The GoCI has recognised that the current system will need a major upgrade and master planning to realise this opportunity and as such have secured funds through a grant from the New Zealand Government and a loan from the People's Republic of China.

This commitment is substantial. It is the largest single infrastructure project in the Cook Islands since the international airport construction in 1974. It is important that what is designed will fulfil its obligations now, and well into the future.

1.1 Te Mato Vai

In order to achieve its commitment of safe reliable potable water to all connected properties by 2015/16 the GoCI received proposals from the China Civil Engineering Construction Corporation (CCECC) and the European Investment Bank (EIB) to upgrade the water supply system. These were brought together to form the basis of Te Mato Vai. Te Mato Vai is the Cook Islands Water Partnership with the People's Republic of China and New Zealand.

The funds from the People's Republic of China will finance the upgrade of the ring main in Rarotonga through the CCECC with other funding made available through the New Zealand Government and funding from the Government of the Cook Islands. The project will cost in the region of $60 million New Zealand dollars to deliver.

In parallel to the water upgrade project, another component of the Te Mato Vai project is the reform of the water sector in Rarotonga and the implementation of water charges through metering; neither of these items are covered by this water Master Plan.

1.1.1 CCECC proposal

The CCECC presented a proposal to the GoCI to upgrade the Rarotonga water supply system, the costs and components of the upgrade are presented in Table 2.

Table 2 CCECC Costs for upgrading the water supply system in Rarotonga (CCECC, 2011)

No	Content	M $NZ
I	**Engineering Cost**	42.32
1	Reservoirs	4.23
2	Slow sand filtration tanks	9.24
3	Trunk line pipes	6.44
4	Access	1.59
	Sub-total 1	**21.5**
5	Inner ring pipes	8.34
6	Inner ring facilities	1.05
7	Outer ring pipes	9.98
8	Link pipes between inner and outer ring	1.15

No	Content	M $NZ
9	Machinery preparation	0.3
	Sub-total 2	**20.82**
II	Other funds of engineering cost	7.68
	Total	**50.00**

The CCECC proposal did not include the costs for water metering.

1.1.2 EIB proposal

In 2012, a proposal was put forward by the European Investment Bank for the upgrade of the infrastructure on Rarotonga. It differed from CCECCs' proposal in that it only considered a partial upgrade of the ringmains. It did however, have cost estimates in for the metering. The cost summary from the proposal is presented in Table 3.

Table 3 EIB Costs for upgrading the water supply system in Rarotonga (EIB, 2012)

No.	Component	Cost $NZ
1	Rehabilitation of 12 intakes	$3,070,000
2	Treatment (roughing and slow sand filters)	$6,150,000
3	Storage tanks 5,000 m³ total volume	$3,200,000
4	Replace 9 transmission lines	$2,920,000
5	Ring main, 50% replacement, 50% repair	$7,110,000
6	Consumer water meters, 6,000 No.	$340,000
7	Operation & maintenance equipment, material	$250,000
8	Project management, training, commercialization	$3,280,000
		$26,320,000

1.1.3 Water Partnership

There were differences between the two proposals, such as the ringmain replacement, the number of intake lines to be replaced and metering. The water partnership was formed and agreed upon a common concept for the upgrade design parameters in Rarotonga (see Appendix A for a summary of the technical workshop outcomes). This included the scope of the upgrade and the criteria to be used for the design of the replacement system. This is contained in Table 4.

Table 4 Concept of water supply system upgrades

Water Intakes	
Storage	36,000 m^3
Treatment Capacity	11,200 m^3/day
Treatment	
Roughing Filters Refurbished	
Slow sand filtration	
UV disinfection	
Possible periodic cleaning of network (chlorination)	

Distribution
Treated water storage 1,600 – 2,400 m^3
Ring mains (up to 90% replacement)
Sub-mains
Water meters

The system component is developed from the following breakdown in Table 5. This was agreed by the Water Partnership and a high level review was undertaken by AECOM. We confirmed that the figures set out are reasonably conservative and lie in the mid-range compared to global figures.

Table 5 Maximum day design criteria used for system capacity determination

System Component	Treatment	
Use	Volume (m^3/day)	Comment
Residential	2,800	Based on resident population of 14,000 people and per capita consumption of 200 l/c/day
Tourist Accommodation	1,600	Based on 4,000 beds with a consumption of 400 l/bed/day
Industrial	1,700	A total value given, no breakdown by property number.
Irrigation/ Gardening/ Agricultural	4,600	A total value given, no breakdown by property number.
Schools, hospitals etc.	500	A total value given, no breakdown by property number.
Total	11,200	Total system demand

It is assumed once the system has been replaced the non-revenue water will be less than 10%. An estimate of the current non-revenue water is between 40% to 70%.

Rarotonga has a dry season and during that time the yields from the intakes at the streams are reduced. To maintain headroom in the supply / demand balance the GoCI currently uses demand management measures which reduces the demand to 4,800m^3/day.

1.1.4 Project City

The Ministry of Infrastructure and Planning (MOIP) has recently completed a substantial upgrade of the network in Avarua; this included a trunkmain from the Takuvaine source, the ringmain and the reticulation system. Meters have also been fitted to properties in the area, but they are not used for charging purposes.

All of the reticulation mains in Avarua have been replaced within the last 10 years as part of this upgrade.

1.2 Water supply Master Plan for Rarotonga

A water Master Plan will aim to undertake the following:

- It identifies the deficiencies in the water supply network due to changes in population growth, legislation, regulation and changes in levels of service;
- It aids analyses of the deficiencies in the system under current peak conditions and future peak water demand conditions;
- Solutions are developed and through a robust optioneering process the suitable ones are selected and the schemes are costed. This enables a financial plan to identify the funding requirements of the network upgrades and when schemes may proceed; and
- Predictions for population growth change and the Master Plans can be updated and refreshed at regular intervals to allow for this.

The primary driver in Rarotonga is a level of service change with the government’s objective to provide a safe, reliable and potable drinking water to all.

Key considerations in the approach to this Master Plan are:

- The overriding purpose of the Master Plan shall be the Governments policy statement of "*Delivering potable water, reliably to all properties connected to the existing water supply network by 2015/ 2016*";
- There has been substantial work already undertaken by consultants, government agencies, MOIP and the Water Partnership. This has identified substantial capital investment on Rarotonga; and
- Much of this work has recommended solutions using different design criteria than what has now been agreed. These designs should be revisited with the agreed criteria to see if any changes are required.

AECOM has undertaken the following approach to ensure this water Master Plan reflects the conditions in Rarotonga:

- Build an all mains water network model to replicate the water network;
- Derive consumption data, leakage and peaking factors from collected data and refresh initial analysis to reflect conditions in Rarotonga;
- Update the model with future population scenarios and analyse deficiencies, size trunkmains, ring mains and storage;
- Review and report pipe materials and specifications for construction;
- Review and report water treatment options;
- Review NRW and options on how to manage it going forward, including customer side leakage;
- Produce cost estimates and spend profile. Review available funding and identify any shortfall; and
- Identify further areas of work beyond the scope of this project.

A successful Water Supply Master Planning Upgrade project will provide the following immediate tangible benefits for the local community:

- An asset which is optimal in design so that it provides a reliable water source to all connected properties and continues to be economic to maintain and operate over the design life;
- Reliable treatment facilities that keep the local communities safe from pathogens, protozoa and viruses such as crypto, giardia and campylobacter within their drinking water ; and
- Governance of the water network structured so that the Cook Islands are in a position to best manage this asset economically, politically, socially, technologically and environmentally.

This project also harbours considerable opportunity to leave a legacy of education within the Cook Islands:

- Up-skilling of local people to operate and maintain the asset, so that more local jobs are created and reliance on outside resource is minimal; and
- Education of the local community on the importance of potable water, its preciousness as a resource and how, at a community level, they can seek to sustain it.

1.3 Existing reports

In preparing the Master Plan, AECOM reviewed a number of previous reports and data and incorporated key elements throughout the Master Plan.

These reports have been funded by development partners and the GoCI. In the main, many of the recommendations presented remain relevant today. Repeatedly, infrastructure studies in the Cook Islands have emphasised the need to address demand management and control of wastage, the need for consistent water quality, levels of service and water catchment protection.

A high level summary of a selection of the key report is set out below (these have been listed in reverse chronological order). A full list of the reviewed documents can be found in the bibliography in Section 17.0.

1.3.1 ADB report (2009) – Preparing the Infrastructure development project: Volume 3: Water Supply and Sanitation Sector TA 7022-COO

The ADB report covers the background, environmental setting, broad design considerations and issues and projects in the water supply. The main issues identified are leaking pipelines leading to high losses and inefficient operation of the distribution systems, unmanaged demand and the lack of awareness of the need for water conservation or of the public health risks that come from a disinfected water supply.

The other main issues identified included:

- The water sector suffers from severe institutional constraints in operation and management of assets due to an overlap of functions arising from policy gaps and a general shortage of professional staff.
- There appears to be adequate water supply at present under normal or average climatic conditions. However, as there is no metering of production or consumption of water by individual and commercial users, consumption is generally profligate and wasteful.
- As none of the water sources is disinfected, consumers either boil the water or buy bottled water for drinking and cooking. Diarrhoea and other water-borne diseases are prevalent on Rarotonga. The only water treatment consists of coarse grade filters which are wholly inadequate for removing disease-causing contaminants. Lack of treatment places the public at serious risk of chronic low-grade infection and occasional serious outbreaks.
- Since the existing supply in Rarotonga is entirely from surface water, seasonal storage is necessary to ensure continuous supply during seasonal variations and anticipated extremes due to climate change.
- To date about 70 percent of the local distribution system has been replaced and the replacement of the remainder (but not of the 32 km ring main) is planned. The effectiveness of the distribution pipe replacements is not known as no metering has been carried out.

  It appears that no allowance has been made for firefighting needs. These circumstances lead to the conclusion that further distribution system upgrading will be required with time, despite the sums being invested now. The uninformed asset renewal that this case exemplifies highlights the need for an asset management plan which would establish monitoring and maintenance works on a systematic basis
- There is no information on user water demand profiles.
- Water losses are also uncertain, but are high.
- The government's investment in water sector assets and support to the annual cost of operation and maintenance are substantial. The government on its own does not have sufficient resources to deliver the water supply and sanitation services that the country needs for its growth. The introduction of user charges for metered consumption would reduce wasteful usage and the costs of meeting demand, and provide a sustainable source of funds for investment and maintenance.
- There has been little effort to raise public awareness on the costs of providing a reliable and safe water supply, or to change user attitudes about consumption and the need to reduce demand on finite water resources.

1.3.2 MOIP report (2009) – Water Safety Plan for Rarotonga

The Water Safety Plan is a systematic assessment of every aspect involved in the provision of safe drinking water identifying all the risks associated with the current water supply system and where possible offers solutions to eliminate or reduce these risks.

The report sets out an improvement schedule covering:

- Sources & catchments;
- Treatment, storage and distribution; and
- Other areas of improvement.

1.3.3 SOPAC technical report (2009) – Hydraulic network modelling of the Rarotonga water supply system Cook Islands

The SOPAC report sets out the work undertaken to create a working hydraulic model of Rarotonga's water distribution system in the Tutrangi area.

The development of the model involved the collection of demand, elevation and pipe layout information. In order to determine demand for the whole of Rarotonga, estimates of domestic, commercial and agricultural demands were made based on metered water use of specific buildings and typical demand values.

Water use in the Turangi zone was also calculated by aggregating demands from houses, commercial properties, etc. at certain spots or junctions.

A demand profile was applied to this demand to reflect usage across a day and model calibration was undertaken using flow and pressure data collected by the Water Works Department. The model only produced results close to the measured flow and pressure data when water use was increased by almost 3 times the estimated user demand. This translates into approximately 65% of water in the Turangi zone being unaccounted for or lost

Results from the modelling indicate that the Turangi intake is not able to supply the entire demand from this zone, as the Turangi stream simply cannot supply this amount of water. The resulting pressures throughout much of the system will also be too low for proper water distribution.

Key recommendations from this report included confirming asset elevations etc. and collating asset data into MapInfo; undertake leak detection and repair; collect flow data from intakes and customers and build a complete hydraulic model for Rarotonga.

1.3.4 CSIRO report (2005) – Economic Valuation of Watershed Pollution in Rarotonga

The CSIRO report estimated that Rarotonga could potentially avoid costs of NZ$7.4 million per year, or $2,900 per household per year, if watershed pollution across the entire island was prevented. The report noted that it is likely that watershed management activities will only recover some part of these avoidable costs. This is because a ‘perfect’ cleanup of the watershed is unlikely to be feasible.

The report’s best estimate is based on a three per cent loss in tourists per annum. Further research is required to more deeply test the relationship between environmental conditions and tourist visitation. If tourist costs are removed, the economic impact is still significant with a best estimate of NZ$4 million per annum or NZ$1,600 per household per annum.

The report highlights that the costs represent 1.32% to 7.41% of the Cook Islands gross domestic product (GDP) placing a significant burden on the local economy. Effective management of watersheds to recover at least some part of these costs will require a combined government, industry and community response including carefully designed policy instruments.

2.0 Governance of the water supply system on Rarotonga

A high level review was undertaken of the current governance and management arrangements for water services on Rarotonga building on the many past studies, the most recent being ADB TA7287-COO. Associated with this, a review was also to be undertaken of the proposed structure as the water supply sector transitions into a State Owned Enterprise (SOE) either separately or combined with other utilities. This would enable water services to be an autonomous, commercial organisation and provide transparency in terms of related costs and standards. Such a development, along with the introduction of tariffs for water supply, is provided for in the National Sustainable Development Plan 2011 – 2015 (NSDP).

Extensive investigation and consultation has been done in these past studies the results of which have all been presented to the Government of the Cook Islands. The Master Plan attempts to summarise these studies with final emphasis on having a single organisation responsible for infrastructure including electricity, water and waste.

2.1 Authority for governance

2.1.1 Current situation

Governance for water services on Rarotonga is currently provided by the Ministry of Infrastructure and Planning (MOIP) which includes in its organisation structure a Water Works Division. The Secretary is head of the ministry, who is responsible to the Minister for MOIP the Honourable Teariki Heather.

MOIP was established in November 2008 when the Office of the Minister for Outer Islands was merged with the Ministry of Works. However, the legal authority for MOIP to be involved in the provision of water services and ownership of assets is unclear. Neither the Government of the Cook Islands Property Corporation Act nor the Cook Islands Investment Corporation Act covers the management and ownership of water supply assets.

The current Water Works Division is not in a position at the present time to consider water supply tariffs. Considerable initial effort will be needed to establish the fixed and variable costs of water supply operations. Present information on connections, consumption, flows, pressures and losses is at best vague and uncertain. Also, considerable improvement is required in the customer service and support areas. Service levels, construction standards and water quality standards have to be developed and agreed with consumers. It is estimated that this effort would likely take a minimum of 18 months.

Current work to date has been reflected in the drafting of a Bill, the “Water Resources Management Act 2006” to provide for the better investigation, use, control, protection, management and administration of water resources. The Act would establish a National Water Resources Advisory Committee to oversee, guide and advice on the management of water resources in the Cook Islands. It also allows for the establishment of a Water Utility Board to facilitate the management, control and regulation of water utilities involved in the supply of water services or works.

Another important objective of the Act is to repeal the “Rarotonga Waterworks Ordinance 1960” which appears to be the main document of any legal standing covering water supply on Rarotonga. The “Water Resources Management Act 2006” has not received wide consultation.

As part of the recently completed ADB TA7287-COO Improving the Delivery of Infrastructure Services, a national policy for water was drafted and issued for comment on the 30th July 2010. The draft policy is quite wide reaching and of particular interest is Section 3.2 which proposes the establishment of a Public Utilities Authority (PUA) to “own, manage and operate water supply and wastewater management assets”. The draft policy proposes the establishment of a PUA by first transferring responsibility to the SOE Te Aponga Uria (TAU) who are currently responsible for electricity, and then enacting legislation to transform into a PUA.

The requirement for the establishment of a PUA is by no means new or revolutionary and reiterates earlier recommendations. TA2070 in 1995 by Barrett Consulting Group recommended establishment of a Public Utilities Authority at TAU covering water supply, power, liquid and solid waste. TA3085 in 2000 by Brockman Tym and MWH again recommended establishment of a PUA at TAU covering water supply, sewerage and power. NSDP 2007-2010 recommended establishment of a National Water Authority to manage the supply of water. The PIMP report in 2007 and TA4605 in 2009 both by Fraser Thomas Partners recommended the establishment of a Rarotonga Water Supply and Sanitation Board.

To the best of our knowledge the draft water policy produced under TA7287 has never been finalised. This policy should be updated to ensure the stated principles and objectives are aligned with decisions that have been made in connection with Te Mato Vai. The policy also overlaps with other policies that have been produced for areas including sanitation and integrated water resource management. It is expected that this update would also remove duplicate sections.

2.1.2 Recent developments

On the 7th September 2012 the Government of the Cook Islands (GoCI) issued a memorandum approving:

- The principle of cost recovery and user charges for water supply to households and business in Rarotonga once the water infrastructure is completed; and
- The principle that a State owned Enterprise will operate the Rarotonga water supply by the time the asset [upgrade water works resulting from the Te Mato Vai project] is completed (currently estimated by 2015).

The memorandum also noted "*that MFEM and MOIP have now commenced working on a plan for the policies governing the whole water sector and will seek Cabinet endorsement of management of the sector going forward, as commented by the Central Agency Committee*."

The GoCI Budget estimates 2013/2014 Book 3 Capital plan dated June 2013 states in Section 4.7 Ministry of Finance and Economic Management that:

> *"Cabinet has approved the creation of a State Owned Entity to run water supply on completion of the project [Te Mato Vai]. The preliminary cost of establishing this will be funded by ADB grant for technical assistance. The current water operational costs (MOIP Water Division/WATSAN staff and Rarotonga water maintenance budget) are expected to be transferred to the SOE. Budgets will need to be increased to fund the cost of an improved water quality system. They will be sustained by introducing user pays charges once water quality reaches 'potable' water standard. This is expected to create quality public service jobs for the foreseeable future".*
>
> *As part of the recently completed TA7287, a range of legislative drafting was commenced. Included in the draft legislation prepared was the Public Utilities Authority Bill 2013 which if enacted would transform TAU into a PUA "to carry out functions relating to the supply of electricity and water, and the collection, treatment, processing and disposal of liquid and solid waste, and for purposes incidental or connected to the supply, collection, treatment or disposal."*

A certain amount of reform was going to be needed in relation to the governance framework of the Cook Islands Investment Corporation (CIIC) in relation to SOEs and vice-versa. As the Public Utilities Authority Bill 2013 and other bills began to be drafted and reviewed, it became very clear that the scope of reform needed around CIIC and SOE's was quite major. The draft Public Utilities Authority Bill 2013 came under very close scrutiny particularly from TAU who would be impacted significantly. It was also acknowledged that because the bill was promoting a cost recovery regime for water, the GoCI needed to proceed with caution and undertake a highly consultative process with all sectors of the community.

The legislative drafting being undertaken as part of TA7287 was then deferred by CIIC in a letter dated 28th February 2103. A much expanded Reform Programme was needed that did not fit with the completion date (or the budget) of TA7287 plus the GoCI had on offer legislative drafting support from the New Zealand Council Service.

2.1.3 Summary

AECOM and its sub consultants were responsible for the work carried out under TA7287 a key outcome of which was confirmation / reiteration of the need for a PUA that would be responsible for the delivery of power, water supply, sanitation and solid waste services on Rarotonga. Our view remains unchanged especially when the practicalities of introducing a cost recovery regime for water are considered. A cost recovery regime for water will require the use of a billing system and the implementation of associated meter reading and payment processes. The systems, processes and customer interaction requirements will be very similar if not identical to the requirements already in place at TAU and it makes good business sense to leverage off what TAU is already doing. The Gentrack software in use by TAU for electricity billing also has available the necessary modules and functionality for water billing.

TAU's 2011 – 2012 Annual Report states a total of 4,582 electricity customers on Rarotonga which would imply a similar number of water customers. It does not make good commercial sense to duplicate billing systems and processes for such a small customer base, however, a certain level of investment will still be needed.

The customer service demands will almost certainly increase when a cost recovery regime is implemented for water supply. Payment for water will set expectations for customers in terms of water quality, pressure and continuity of supply. If their expectations are not being met they will be quick to complain and there will be a myriad of complaints and actions normally associated with issuing bills and collecting payments for water. TAU will already have extensive experience in dealing with electricity customers and should be able to easily extend this experience to deal with water supply customers.

A PUA will need to have a strong focus on Asset Management as the use of assets to deliver an agreed level of service will be at the core of its business model. From the review work done under TA7287, TAU has already been identified as having implemented many of the basic elements of Asset Management and it will be able to share this knowledge and experience with the Asset Manager/s for water supply, sanitation and solid waste services.

2.1.4 Organisation structure review

In MOIP's 2013-2014 Business Plan which was submitted for approval, the 2012-2013 organisation structure was shown as follows:

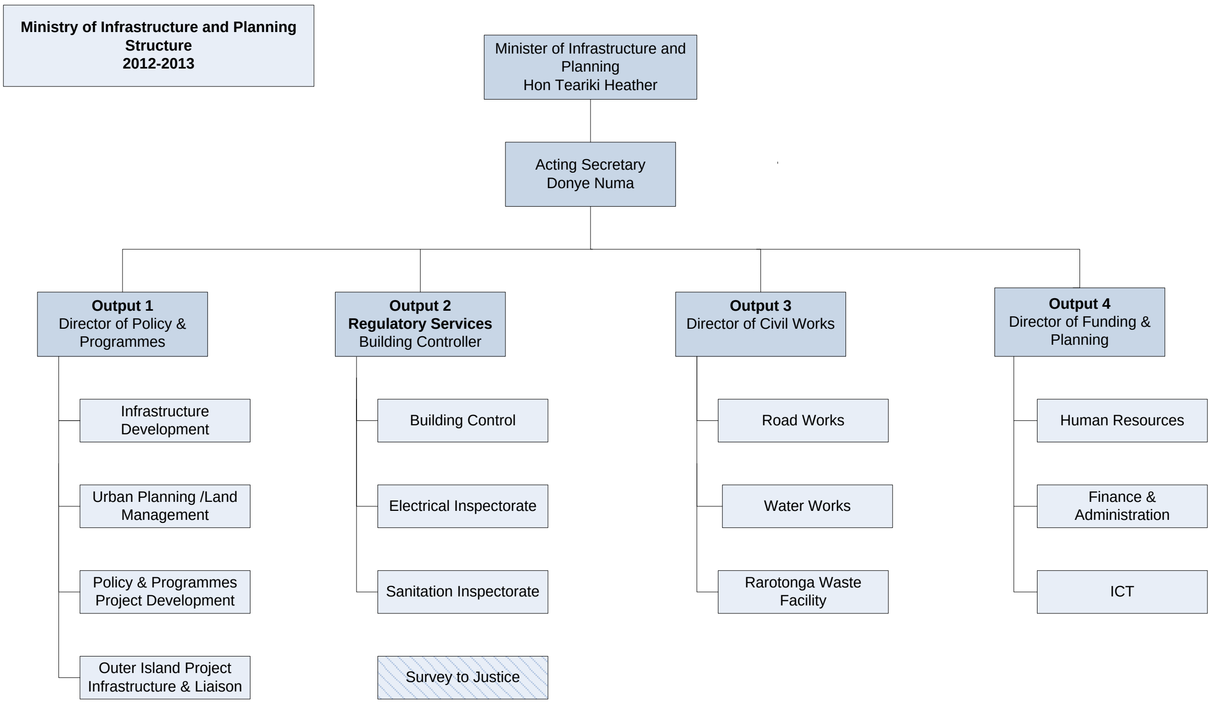


Figure 1 MOIP 2012-2013 organisation structure

Associated with the Water Works Division is the Water, Waste and Sanitation unit (WATSAN). The unit was established in 2011 to focus on the protection of the Cook Islands unique environment; especially the fragile lagoons. Its role or activity is project related and its most significant project to date has been the replacement of ageing / non-compliant residential septic tanks in the Muri-Avana area. MOIP will also use WATSAN as the vehicle for managing Te Mato Vai in particular the water supply upgrade works which are due to commence shortly.

In MOIP's 2013-2-14 Business Plan which was submitted for approval, a new organisation structure was proposed as shown in Figure 2.

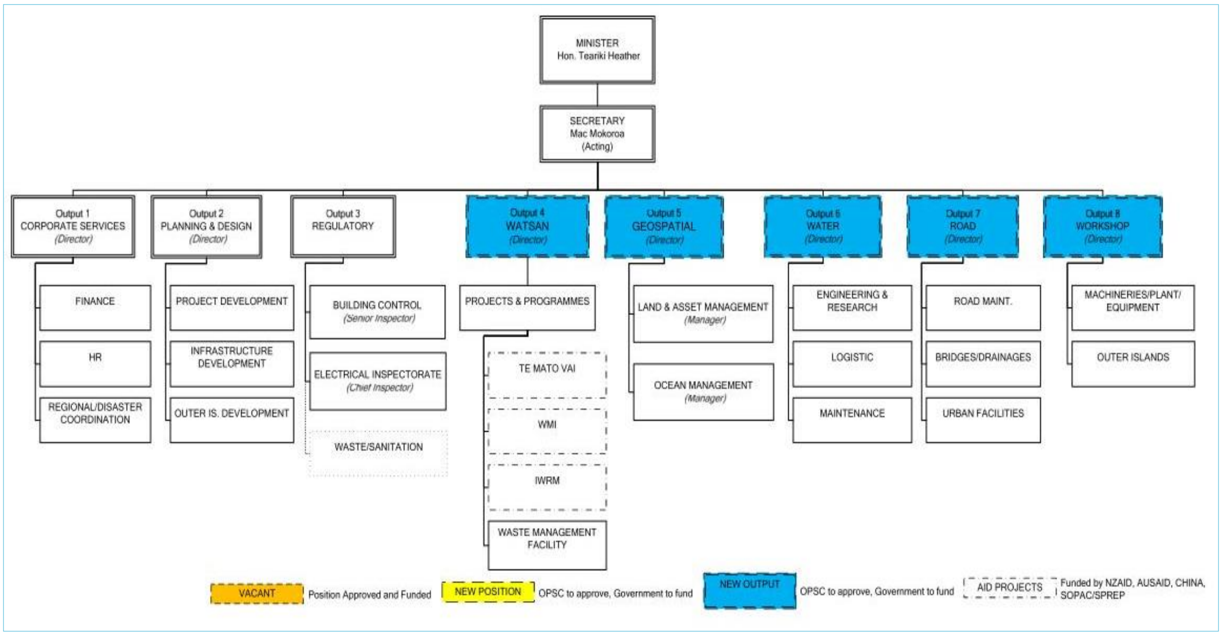


Figure 2 MOIP 2013-2014 organisation structure

Interestingly, the NSDP 2011 – 2015 states that for Priority Area 2: Infrastructure Strategy No. 5 involves strengthening Asset Management and "*We [the Cook Islands] will strengthen the management of our public assets. As a matter of priority we will develop and implement Asset Management planning frameworks in 2011-2015.*"

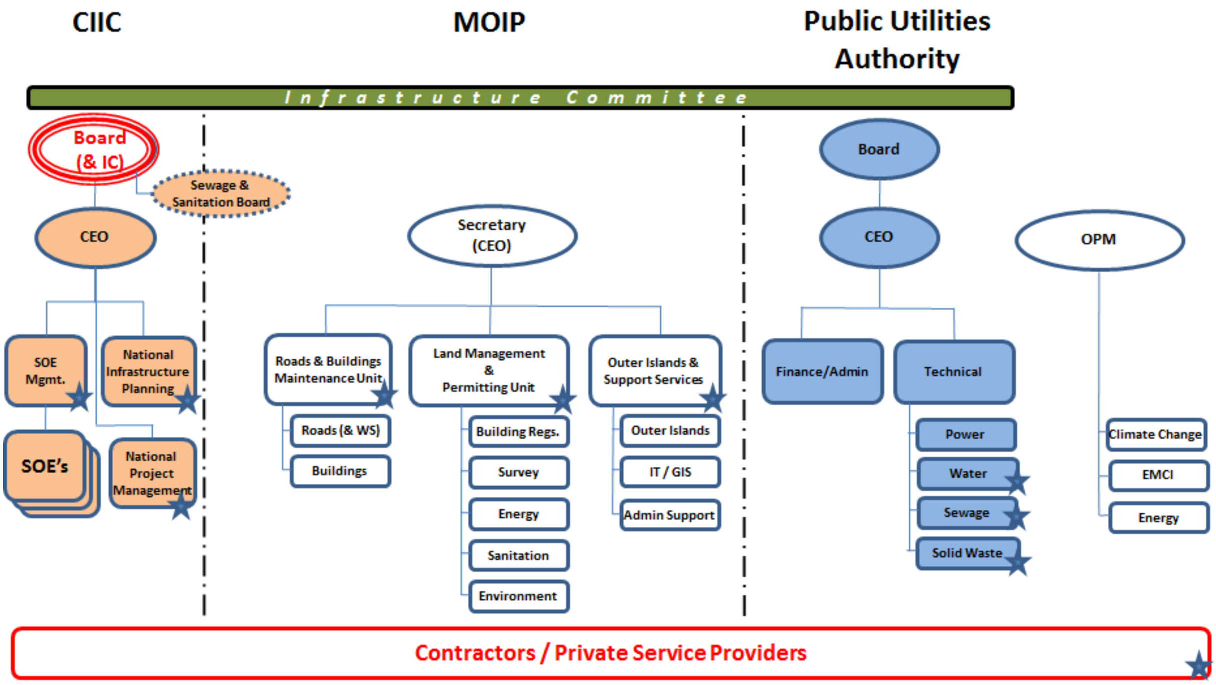
The implication of this strategy is that there needs to be more Asset Management focus within organisation structures responsible for infrastructure. Asset management (AM) cannot be just an add-on function in organisations – it needs to be embedded within organisations and closely aligned with planning and development. The organisation structure proposed in Figure 2 treats Asset Management as an add-on function. Asset Management is also not a sub-function of Geospatial – if anything; Geospatial is a sub-function of Asset Management.

The most practical and most appropriate place for Asset Management in the above organisation structure would be under Output 2 – Planning and Design.

2.1.5 Proposed organisation structure

The organisation structure shown in Figure 2 is rather academic given the confirmation / reiteration of the recommendation in Section 2.1.3 which is to transform TAU into a PUA to be responsible for the delivery of power, water supply, sanitation and solid waste services on Rarotonga.

Under TA7287 an Infrastructure Forum was held in Rarotonga between the 26th and 28th July 2010. At the conclusion of the forum the Consultant was given the opportunity to make a presentation that summarised the TA's findings to date and included outcomes from deliberations during the forum. As part of that presentation an organisational recommendation was tabled that in essence brought together a number of organisational recommendations as shown in Figure 3. The proposed organisation structure is still relevant in that it highlights the establishment of a PUA and how that might look at a high level but it also highlights the separation of regulatory functions which would sit under MOIP.



★*(Denotes where additional capacity building support will be required during the change implementation process)*

Figure 3 Recommended organisation structure

Of importance will be how the PUA is structured internally. As commented in Section 2.1.4, it will be important to adopt Asset Management principles into the organisation design which will separate out the roles of:

1) The 'Asset Owner' role which sets the short and long term investment objectives for the assets.

2) The 'Asset Management' role which makes decisions to satisfy the Asset Owner objectives whilst managing the balance between asset life, levels of service and capital and operational expenditure.

3) The 'Asset Service Provider' which provides services to satisfy the decisions made by the Asset Manager

While these roles are separated out they should be linked so that there is alignment across the organisation. Asset Management is a function that should be embedded across the entire organisation. The roles or functions are not necessarily attributable to individual persons and are likely to be spread across multiple persons.

Using water supply and an example (but ignoring the shared finance and admin functions), the above Asset Management approach would translate into an organisation structure something like the following:

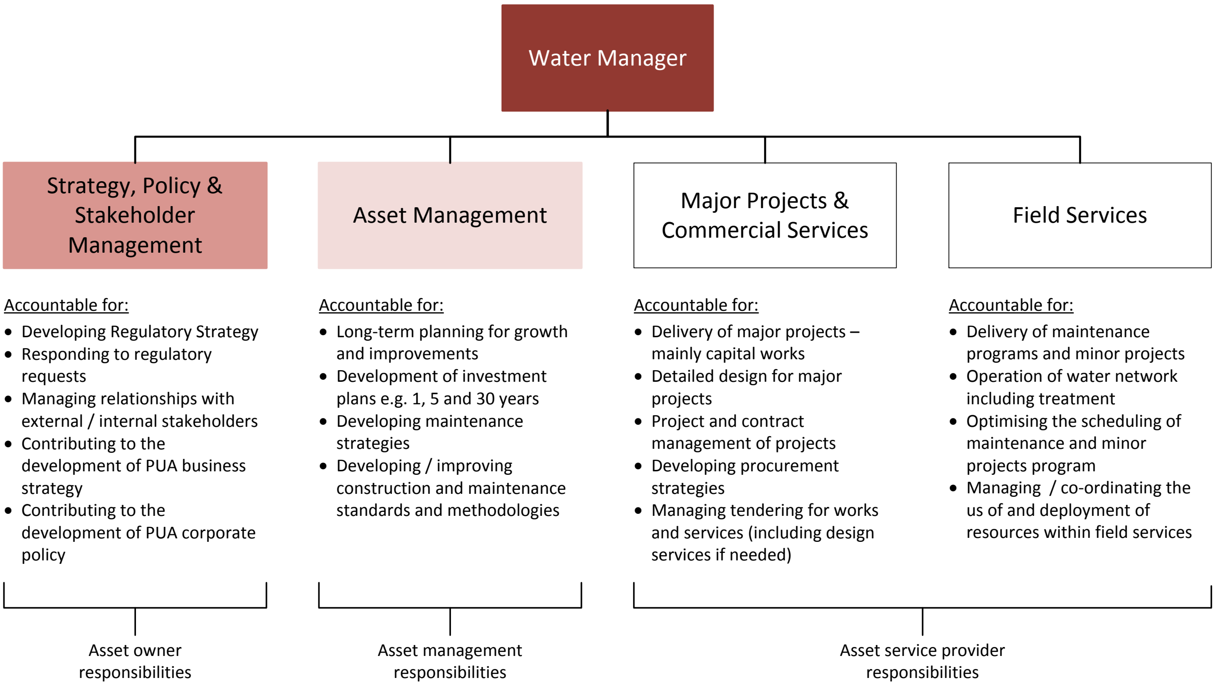


Figure 4 PUA Water component organisation structure

The Government of the Cook Islands is taking Asset management seriously. The structure proposed in Figure 4 sets out what we believe to be the most effective organisation structure but working within the PUA already proposed. This is based on our involvement and witnessing of organisation restructures as Asset Management has evolved in New Zealand, Australia and globally.

In reality, it is likely the Water Manager role would also encompass responsibility for sanitation and solid waste given their small scale at present. If Rarotonga progresses to collecting and treating wastewater, the specialist nature of this service particularly wastewater treatment, would probably demand a dedicated Wastewater Manager although there might be some sharing with water of the underlying roles of Asset Owner, Asset Management and Asset Service Provider.

One important function or role not detailed above is that of data or information management. Given the small size of the asset base for which PUA will be responsible, a centralised data or information function should be sufficient for managing all the different assets. Whether it is electricity, water or wastewater assets, they will require the use of the same types of systems which should include a Geographic Information System (GIS) and an Asset Management Information System (AMIS). A core group of staff should be established and take responsibility for maintaining all the asset data within the GIS and AMIS and provide support to the different technical areas requiring access to and use of the systems.

2.1.6 Other areas of work

The move towards a PUA that will charge for water and upgrading the water system to a potable standard will require legislation to be enacted to protect public health, minimise water wastage and manage Rarotonga's groundwater resources:

- Backflow prevention and plumbing bylaws: It is important to ensure contamination cannot enter the public water supply; this may need changes to the building regulations for all new builds with respect to plumbing. For the existing buildings and properties a risk assessments will have to be undertaken and for those where there is a risk of contamination, remedial measures will have to be put in place. This is discussed further in section 10.0.
- Water Losses: The GoCI are proposing to spend millions of dollars upgrading the public water supply, there will be issues with leaks on private pipework once the system has been renewed. Much of this pipework is old and its condition is unknown. This issue has occurred recently in Avana as a result of the Project City upgrade (Cook Islands News, 2013). There is legislation in the Rarotonga Waterworks Ordinance 1960 to deal with water wastage, however it will need to be updated and a strategy combined with legislation will need to be developed to provide a framework to address these problems.

- Groundwater Management: Previous work has identified substantial groundwater resources in Rarotonga (ADB, 2009), and this has been further highlighted as an area of development in the Water Safety Plan for Rarotonga (WHO, 2007). These groundwater sources could be utilised in times of drought. However a system of permitting or licensing will need to be developed to allow the government to manage these resources on behalf of the citizens of Rarotonga. This will help prevent over abstraction and the risk of salt water intrusion contaminating the aquifer. This will become more urgent with the introduction of water charges which will lead to individuals and companies exploring other sources for their water, which could lead to over abstraction. The management of this resource could be undertaken by one of the existing bodies.
- Water resource ownership is outside the scope of the Master Plan; however, it is recommended that catchment management plans be considered to provide for the control of catchments supplying water for the potable supply. Engagement with catchment landowners would be advised in the development of any policy, legislation or regulation.
- A policy should be considered to establish the level of service to customers where there is non-payment of water bills.
    - For example, where a person is unable to pay their water bill under a user pays scheme, that there are measures in place to deal with the issue.
    - The policy may determine that no supply will be terminated on non-payment of a water bill, however a restricted supply will be provided to supply basic sanitation water needs until the matter is resolved.
    - For users with low income, or struggling to pay their bill, assistance could be given to help use their water more efficiently, or alternative payment terms.

3.0 Existing water supply system

3.1 Description

Rarotonga's water network is supplied by spring and surface water intakes situated between 90 and 49m above mean sea level (AMSL). The network can be described in terms of a hierarchy of pipes distributing water from the source to the end user. The system employs trunkmains to convey flow from the intakes down to the transmission network, consisting of interior and coastal ring mains and regular cross connections. Water users are supplied by a distribution network of smaller diameter sub-mains.

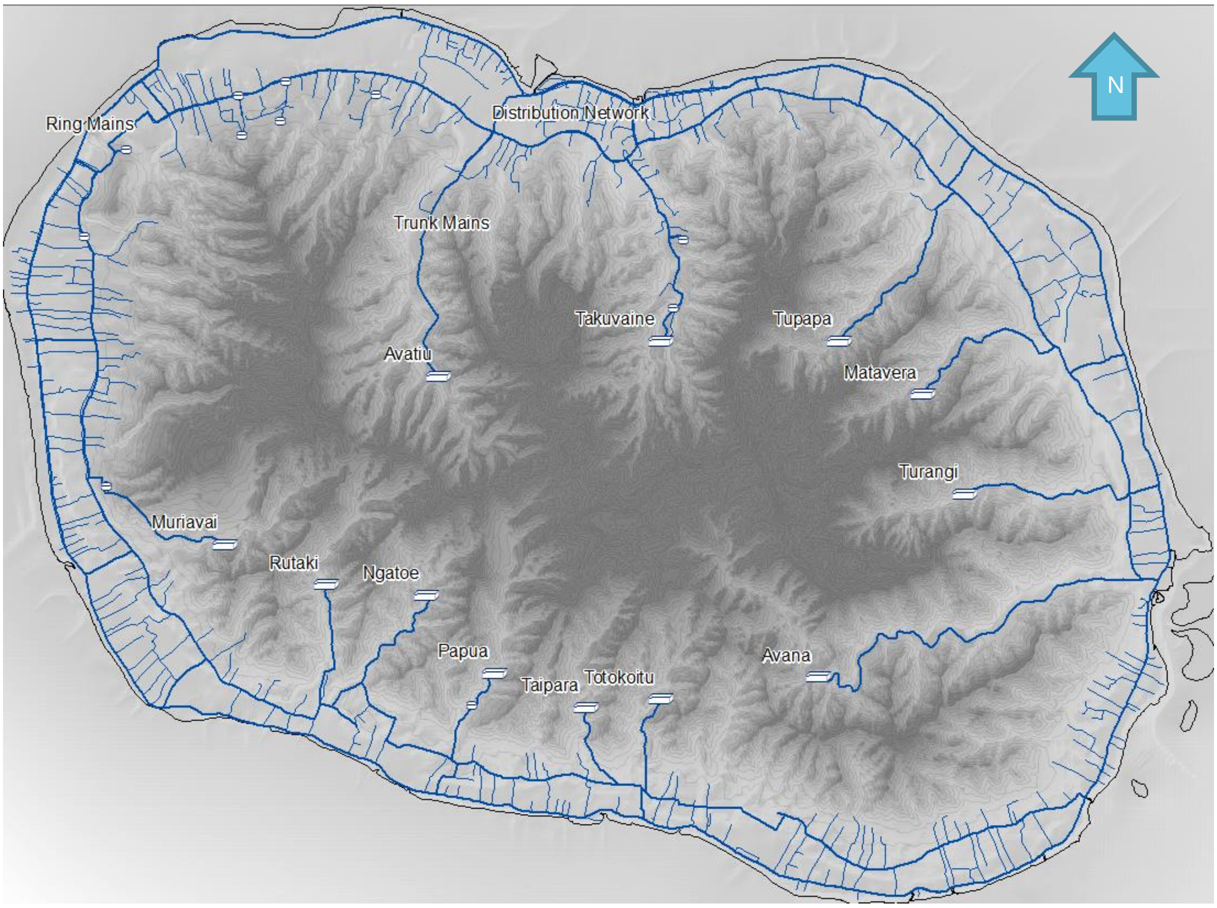


Figure 5 **Network overview**

3.2 Intakes

Details for each of Rarotonga's 12 intakes are included in Table 6. With the exception of the Papua intake, the only measures for water treatment in the existing network are the coarse gravel screens at 8 of the intakes. A semi-automatic filter unit manufactured by Arkal filtration systems is in operation at Papua. The location of the intakes is shown in Figure 5 .

The Muriavai intake on the South Western side of Rarotonga serves the Akaoa reservoir. The source is reportedly unreliable particularly in periods of drought; AECOM has elected to not consider it as a source for supply. In all modelled simulations the pipework connecting the Muriavai trunkmain to the interior ring main has been modelled as a closed pipe. It has been assumed that the remaining 11 intakes offer adequate yields to meet demand across Rarotonga.

Table 6 Rarotonga intake structure details

Intake	Catchment (ha)	Elevation (m AMSL)	Date Commissioned	Intake Type
Avana	243	81	1964	Direct
Avatiu	135	80	1990	In-stream gravel filter screen
Matavera	83	65	1992	Offline intake with gravel filter screen
Muriavai	144	64	1967	Direct
Ngatoe	98	65	1993	Offline intake with gravel filter screen
Papua	163	49	1965	Direct
Rutaki	109	51	1989	In-stream gravel filter screen
Taipara	84	49.5	1988	In-stream gravel filter screen
Takuvaine	161	69	1990	In-stream gravel filter screen
Totokoitu	70	65	1963	Direct
Tupapa	101	65	1992	Offline intake with gravel filter screen
Turangi	118	72	1990	In-stream gravel filter screen
Total	**1,509**			

3.3 Storage

There are 11 existing reservoirs in the Rarotonga network with a total storage capacity of approximately 14,500 m^3. Three reservoirs are currently out of service, reportedly due to water quality issues, including the large open Akaoa reservoir. This reduces the available in service storage to approximately 3,600 m^3 which represents a very small proportion of the total daily demand across the existing water supply system. Details of the existing reservoirs are given in Table 7 and shown in Figure 6.

Table 7 Existing reservoir details

Reservoir	Storage Volume (m^3)	Elevation (m AMSL)	Status
Kia Orana Tank	178	52	In service
Takuvaine Reservoir	2,500	41	In service
Papua Distribution Tank	450	23	Out of service
Sanatorium Distribution Tank	450	43	Out of service
Tereora Holding Tank	45	9.5	In service
Tereora Distribution Tank	135	32	In service
Tepuka Holding Tank	90	9	In service
Tepuka Distribution Tank	135	48	In service
Prison Holding Tank	90	17	In service
Airport Distribution Tank	450	19	In service
Akaoa Reservoir	10,000	32	Out of service
Total	**14,523**		
Total in service	**3,623**		

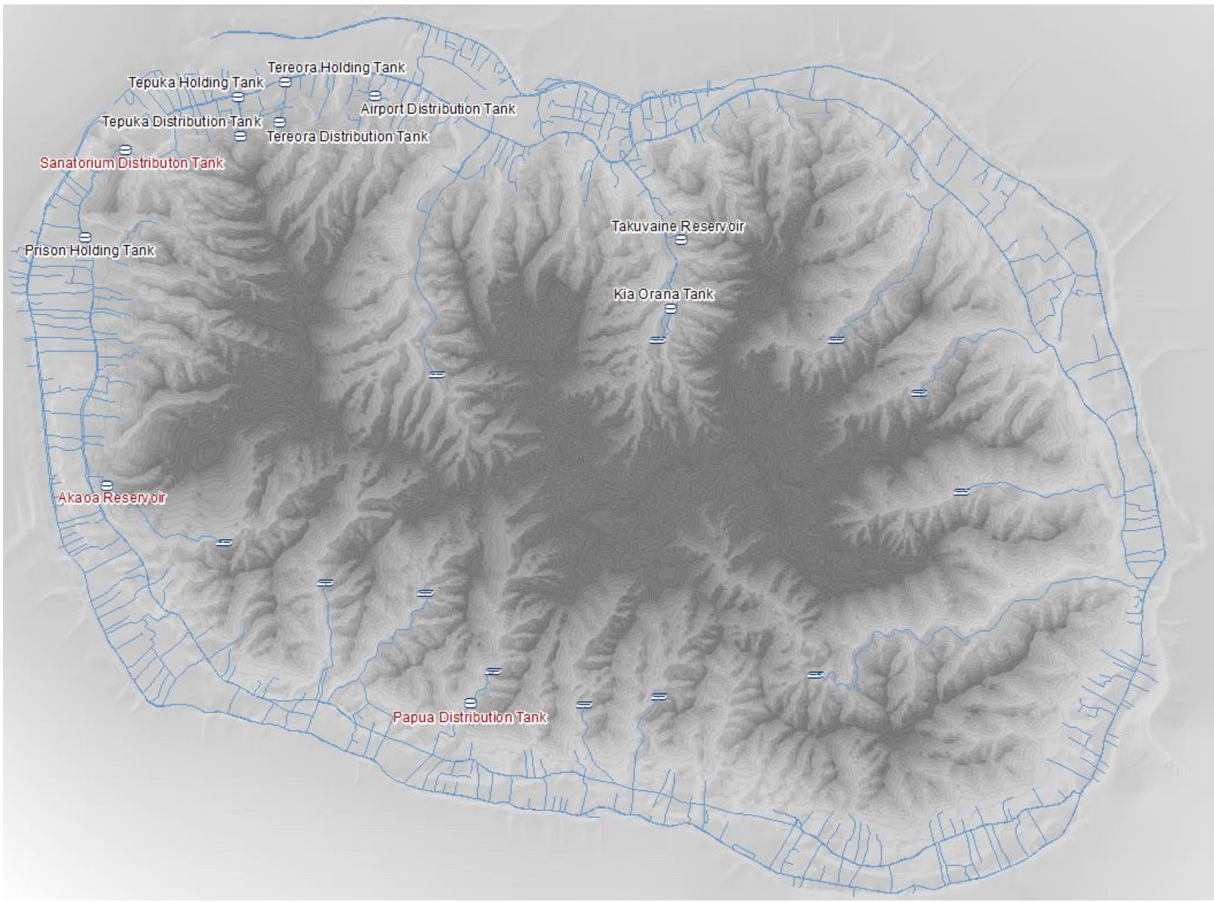


Figure 6 **Rarotonga storage reservoirs**

3.4 Pumps

The existing network includes two booster pumps which feed the Tepuka and Tereora distribution tanks above the airport. AECOM has received no data for these pumps other than their spatial location. A standard pump curve was assumed for the model build and should be replaced when data becomes available. These pumps are reasonably small so any changes to the model will cause no impact on the Master Plan or water supply system.

3.5 Trunkmains

Raw water from the intakes is fed into the distribution system through trunkmains which range from 150 mm to 250 mm in diameter. The majority of existing mains are either AC or uPVC, however, the Takuvaine trunkmain was upgraded from an AC to a DI pipe in 2013. Details of the existing trunkmains are given in Table 8.

Table 8 **Existing trunkmain details**

Trunkmain	Diameter (mm)	Material	Length (m)	Year installed
Avana Trunkmain	250	AC	4,174	1965
Avatiu Trunkmain	150	AC	2,624	1965
Matavera Trunkmain	200	uPVC	1,709	1993
Muriavai Trunkmain	150	AC	1,617	1965
Ngatoe Trunkmain	200	uPVC	1,589	1993
Papua Trunkmain	150	AC	1,503	1965
Rutaki Trunkmain	200	uPVC	1,170	1993

Trunkmain	Diameter (mm)	Material	Length (m)	Year installed
Taipara Trunkmain	200	AC	873	1965
Takuvaine - Trunkmain	200	DI	1,958	2013
Totokoitu Trunkmain	150	AC	1,200	1965
Tupapa Trunkmain	200	uPVC	1,864	1993
Turangi Trunkmain	200	uPVC	1,695	1993
Total			**21,976**	

3.6 Ringmains

The existing ring main was constructed in 1967 / 1968 along the outer and inner coast road. The majority of the main is AC, with a small portion being uPVC. The sections in Avarua were replaced in 2012/ 2013 with DI and uPVC – refer Figure 7.

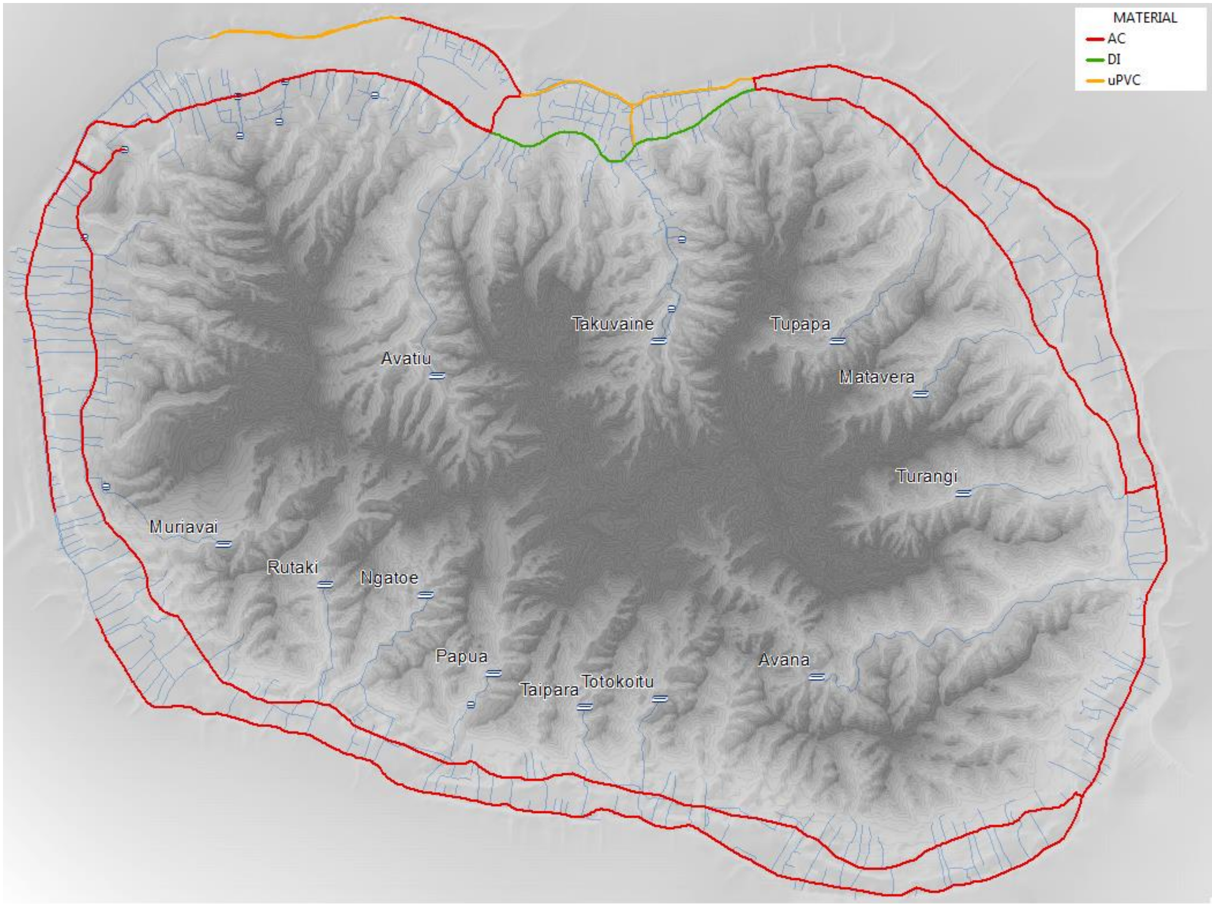


Figure 7 Ringmain pipe materials

3.7 Local reticulation

Over the last 10 years MOIP has systematically replaced the reticulation mains on Rarotonga. The final sections in Avarua have been completed as part of Project City. The main materials for the reticulation mains are uPVC and more recently PE – refer Figure 8.

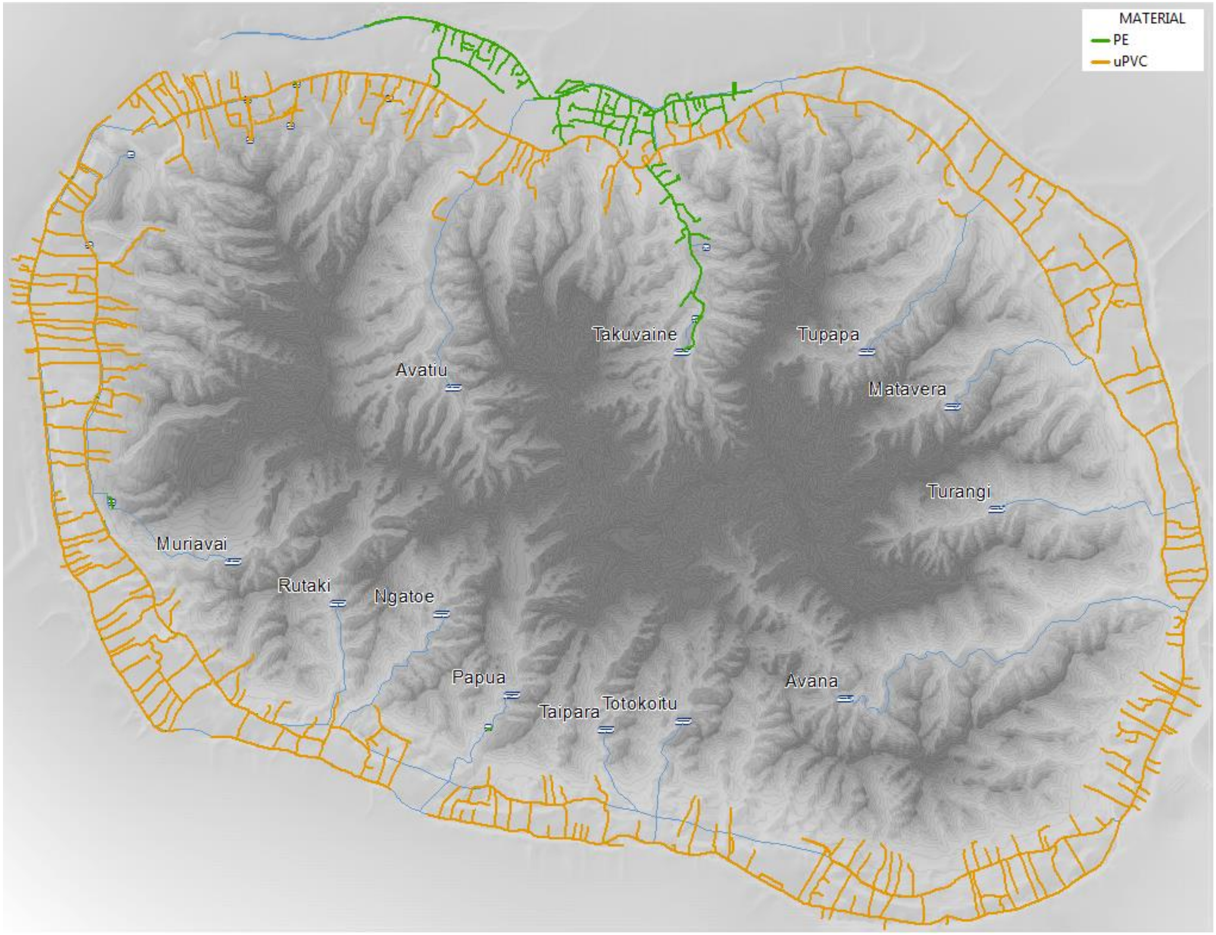


Figure 8 Reticulation pipe materials

3.8 Water tank subsidy

The MFEM has announced a scheme to subsidise the installation of water tanks at residential properties. The subsidy is capped at $1,500 per property.

The Water Tank Subsidy project would appear to be driven by a desire to increase the resilience of Rarotonga's water supply through providing additional storage capability for drought periods, cyclones or pipe breaks.

For dual supplies, usually a tank would be used to harvest rainwater and connected to the reticulated supply to top up when needed. The water could be used in the garden, or connected into the household system for laundry and toilet use. Drinking water would be from the mains supply directly or rain water could be treated and used for supply. There would be regulations around how the tank was connected to the mains supply, backflow prevention and maintenance of the tank system. It is generally not recommend from a public health perspective to drink untreated tank water. Further work should be undertaken to communicate and manage the health and water quality issues if the tanks from the Water Tank Subsidy programme where to be connected to the public potable supply.

There is a risk to the GoCI that the uptake of water tanks may impact the willingness to connect to the potable water system.

4.0 Field studies and flow monitoring

As part of this study it is required to derive criteria for use in Rarotonga to ensure that the hydraulic model represents reality and the conditions in Rarotonga. Presently tailoring of the model to suit local conditions has not been completed because of a delay in receiving and installing the monitoring equipment. It was agreed in September 2013 to progress on with the Master Plan using the assumptions agreed by the Water Partnership in Table 4 and Table 5. Once the equipment has been installed, it is recommended the model is updated with the new measured values and if necessary the proposed works updated to reflect any changes. The following sections reports upon the equipment required, when installed and what they will be used for.

4.1 Flow metering at source

To measure the flows into supply, electromagnetic flow meters will be installed near each source. This will enable assessments to be made of total system demand, leakage and peaking factors from average day flow to peak hour flow.

AECOM made recommendations to local field staff with regards the siting of flow metering as follows:

- It is advised that flow logging be best sited slightly lower down the trunkmains – if meters are sited immediately at the intakes, flows into the treatment plants will be recorded, but further meters below these plants will be required to accurately understand what is flowing into the distribution network after raw water storage & treatment.
    - In addition, having the meters at too high an elevation may result in incomplete data (until the Master Plan works are implemented) as the trunkmains are currently unpressurised at the intake, only becoming pressurised further down the trunk main.
    - Flow measurement should be undertaken before there are any lines or demand coming off.
- For calibration of the hydraulic models, surveyed elevations at the pressure loggers and the 12 sources will be required.

4.2 Customer metering

Meters will be installed for selected customers and these values will be compared to those used in the model and any adjustments required will be made.

- The Project City commercial and domestic meter readings should be collated and used to calibrate the hydraulic models.
- For calibration of the model, flows for the significant users should be logged, maybe top 10 users, or else users that use over 5kL per day.
- The largest resorts should be metered and logged (e.g. Edgewater, Rarotongan, Club Raro, etc.)

4.3 Pressure logging

Pressure loggers will be deployed along the network and these will be used to determine how the system performs under demand conditions.

Recommendations were made to local field staff with regards the siting of pressure logging as follows:

- Pressure on the trunkmains should be recorded on the lower reaches towards the ringmains. It would also be beneficial to take readings on the ringmains, particularly on the Western side of the island furthest from the sources.
- Both ringmains should be logged, perhaps 8 flow and pressure loggers total – 4 on each, spaced around the ring mains and adjacent to each other.

5.0 Hydraulic analysis of current system

A hydraulic analysis was undertaken of the existing system.

5.1 Model build

The following sections describe the steps taken to build the network model for use on Rarotonga.

5.1.1 Digital Elevation Model

AECOM received 2 sources of contour data. The first, a digitized copy of a 1972 NZ Department of Survey (NZDOS) plot with elevations from 0 – 28m at 2m intervals. The second, a digitized copy of a NZDOS plot with elevations from 30m upwards at 5m intervals. The two data sets were merged to create a complete Digital Elevation Model (DEM) covering the full extent of Rarotonga – refer to Figure 9. The elevations of modelled nodes and junctions throughout the network were interpolated from the DEM surface.

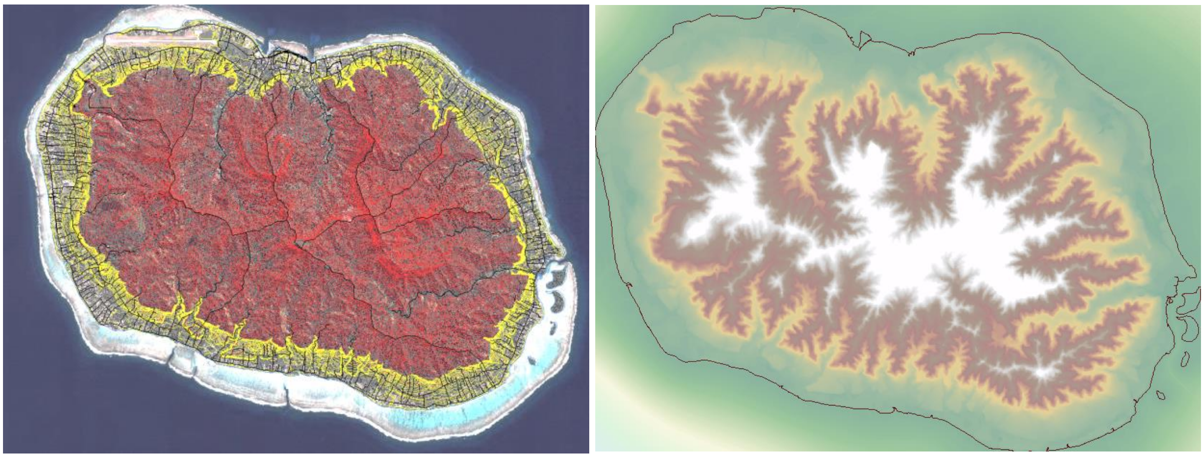


Figure 9 Contour data and DEM

5.1.2 Source limitations

The available yield of the 12 intakes supplying the Rarotonga network is dependent on the amount of rainfall the island receives. In periods of drought, lower yields will be available and in extremely dry conditions some of the island's sources run dry. A previous report prepared by the ADB provides limited empirical data maximum and minimum yields for the 12 intakes. The model has been built assuming normal operation outside of drought conditions. The contribution of each source in the model has been capped at the maximum yield given in Table 9 to avoid overstating the yield. Further assessment of the empirical yield of each catchment based on recent rainfall data and intake flow metering must be undertaken to verify the data presented by the ADB. Empirical source yields should then be compared with measured flow meter data as it becomes available.

Table 9 Intake yields source: (ADB, 2009)

Intake	Catchment (ha)	Minimum Yield (l/s)	Maximum Yield (l/s)
Avana	243	14.70	39.31
Avatiu	135	5.41	19.31
Matavera	83	3.87	15.84
Muriavai	144	0.00	8.80
Ngatoe	98	2.65	23.15
Papua	163	13.90	23.40
Rutaki	109	3.90	21.27
Taipara	84	23.10	25.20
Takuvaine	161	7.80	34.06

Intake	Catchment (ha)	Minimum Yield (l/s)	Maximum Yield (l/s)
Totokoitu	70	4.90	22.37
Tupapa	101	3.25	14.26
Turangi	118	22.91	42.59

It is recommended that a drought management plan and contingency water sources are developed to ensure the long term security of supply for Rarotonga.

5.1.3 Watermain network and network topology

AECOM had GIS data of the water network on Rarotonga; there were however, connectivity issues with this data, an example of which is shown in Figure 10.

Figure 10 Example of connectivity issues with the GIS data

These issues were corrected using GIS tools which traced and connected the network. Figure 11 shows a network trace being performed on the ringmain to the West of the airport. The sections of the network highlighted (in light blue and light green) indicate all connected pipes and nodes. Disconnected sections of the network can subsequently be identified, analysed to confirm their connectivity and connectivity issues repaired.

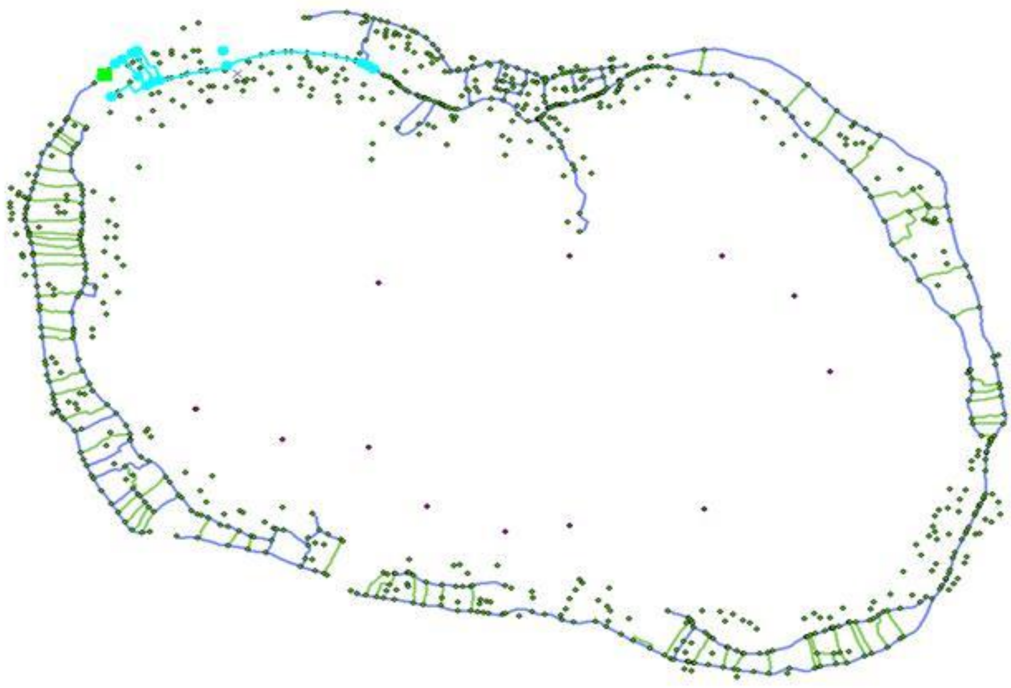


Figure 11 Connectivity repair using topology tools in GIS

5.1.4 Pipe roughness

The Hazen-William's equation was utilised for the calculation of pipe friction losses throughout the network. The roughness coefficients used in the network model are set out in Table 10.

Table 10 Hazen-William's roughness coefficients

	Roughness C values		
Pipeline Type (All diameters)	<10 years	10 to 25 years	> 25 years
uPVC	150	140	140
PE	150	140	140
AC	140	130	120
DI	140	125	110

5.1.5 2013 demand allocation

AECOM received a set of design guidelines for the distribution of future water use across different sectors (Te Mato Vai Technical, 2012). These guidelines were used as a starting point to derive demand allocation assumptions for the current (2013) demand also. Demand allocation assumptions for each demand class are outlined in the following sections.

5.1.5.1 Building and land use classifications

AECOM received building footprint and land use polygon data. Building footprints were classified as residential, commercial / industrial, critical facility, education, hazardous facility, health, public / community or other (refer Figure 12). A secondary usage field included further details on the buildings usage which helped to identify tourist accommodation providers. Usage classifications were used to group buildings into demand categories as either commercial, residential or tourist demand. Land use polygons divided areas across Rarotonga into parcels of land with a particular usage including agricultural, forestry and livestock. The centroids of these polygons were used as the basis for allocating agricultural demand across Rarotonga.

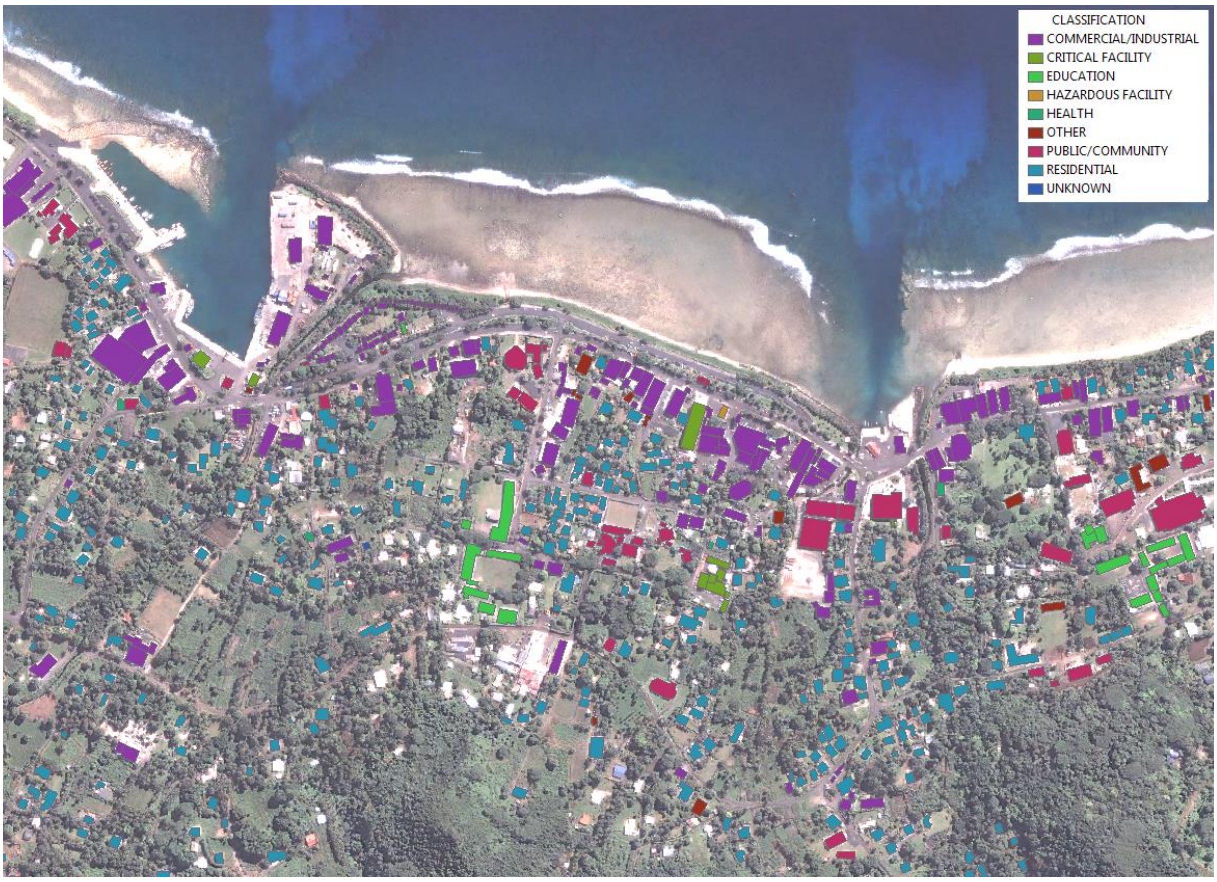


Figure 12 Building classifications

Residential demand

The census 2011 figure of 10,600 was used for the current population. A per capita demand of 200 l/c/d (Te Mato Vai Technical, 2012) equates to a current residential demand of 2,120 m³/d.

The residential demand based upon the population figure has been distributed evenly among the buildings designated as residential properties.

Commercial demand

The commercial demand is separated into two components, an industrial demand of 1,700 m³/d and an institutional demand of 500m³/d.

Industrial and institutional demands have been distributed evenly among the buildings designated as industrial and Institutional properties respectively.

Tourism

Current peak tourist occupancy of 3,300 beds was taken from 2011 census data. Per capita tourist demand has been estimated at 400 l/c/d giving a current demand of 1,320m³/d.

The largest tourist accommodation facilities were dealt with individually and allocated a specific demand proportional to the number of beds they have the capacity to host. The remaining demands were distributed evenly across the buildings designated as tourist accommodation.

Agricultural demand

The agricultural demand of 4,600m³/d has been assumed to remain constant over the design horizon and has been allocated to the centroid of land use polygons (Figure 13) described as either “Agriculture” or “Livestock/freshwater”, distributed based on the area of the contributing polygon.

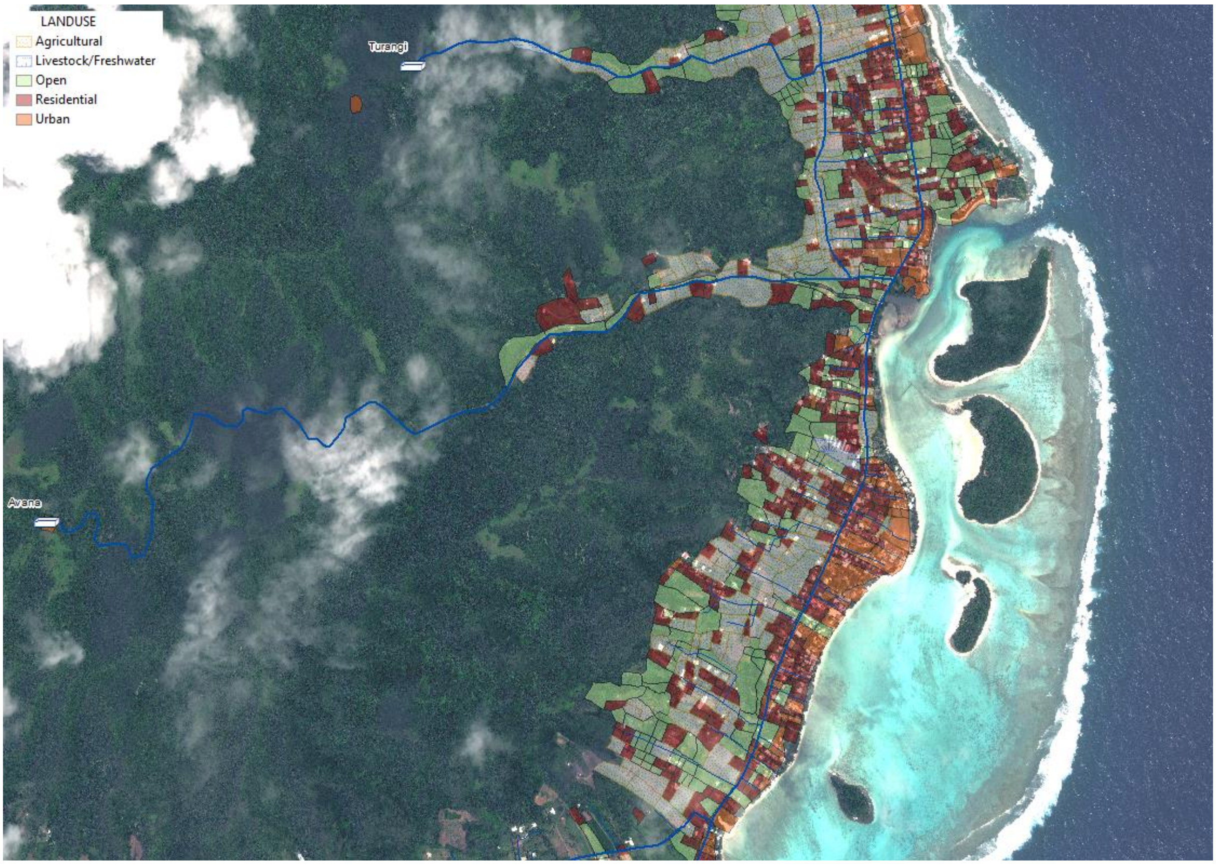


Figure 13 Land use polygons for the Muri region

The model assumes that agricultural demand will be met from the distribution network. Although this will mean treating an additional volume of water, this is significantly cheaper than running a separate distribution network for agricultural water. Use of the existing network as a separate distribution network for agricultural water is not feasible due to the poor condition of the network and anticipated high ongoing maintenance costs associated with this.

Non-revenue water

Non-revenue water has been associated with residential properties; it has been assumed that leakage at the point of supply accounts for the majority of water loss from the system. Previous work undertaken by the ADB (ADB, 2009) has estimated leakage at anywhere between 10 – 70 %. The model of the existing system assumes NRW of 29%.

Total demand

Total demand for 2013 excluding unaccounted for water is calculated to be 10,600 m^3/d. With an additional NRW demand of 4,100m^3/d the overall total demand is 14,300m^3/d – refer Figure 14.

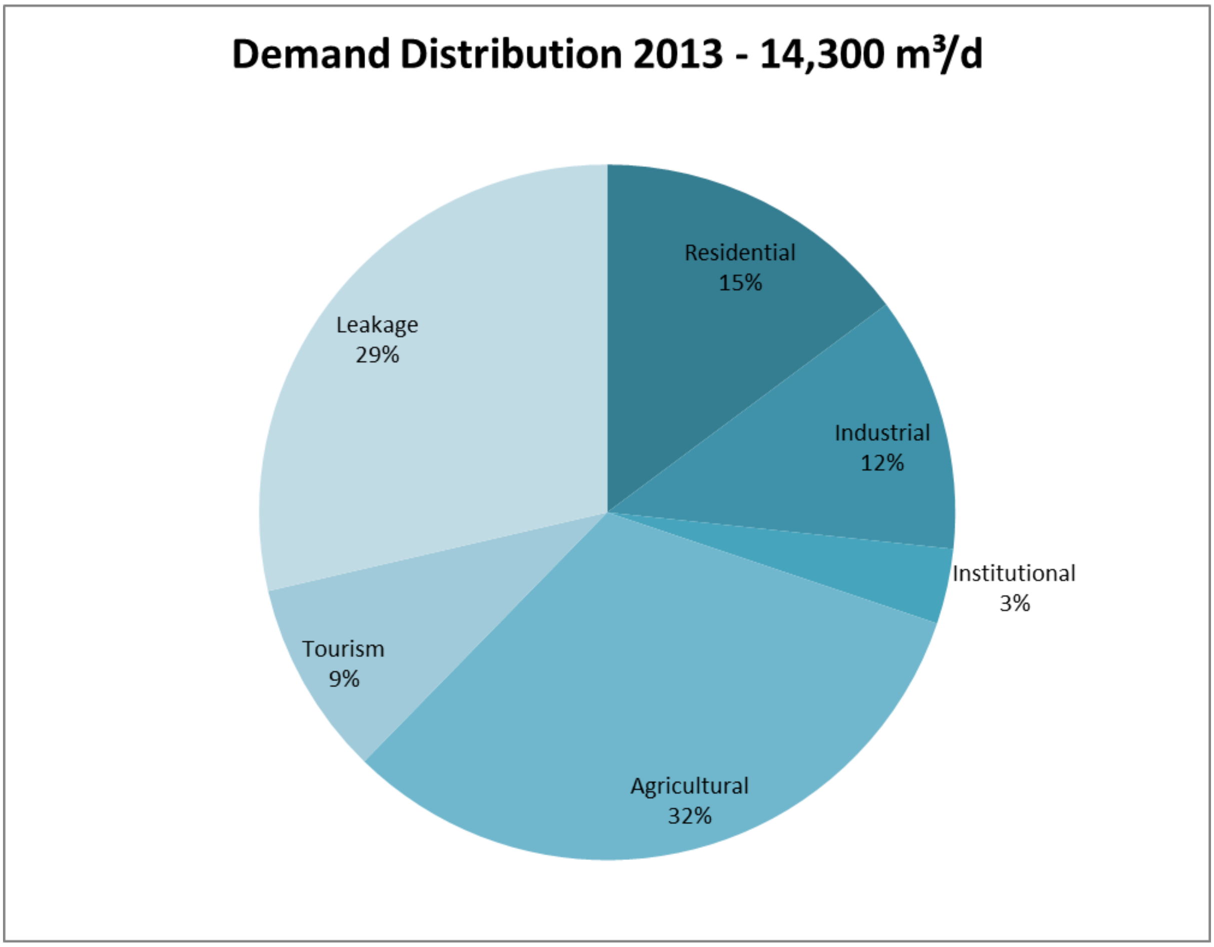


Figure 14 2013 demand distribution

5.1.6 Demand profiles

The demand patterns depicted in Figure 15 represent the standard demand profiles which AECOM has adopted for the model build in lieu of flow meter data. As flow meter data becomes available, demand profiles specific to Rarotonga can be derived to replace these profiles. While the timing of peaks may differ, there are a number of common characteristics which AECOM expects would be observed in demand patterns specific to Rarotonga. Common demand curve characteristics include the presence of a morning and evening peak in the residential demand profile, and elevated leakage losses throughout the night when static pressures throughout the network are at their highest.

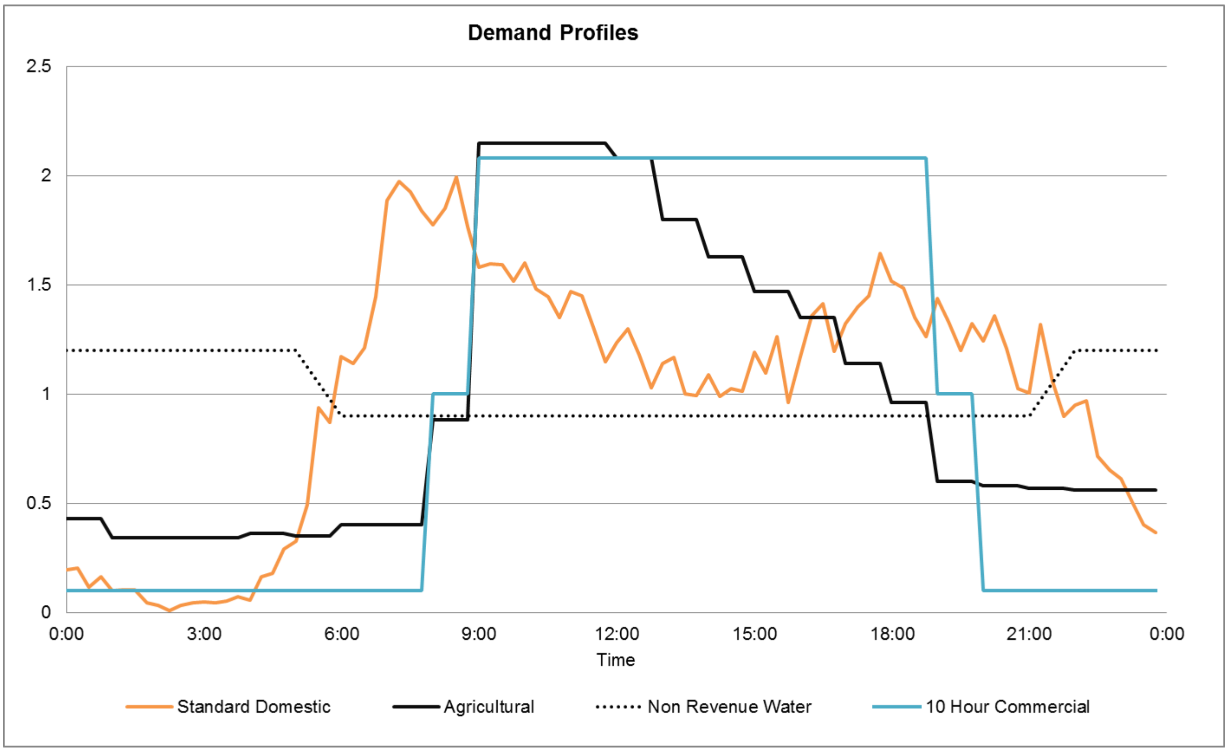


Figure 15 Standard demand patterns

5.1.7 Water pressures

In times of low rainfall, the yields are not high enough to pressurise the system and as a result the pressures in the system are lower than expected. MOIP undertakes regular pressure monitoring at the inner ring road. Typical results are shown in Table 11.

Table 11 Water pressures at the inner ringroad (Te Mato Vai)

INTAKE	12-Apr-13	%	15-Apr-13	%	17-Apr-13	%	19-Apr-13	%	22-Apr-13	%	24-Apr-13	%	26-Apr-13	%	29-Apr-13	%
AVATIU	15	50	18	60	18	60	16	53	15	50	13	43	12	40	14	47
TAKUVAINE	20	67	25	83	22	73	22	73	15	50	14	47	15	50	14	47
TURANGI	25	83	16	53	15	50	24	80	18	60	16	53	15	50	16	53
MATAVERA	50	100	40	80	30	60	45	90	38	76	35	70	25	50	20	40
TUPAPA	54	98	45	82	35	64	46	84	40	73	38	69	30	55	26	47
GOLDIE	54	98	45	82	35	64	44	80	40	73	38	69	30	55	30	55
AVANA	45	64	45	64	35	50	62	89	45	64	35	50	35	50	25	36
TOTOKOITU	40	80	38	76	25	50	35	70	30	60	25	50	25	50	18	36
TAIPARA	32	71	30	67	25	56	30	67	28	62	25	56	25	56	18	40
PAPUA	40	89	35	78	28	62	35	78	30	67	28	62	28	62	24	53
NGATOE	30	86	32	91	24	69	30	86	25	71	25	71	25	71	17	49
RUTAKI	30	86	32	91	24	69	30	86	25	71	25	71	25	71	17	49

** the actual pressures recorded (in metres head) are shown in the white cells*

Intake elevations in the existing model have been adjusted to calibrate pressures at the base of the trunkmains with the pressure logging data AECOM received from MOIP. The modelled approach of reducing the head at the intakes represents a system not fully pressurised at the source.

5.2 Proposed levels of service and criteria for analysis of the system

AECOM has proposed the levels of service and performance criteria set out in Table 12 to assess the hydraulic performance of the existing system and the efficacy of proposed network upgrades. These levels of service were derived from the CCECC proposal, existing NZ standards and good engineering practice as outlined below.

Table 12 Proposed levels of service and criteria

Criteria	Category	Threshold (Peak Day)	Basis of Level of Service
Supplied Pressure	Minimum pressure measured at the customer meter	Minimum of 10m residual head below the 30m contour	Based on the CCECC proposal.
Pipe Velocities	Maximum velocity	Target maximum velocity of 1.0m/s absolute maximum velocity of 1.5 m/s	Good engineering practice taking into account the constraints of the available head, the maximum source yields and Rarotonga's existing infrastructure.
Fire flows	Minimum residual pressure	Minimum of 10m residual head available at ring main during fire flow simulation	Based on the NZ standard.
	Fire flows	Minimum available flow of 12.5 l/s at ring main during fire flow simulation.	Based on the NZ standard of 12.5L/s (per hydrant)
Water quality	Maximum water age	72 hours from treatment to issue at tap	WHO water quality standards.

5.3 Analysis and performance of the current system

Rarotonga's existing network does not supply adequate pressure at peak demand and does not meet the proposed minimum levels of service – refer Table 13.

Table 13 2013 network performance summary

Criteria	Category	Value
Supplied Pressure	Nodes < 10m > 5m Residual Pressure	103 (10%)
Supplied Pressure	Nodes < 5m Residual Pressure	490 (47%)
Pipe Velocities	Maximum Pipe Velocity in ringmains and trunkmains	3.78 m/s
Fire flows		N/A*
Water quality		N/A*

* Fire flow and water quality analysis was not undertaken for the 2013 and 2016 scenarios

Pressure problems are distributed right across the island and high velocities are predicted in both trunkmains and ringmains – refer to Figure 16.

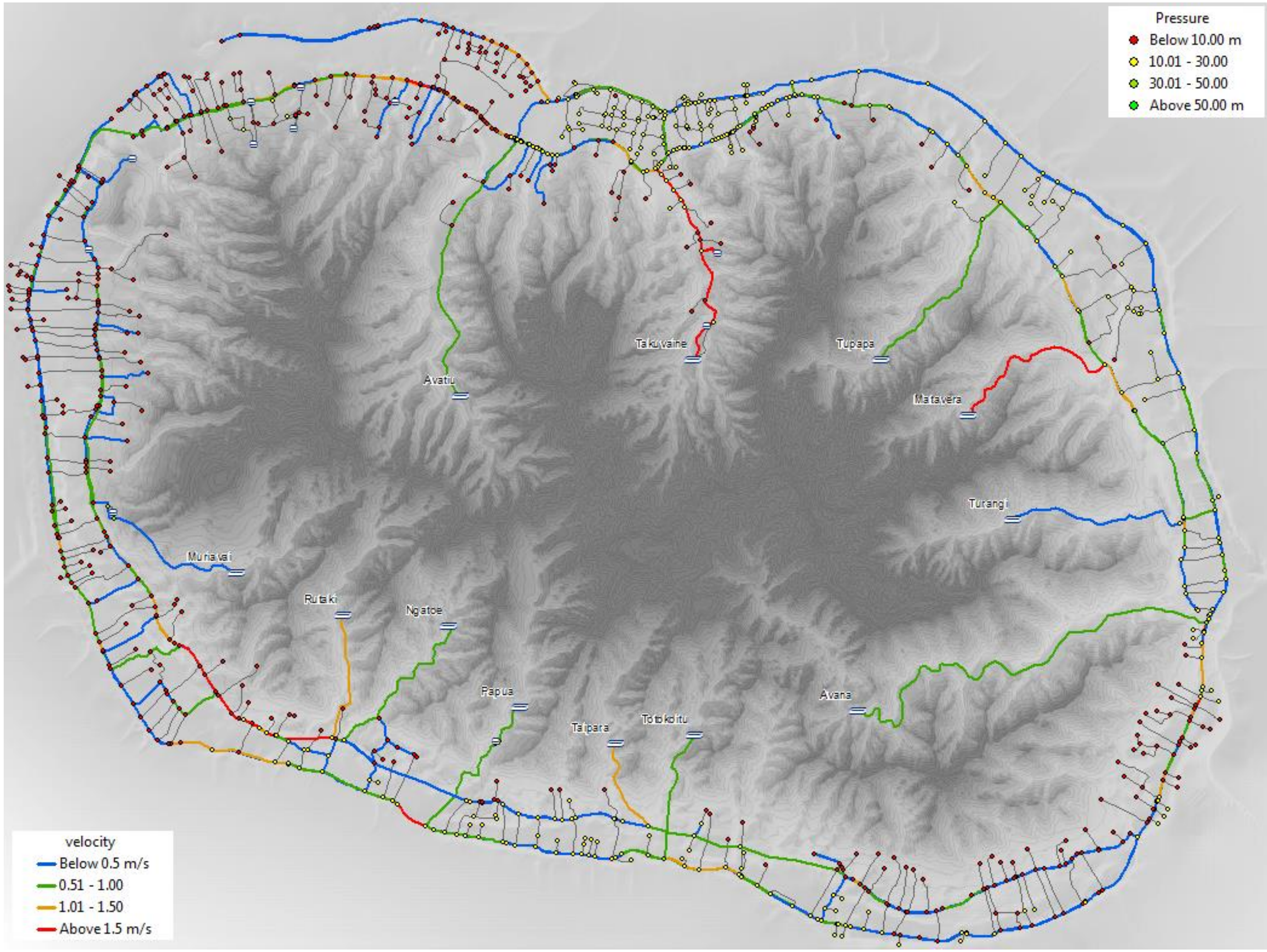


Figure 16 2013 network performance

A number of sections of ringmains and trunkmains exhibit velocities in excess of 1.5m/s with a maximum modelled velocity of 3.78m/s. The most notable of these are the trunkmains from Takuvaine and Matavera and the ringmains in the southwest of the island and around Avarua in the northwest (these pipes are shown in red in Figure 16).

Ringmain pressures from Avarua to the southwest of the island and in the southeast all show pressures below the 10m target pressure (these nodes are shown as red dots on the ringmains in Figure 16). This equates to 57% of the modelled nodes across the island.

6.0 Hydraulic analysis of current system with ringmain upgrade

6.1 CCECC ringmain upgrade project

CCECC has proposed a complete renewal of Rarotonga's inner and outer ringmains, replacing the existing AC and uPVC pipes with PE pipes – see Figure 17. AECOM has modelled the network with the proposed ringmain design to assess the hydraulic performance of the network under current and future demands.

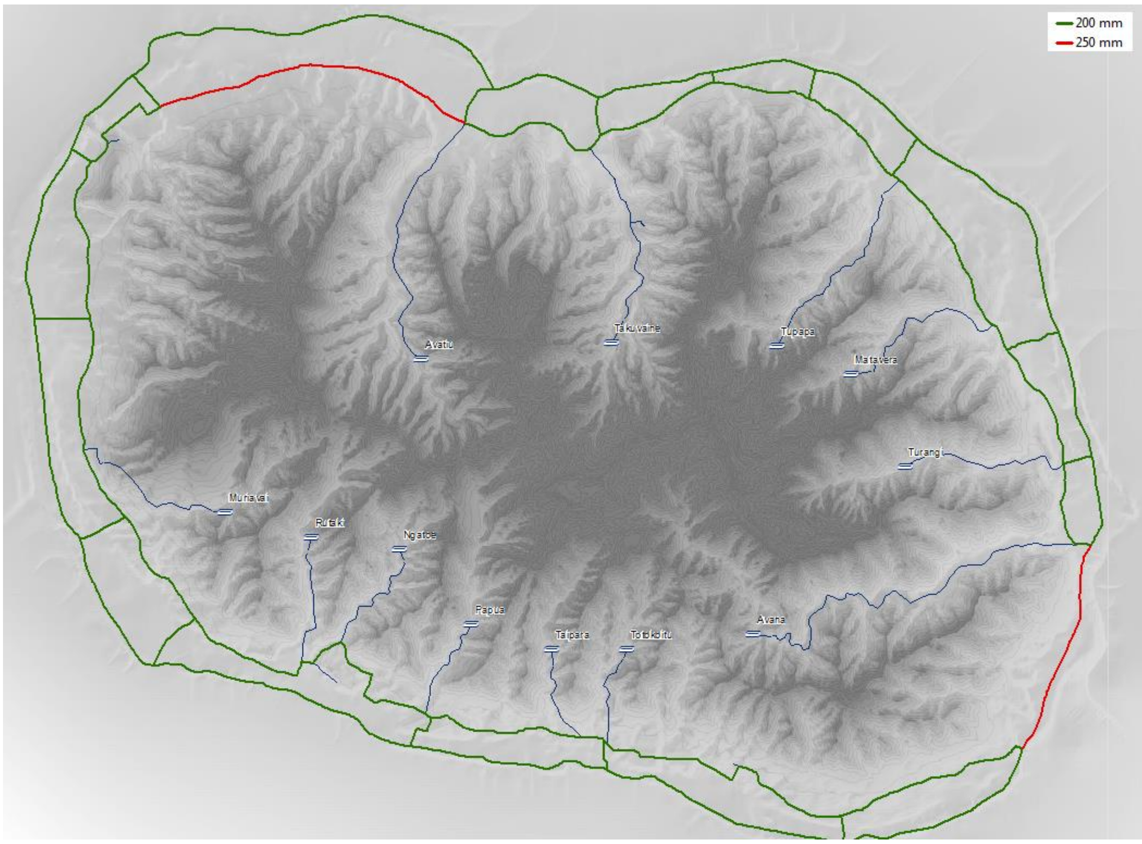


Figure 17 Proposed CCECC ringmain upgrades

6.2 Analysis and performance of the system with the ringmain upgrade

The network model with the ringmain upgrades shows improvement across all network performance criteria – see Table 14 and Figure 18. High velocities in the ringmains and the associated head losses are greatly reduced, corresponding to a slight improvement in pressures across the full extent of the network. The 2016 demand scenario has been built with the same underlying assumption as the existing scenario, that full pressures at the intakes will not be realised.

Table 14 2016 network performance summary

Criteria	Category	Value
Supplied Pressure	Nodes < 10m >5m Residual Pressure	245 (24%)
Supplied Pressure	Nodes below 5m Residual Pressure	260 (25%)
Pipe Velocities	Maximum Pipe Velocity in ringmains and trunkmains	2.2 m/s
Fire flows		N/A*
Water quality		N/A*

* Fire flow and water quality analysis was not undertaken for the 2013 and 2016 scenarios

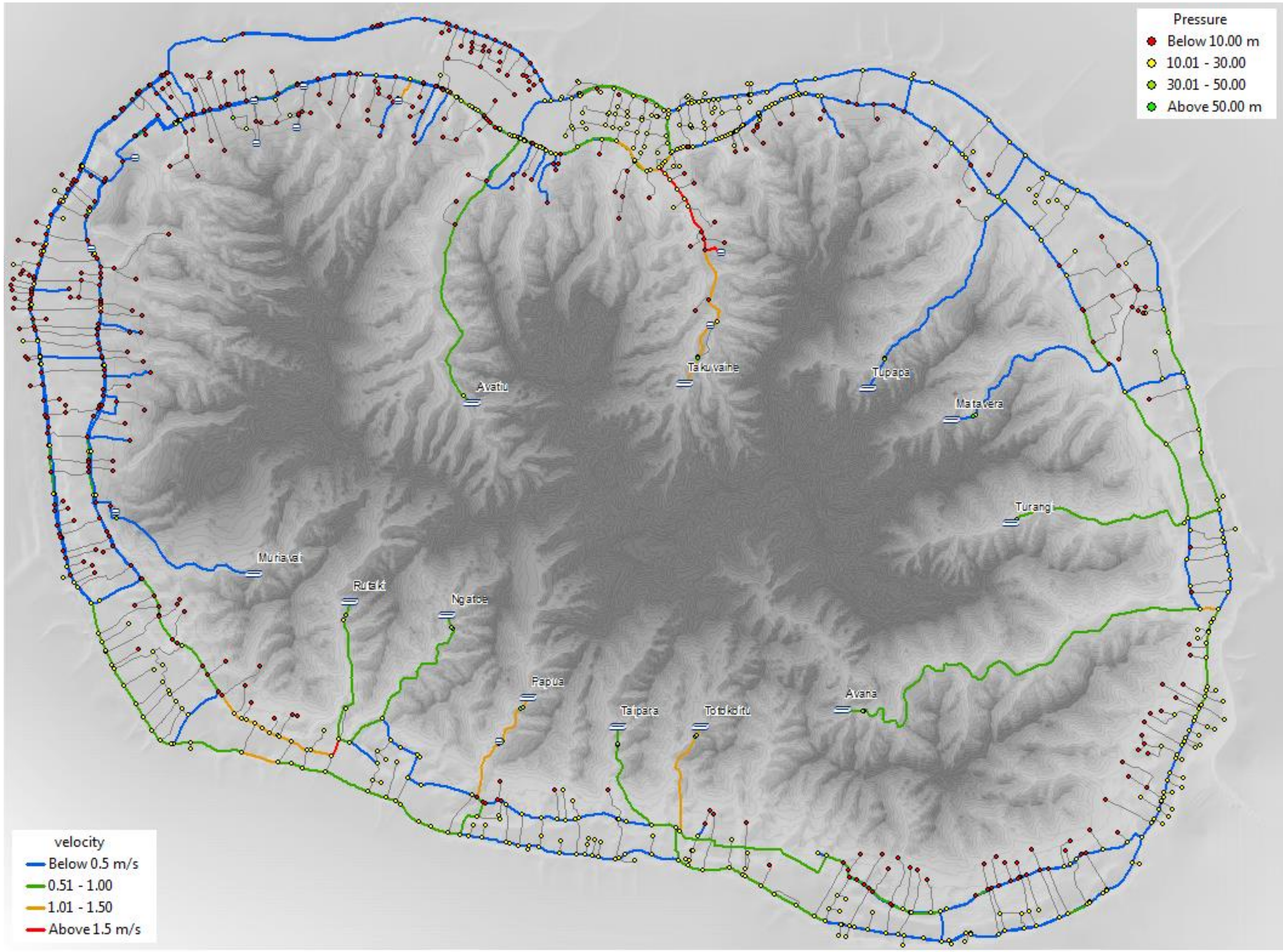


Figure 18 **2016 network performance**

7.0 Hydraulic analysis of system in 2031

The 2031 system incorporates the proposed CCECC ringmain upgrades as for the 2016 scenario. The future scenario also considers the hydraulic implications of proposed future projects. The three projects of greatest significance are the construction of storage reservoirs at each of Rarotonga's intakes, the construction of water treatment plants and the renewal of the trunkmains. The 2031 analysis assumes that the proposed upgrades will facilitate the effective function of the network as a fully pressurised system, preventing partially full pipe flow in the trunkmains and reducing water loss and the ingress of air and contaminants into the network.

7.1 Growth assumptions

Population projections for Rarotonga (Figure 19) suggest that the residential population of Rarotonga in 2031 may be approaching 13,000 if a high growth model is assumed. The demand assumptions developed in the Rarotonga Water Supply Technical Workshop (Te Mato Vai Technical, 2012) derive an estimate for domestic demand based on the residential population of 14,000 for 2031 allowing a contingency for growth. AECOM has adopted these assumptions for the purposes of estimating future demand in the 2031 water supply network model (see Appendix A for a summary of the technical workshop outcomes).

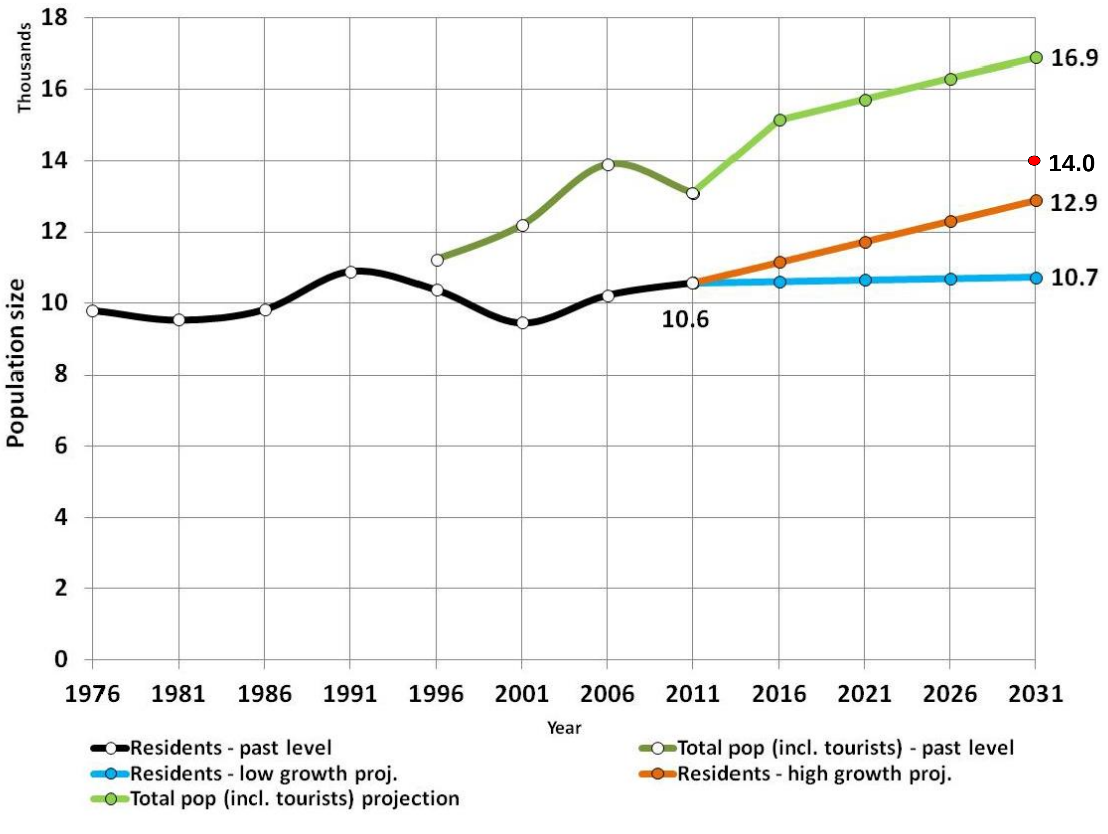


Figure 19 Rarotonga population projections 2011 – 2031 (Demmke, 2013)

7.2 2031 demand allocation

It has been assumed that demand remains static between the existing and future scenarios for institutional, industrial and agricultural demands. Residential and tourist demands are expected to increase as the residential population and visitor numbers increase as agreed during the Te Mato Vai technical workshop (Te Mato Vai Technical, 2012). Non-revenue water is expected to decrease as leakage and unmetered water use reduces. The demand allocations, set out in the following section for the 2031 scenario, represent a peak day scenario. However, due to uncertainty regarding the proportion of leakage and water loss in the existing network and the corresponding figures for 2031, once NRW reduction strategies have been employed, AECOM has scaled up the demand in simulations by an additional 30% as a contingency measure to account for unforeseen increases in demand over the design horizon, or persistent problems with non-revenue water at higher than expected levels.

Residential demand

The 2031 scenario assumes a residential demand of 2,800m³/d based on a per capita consumption of 200 l/c/d with a population of 14,000.

Commercial demand

The industrial demand of 1,700 m³/d and the institutional demand of 500m³/d remain unchanged in the 2031 scenario.

Tourism

Tourism demand for 2031 was given as 1,600 m³/d based on assumed peak occupancy of 4,000 beds for the resorts and tourist accommodation facilities on Rarotonga. The estimate for per capita tourist demand remains at 400 l/c/d for the 2031 scenario.

In the 2031 scenario the abandoned Sheraton hotel development has been assumed to be complete. This assumption implies that the majority of the additional beds on Rarotonga will be associated with the Sheraton development, introducing a large point load onto the supply network rather than an evenly distributed increase in demand across the entire island.

Agricultural demand

The agricultural demand of 4,600m³/d remains unchanged for the 2031 scenario.

Non-revenue water

The future 2031 scenario assumes leakage and administrative losses in the system have been reduced to 10% of the total network demand. This assumption was set during the Te Mato Vai technical workshop (Te Mato Vai Technical, 2012). Whilst a 10% leakage target is excellent when benchmarked globally, it is believed to be a reasonable assumption considering the significant investment in new pipes across the network. However, it is recommended that a programme for leakage control and management of non-revenue water is initiated to aid in meeting this target.

Total demand

Total demand for 2031 is 11,200m³/d with additional NRW demand of 1,120m³/d giving a total future demand of 12,320 m³/d – refer Figure 15.

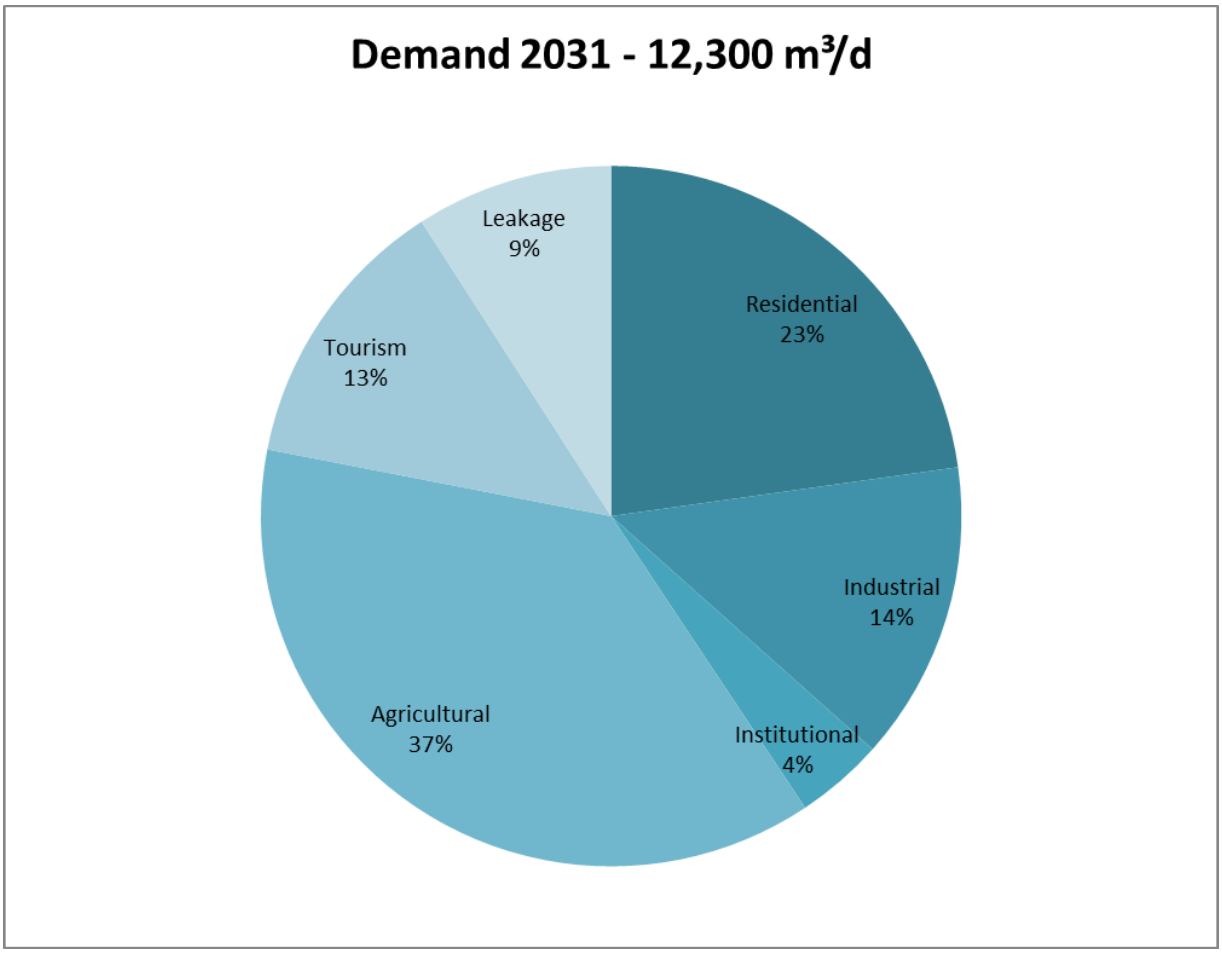


Figure 20 2031 demand distribution

7.3 Preliminary reservoir design

Guidelines developed during the Te Mato Vai technical workshop set a target of 36,000 m³ of raw water storage on Rarotonga, the equivalent of 3 days of supply at peak demand (Te Mato Vai Technical, 2012).

Existing reservoirs potentially contribute more than 14,000 m³ capacity. The large open Akaoa reservoir makes up a large proportion of this storage with an estimated volume of 10,000m³. The Akaoa reservoir has been decommissioned however, and has not been considered a part of the required 3 days storage. The reservoir reportedly never filled due to inadequate flow from the Muriavai intake and high evaporation losses. The Takuvaine reservoir is currently in service and contributes 2,500 m³ of storage; however, it is reportedly in poor condition. 7 smaller distribution tanks are distributed around the island, 5 of which are currently in service.

Proposed reservoir volumes to provide at least the required (Te Mato Vai Technical, 2012) 36,000m³ of raw water storage are given in Table 15. AECOM's model included an additional 1,215m³ of existing network storage in the future 2031 model.

Reservoir sizes were derived using an iterative process beginning with a volume equivalent to three times the maximum daily yield of the corresponding intake. Storage was subsequently reduced at intakes where model outputs indicated that the yield of a source was inadequate to fill the tank volume under peak demands. The process was repeated until the target volume of 36,000 m³ was achieved.

Table 15 Proposed reservoir volumes

		Intake Yields (l/s)	Reservoir volume (m^3)
Intake reservoirs (raw water)	Avana	39.3	10,000
	Avatiu	19.3	1,000
	Matavera	15.8	1,000
	Ngatoe	23.1	200
	Papua	23.4	1,000
	Rutaki	21.3	2,000
	Taipara	25.2	4,000
	Takuvaine (Kia Orana)	34.1	4,000
	Totokoitu	22.4	200
	Tupapa	14.3	2,000
	Turangi	42.6	12,000
	Muriavai	8.8	200
	Subtotal	**289.6**	**37,600**
Existing network storage (treated water)	Airport tank		450
	Prison		90
	Sanatorium		450
	Tepuka		90
	Tereora		135
	Papua	Not in service	
	Akaoa	Not in service	
	Subtotal		**1,215**
	Total	**289.6**	**38,815**

** Total raw water reservoir volume exceeds the target 36,000m^3 due to the rounding up of capacities to standard reservoir sizing's. Where possible standard sizes have also been used to minimise system variability and installation costs.*

7.4 Preliminary trunkmain design

AECOM's 2031 model includes proposed upgrades to the asbestos cement pipes that remain in service in Rarotonga's network. The 5 PVC trunkmains installed in 1993 are adequately sized and are considered a lower priority for upgrade. The Takuvaine trunkmain has recently been upgraded to a 200 mm DI pipe. No further upgrades have been considered for this line. Pipes upgrades have been sized to keep velocities in the trunkmains below 1.0 m/s at peak demand. Trunkmain details are given in Table 16 and Figure 21.

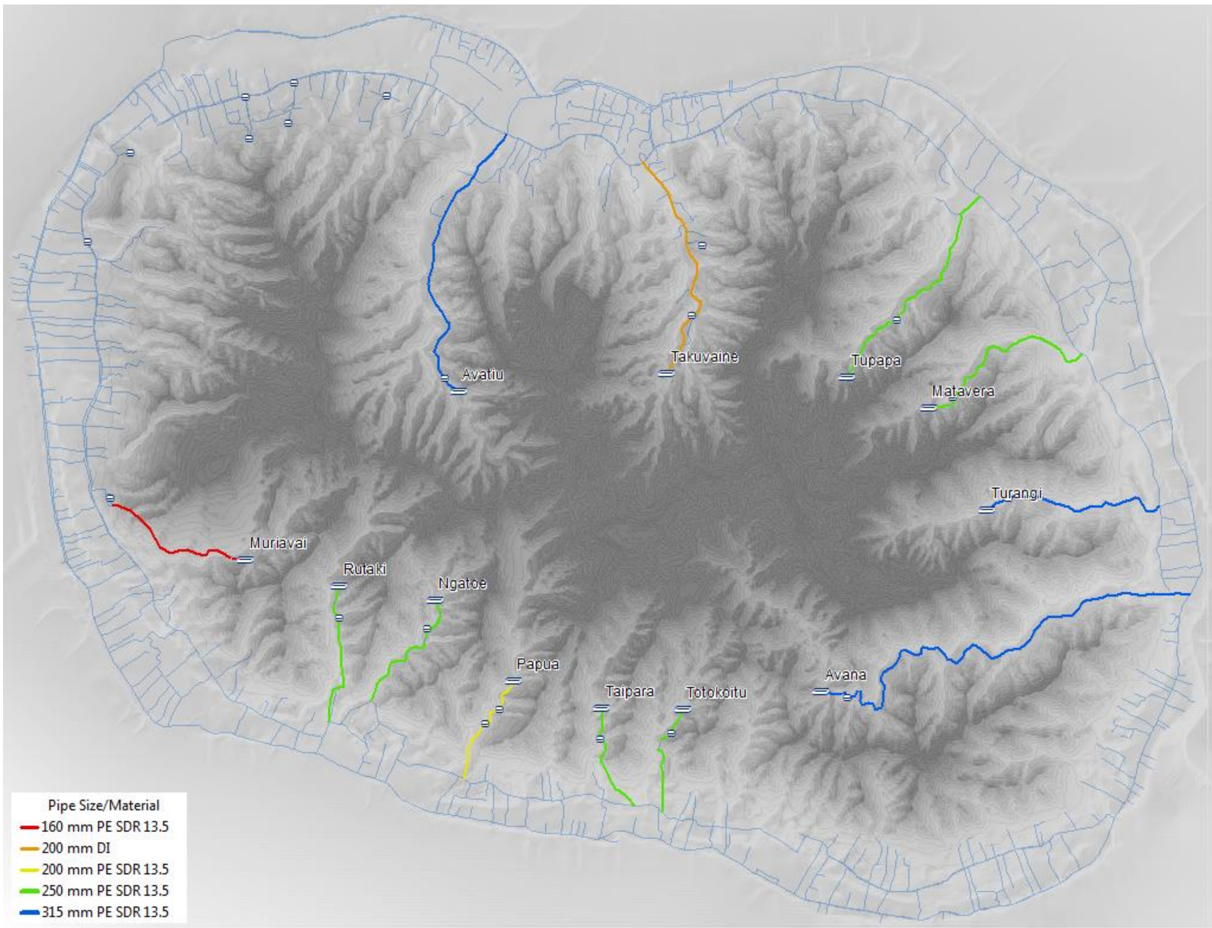


Figure 21 Rarotonga trunkmain upgrades

Table 16 Trunkmain upgrade details

Intake	Existing Trunkmain	Proposed Upgrade Size and Material
Avatiu	150 AC	315 mm PE 100 SDR 13.5
Tupapa	200 uPVC	250 mm PE 100 SDR 13.5
Matavera	200 uPVC	250 mm PE 100 SDR 13.5
Turangi	200 uPVC	315 mm PE 100 SDR 13.5
Avana	250 AC	315 mm PE 100 SDR 13.5
Totokoitu	150 AC	250 mm PE 100 SDR 13.5
Taipara	200 AC	250 mm PE 100 SDR 13.5
Papua	150 AC	200 mm PE 100 SDR 13.5
Ngatoe	200 uPVC	250 mm PE 100 SDR 13.5
Rutaki	200 uPVC	250 mm PE 100 SDR 13.5
Takuvaine	200 AC	200 DI*
Muriavai	150 AC	160 mm PE 100 SDR 13.5

** Upgrade completed*

7.5 Balancing network pressures

There is a large variance in the elevations of Rarotonga's intakes. Following the proposed upgrades, Rarotonga's network will function as a fully pressurised system. The intakes with a higher head will drive the network, while the lower head sources contribute less to meet the network demands. The proposed network will be designed to function as an open system without distinct pressure zones. AECOM recommends that pressure reducing valves (PRVs) are installed on the trunkmains together with zoning valves in order to balance pressures around the island and provide a way of managing the draw on each source. AECOM's 2031 model includes PRVs which regulate the total head along the trunkmains to within the range of 45m and 56m.

The installation of PRVs will also aid to reduce non-revenue water and future watermain burst rates.

7.6 Analysis and performance of system in 2031

The future model scenario incorporating;

- the ringmain and trunkmain upgrades;
- additional storage at the intakes; and
- pressure reducing valves along the trunkmains.

Improvement across all network performance criteria is set out in Table 14. High velocities in the trunkmains and the associated head losses are greatly reduced and the additional head available at the intakes resolves the majority of pressure problems around the island (refer to Figure 22). Those properties still receiving less than adequate water pressures are all located at elevations above 30m. Velocities in the ringmains and trunkmains are kept below 1.0 m/s in most cases with the Takuvaine trunkmain and small sections of the interior ring showing velocities greater than 1.0 m/s but still below 1.5m/s. The short section of pipework connecting the Sanatorium distribution tank with the inner ring main experiences high velocities above 1.5 m/s as it rapidly fills and discharges. This section of pipe could be considered for upgrade but is outside of the scope of the current hydraulic analysis.

Table 17 2031 network performance summary

Criteria	Category	
Supplied Pressure	Nodes below 10m Residual Pressure	81 (7%)
Supplied Pressure	Nodes below 5m Residual Pressure	49 (4%)
Pipe Velocities	Maximum Pipe Velocity in ringmains and trunkmains	1.4 m/s
Fire flows	Minimum of 12.5 l/s supplied from Ringmains at 10m residual head	Refer Figure 23
Water quality	Maximum water age of 72 hours	Refer Figure 24

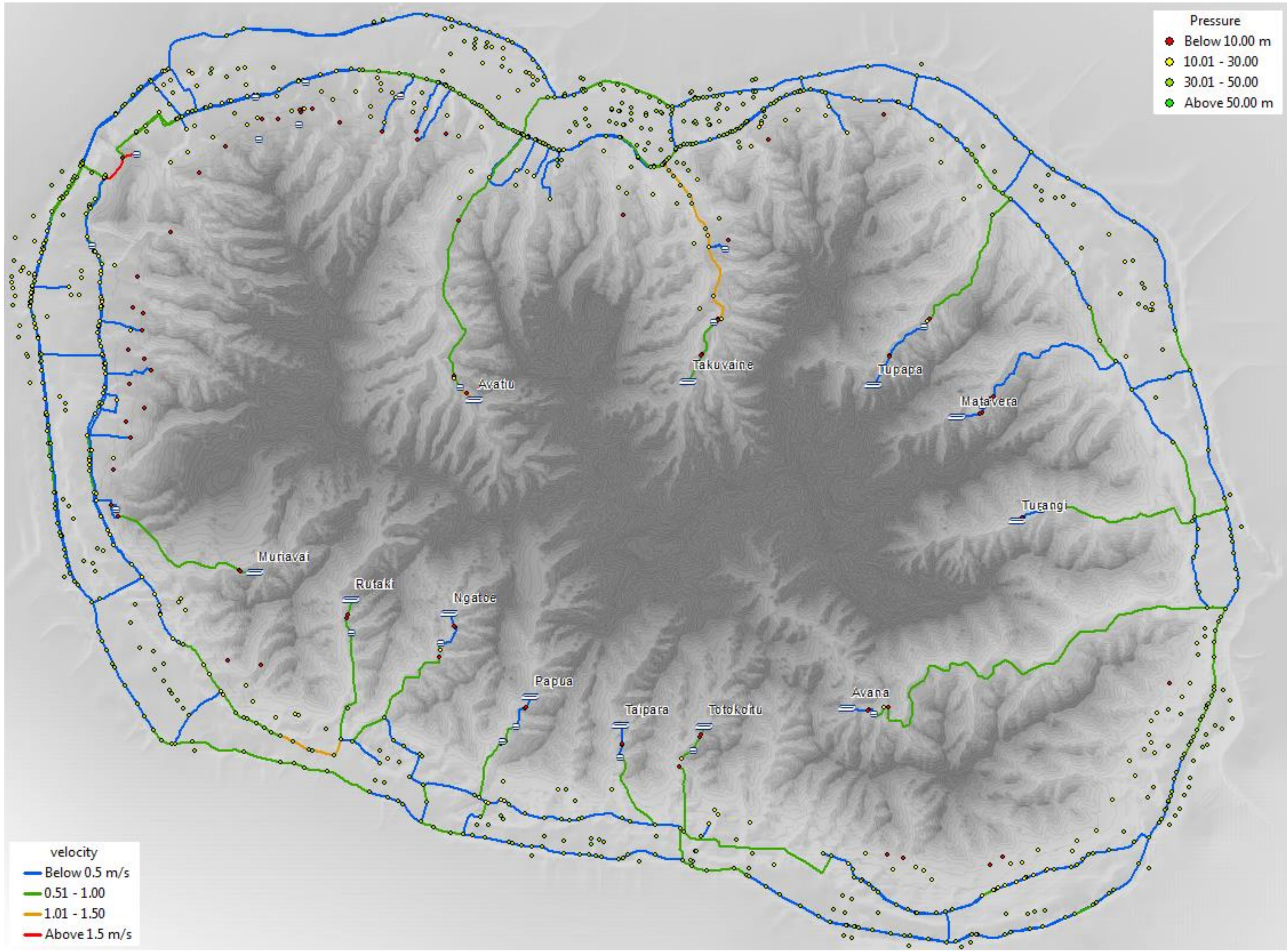


Figure 22 2031 network performance

7.7 2031 fire flow analysis

A fire flow analysis of the 2031 network model was undertaken to assess the ringmains capacity to deliver additional fire flow at a minimum residual pressure of 10m delivering a flow rate of 12.5 l/s (New Zealand Fire Service, 2008). Typically a fire flow simulation will assess network flow capacities and residual pressures at 60% of peak flow; however, the analysis on Rarotonga's ringmains has been run at peak demand, as a contingency measure given that specific demand patterns in Rarotonga were unavailable when the analysis was conducted. Fire flow analysis indicates that fire flow requirements can be met over the full extent of the island. Refer to Appendix B for full fire flow results of residual pressure and available flow.

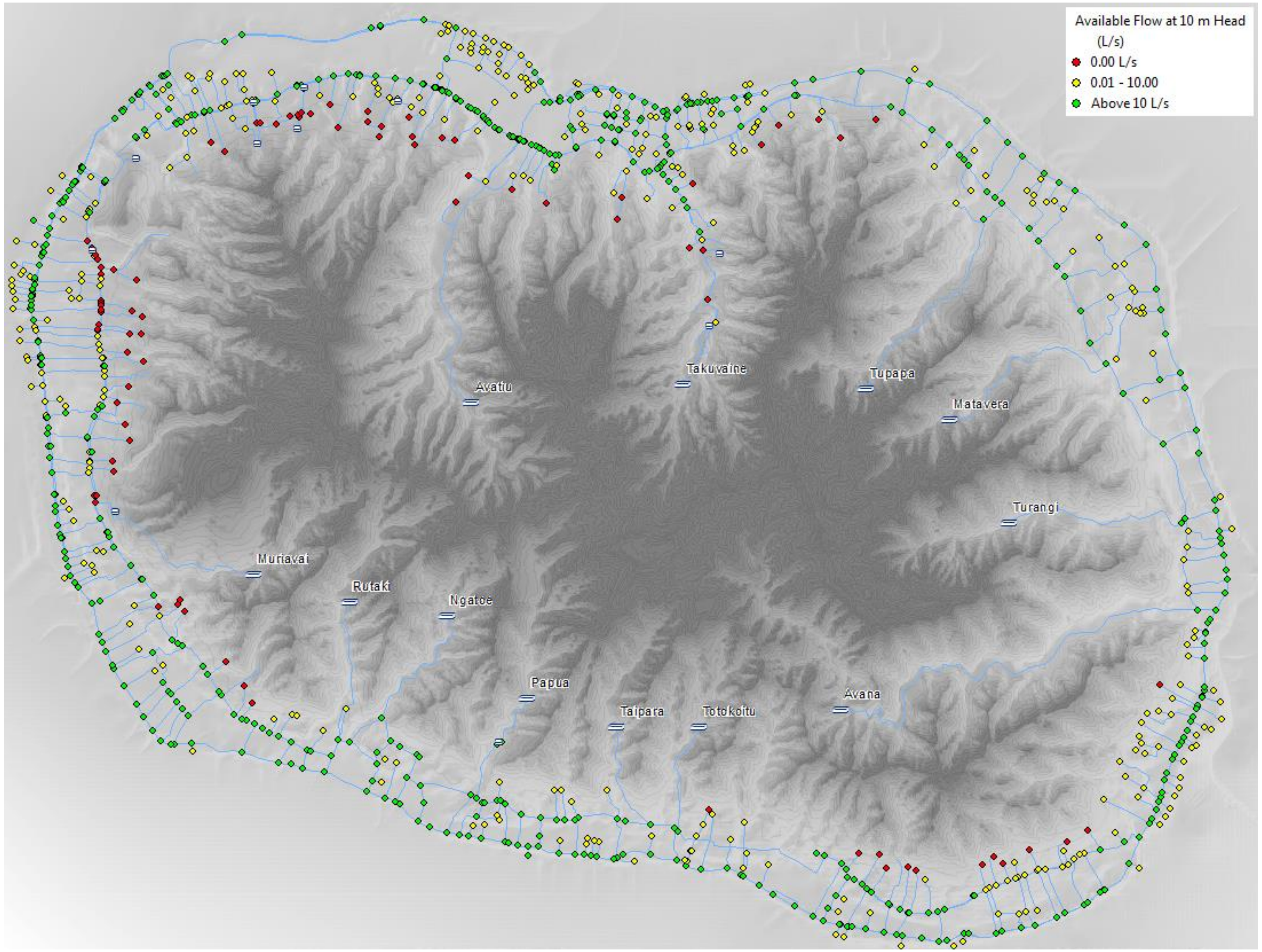


Figure 23: 2031 fire flow analysis available flow at 10m head

7.8 2031 water age analysis

A water age analysis was conducted on the 2031 network to give a preliminary indication into which sections of the network may have issues with an extended detention time (exceeding 72 hours). The analysis reveals no issues in the ring mains and trunkmains (refer Figure 24).

Pipes with an extended residence time are without exception part of the distribution network. This is often a result of the demand allocation process which assigned demands to the nearest node. In certain circumstances this can result in underestimated demand at the end of these lines, allocating demand at the junction where the pipe connects to the ringmain or submain rather than to the node at the end of the pipe, resulting in low flows and corresponding long residence times in the pipes.

The small area above the airport fed by water pumped to the Tepuka and Tereora distribution tanks also shows potential issues with extended residence times. This may be a result of the above demand allocation process. If this is confirmed as being an issue, we recommend the routine flushing of pipe sections that are known to exhibit high water age to eliminate potentially accumulated sediments. This should be timed to coincide with periods of water abundance to minimise impact upon water availability.

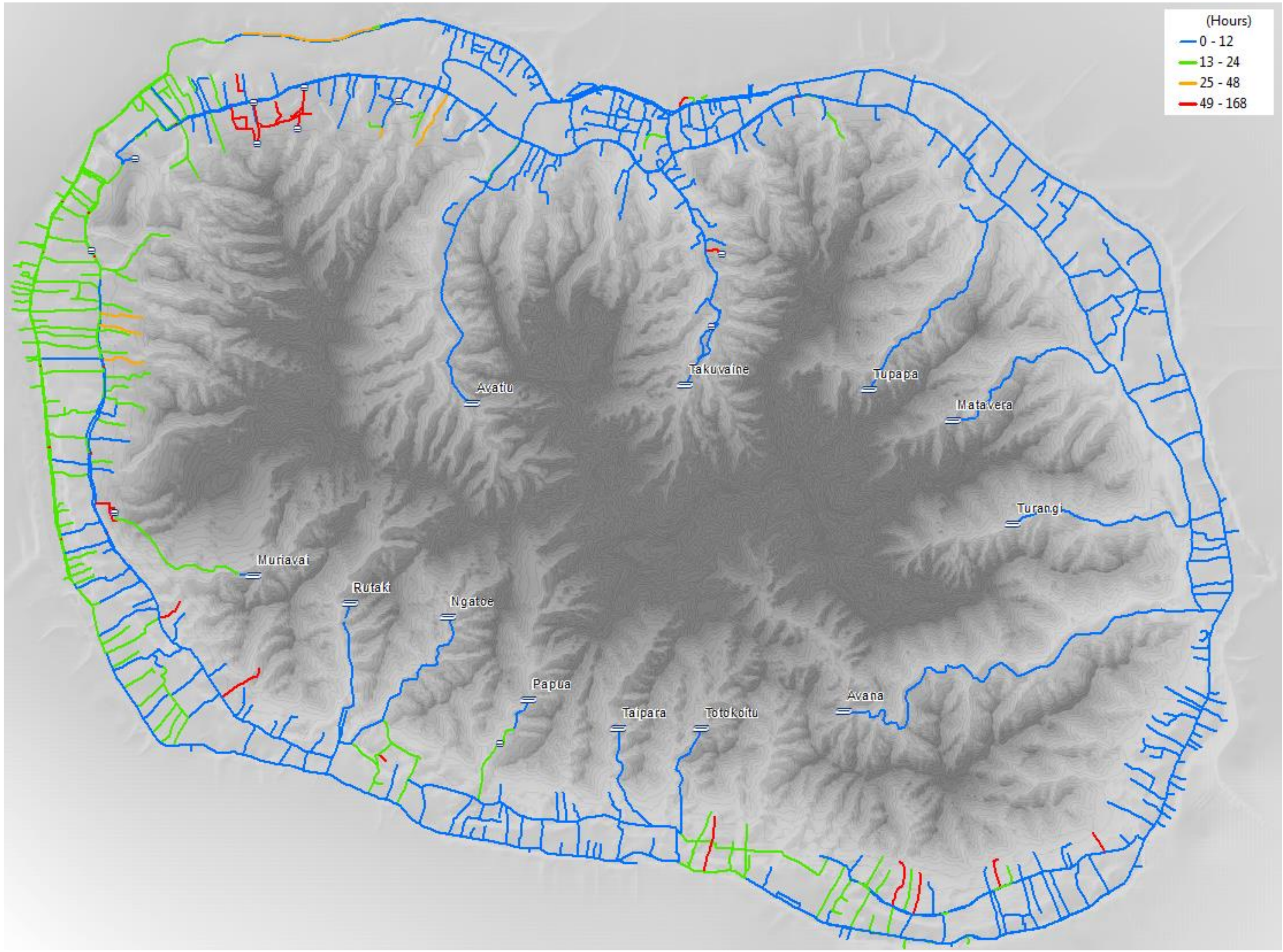


Figure 24 2031 water age analysis

7.9 Recommendations from hydraulic analysis

Upon the completion of the proposed ringmain upgrades, the order in which subsequent upgrades are undertaken has significant impacts regarding the level of service the network has the capacity to provide. The works should be scheduled in such a way that the projects delivering the greatest hydraulic benefit are prioritised. From the initial hydraulic analysis AECOM recommends the following projects as a high priority:

- The installation of raw water storage at Avana and Turangi due to the consistent yield and high elevation of these sources.
- Upgrades to the Kia Orana reservoir at Takuvaine due to the intakes location as the primary source serving the project city area and the reportedly poor condition of the existing Takuvaine reservoir which sits at a relatively low elevation.
- Data presented by the ADB (refer to Section 5.1.2) indicates that the Taipara intake is the most consistent source on the Southern Coast. For this reason, installation of raw water storage at Taipara intake to improve the security of supply and pressures on the Southern Coast and in particular the South Western region of the network.

8.0 Water treatment

The purpose of this section is to recommend water treatment unit processes and distribution system infrastructure and operations strategies to provide and maintain drinking water quality in the Rarotonga water supply system.

8.1 Current water quality

Limited raw water quality data is available. The need was identified for more sampling but the single sample originally planned at each site was considered to only provide very limited information. A single sample is a snap shot – it does not provide information on what happens under different conditions or at other times of the year.

Analysis, of the parameters targeted, that can be undertaken is limited by the laboratory facilities on Rarotonga, and the time periods for shipping samples elsewhere.

It may be possible to carry out raw water quality monitoring with some guidance from Watercare labs, or samples could be air freighted to Auckland for analysis. We would recommend doing this over the next year in preparation for the detailed treatment design solution at each site – including following storm events. However, these samples need to be targeted or a full sampling programme commenced. As mentioned above, 1, 2 or even 3 samples is a snap shot in time; it does not provide information about water quality under different conditions e.g. weather, rain, seasons, etc.

The sampling suggested above could be difficult and costly – if the existing raw water quality data is considered sufficient to support the Master Plan's baseline recommendation, we recommend moving forward with the detailed design phase, where we would suggest design and pilot testing which should provide invaluable information.

If it is felt that the data collected and stated in previous reports are still representative of the current situation, then the presence of E. coli is sufficient to demonstrate that pathogens are present; the presence of farming activities are enough to suggest that chemicals (pesticides, herbicides) are likely present and rain events certainly confirm that turbidity is an issue at times. With this information, the treatment strategy set out below proposed addresses a wide range of contaminants, both microbial and chemical, particularly if ultra-filtration membranes are adopted. Extracts setting out the raw water quality data in each report are set out below (these have been listed in reverse chronological order).

8.1.1 ADB report (2009) – Preparing the Infrastructure development project: Volume 3: Water Supply and Sanitation Sector TA 7022-COO

Water Quality

102. Information on water quality in Rarotonga and Aitutaki is scarce. While the consultants for previous studies of the water sector refer to testing to "WHO and NZ Water Quality Standards" the results of these tests are not incorporated within the available documents and have not been located, despite an extensive search of archived documents.

103. The Interim Report of the Integrated Urban Infrastructure Project for Rarotonga of 1995 alluded to water testing conducted over three years. Over a period between June1987 and June 1993 only one test of the 265 samples taken indicated no faecal coliform.The mean count within the network after the intakes was 108 faecal coliform per 100ml of water, and 255 total coliform. Under WHO standards for drinking water supplies, with (say) less than 40 tests per month in Rarotonga, no more than one sample per month is permitted to be positive in total coliform.

104. Other test results (April 2006) are available for the Avatiu, Matavera, Takuvaine and Tupapa intakes. Tests were conducted at the water intakes, (outside the intake stream) as well as downstream from the network, and within the network below the intake. The results show high total coliform, faecal coliform and E-coli counts. Total coliform ranged from a high of 4,423 /100ml at Avatiu to a low of 2,702 /100ml at Takuvaine with the other intakes falling within the band. Faecal coliform ranged from 384 /100ml at Matavera to 81 /100ml at Tupapa, with E-coli within a range of 276 /100ml at Avatiu and 56 /100ml at Tupapa. Tests of the water within the network showed similar high total coliform (2,306 /100ml to 1,397 /100ml), faecal coliform (388 /100ml to 21 /100ml), and E-coli (237 /100ml to 70 /100ml).

105. Contamination of the water supplies in Rarotonga therefore consistently does not meet the WHO recommended standards for presence of dangerous bacteria. Disinfection is therefore a necessity if serious public health issues are to be avoided.

115. All sources are bacteriologically contaminated and therefore the raw water is unsafe for potable use without disinfection……. There is strong risk therefore of transmission of water-borne bacteria and related disease.

Filtration and Disinfection

139. Water from the intakes will be piped to the treatment facilities which will be located typically a short distance downslope at an elevation of approximately 10m below that of the intakes in order to develop sufficient pressure heads for operation. An advantage of locating the treatment works near the intakes is that the high elevation will enable servicing of most of the existing populated areas of Rarotonga by gravity. In most cases, users situated at elevations of up to about 30m above sea level (MSL) will be supplied, except in the south west part of the island where maximum elevation for gravity feed will only be about 25m above MSL. The treatment facilities will comprise fine filtration and disinfection processes to ensure that the water supply of Rarotonga meets WHO drinking water quality standards. The capacity of the treatment works at each intake is presented in Table 18. However, the figures given for capacity are based on maximum "production rates" as advised by MOW and will need refinement based on a more detailed model of the Rarotonga water supply system as a whole. Detailed modelling is expected to take place on the formation of the new Water Board which is expected to have the technical capacity and/or the ability to contract professional services for this task, as discussed in Volume 2. Consulting support is proposed through the Loan TA to assist with modelling. Capacity allows for peak demand to be placed on the treatment works.

140. Slow sand filters would be ideal for small schemes such as those on Rarotonga, as they require little maintenance, are easy to operate and produce treated water of high quality. A total combined filter area of around 1 hectare (ha) and some 53,000 tons of sand, would be required. Unfortunately, sand of suitable quality is unavailable on Rarotonga in such quantities and its importation would not be practical.

141. It is instead recommended to use pressure filters using synthetic filter materials. One such system is the self backwashing Arkal filter, currently used at the Tupapa intake. These filters, when designed and operated properly, function in an automatic self backwash mode thus reducing regular maintenance needs to a monthly visit to replace the elements (which are washed and kept for re-installation during the following maintenance visit). As the influent to the treatment works will pass through the small aperture screens, the solids and turbidity levels suspended in the influent will be low. A drinking water quality standard for the Cook Islands needs to be specified and enforced by Regulation, as discussed in Volume 2. enough to use 50 micrometer (μm) filter elements which in turn will produce water quality suitable for disinfection in the form of either chlorination or ultraviolet (UV) radiation.

142. Hydraulically driven backwash requires an operating pressure head of about 50 m. As the normal gravity operating head will be only 10 m, additional pressurizing units will be needed. One of the most cost-effective ways to achieve this is through the use of an air-aided backwash and a compressor. The air infusion will enhance backwash. As the treatment plant locations are remote from the main electricity grid, the compressors will be powered by solar panels and batteries. As the intakes are in heavily forested areas, the solar panels will be installed on an elevated pole or placed on the hillsides above the filters to provide access to sunlight. The solar panels and their support structures will need to withstand heavy winds and wind borne debris during cyclones. An 80-litre tank will also be needed for storing filtered water for backwashing. Backwash water will be piped back to the stream.

143. The outflow from the filtration units will be disinfected to ensure that the water supply is free of bacteriological contaminants. The community attitude survey (see Volume 5 of this report) revealed a significant objection to the taste of chlorine in water (44 percent objected, 9 percent were unsure, 30 percent had no objection to it and 16 percent would accept but prefer an alternative if practical) Although UV radiation would be well suited to the Rarotonga environment, the cost of such a system would be around US$616,000 compared with about US$130,000 for chlorination. A further issue with UV would be the retention time of disinfected water in the distribution system; it must be short enough to prevent regeneration of bacteria following UV radiation. This would not be an issue with chlorine which would retain residual dosing. The advantages of chlorination together outweigh the taste disadvantage and it is therefore recommended that chlorination be used for disinfection. This will require the installation of a secure and well ventilated shed to store the chlorine in a safe, dry condition, a mixing tank to prepare the solution, a dosing hopper, a mixing pump and a metering pump to inject the solution *into the filtered water. Training the operators, in safe handling and application of the chlorine compound will also be required and will be provided for in the consulting services for detailed design and implementation.*

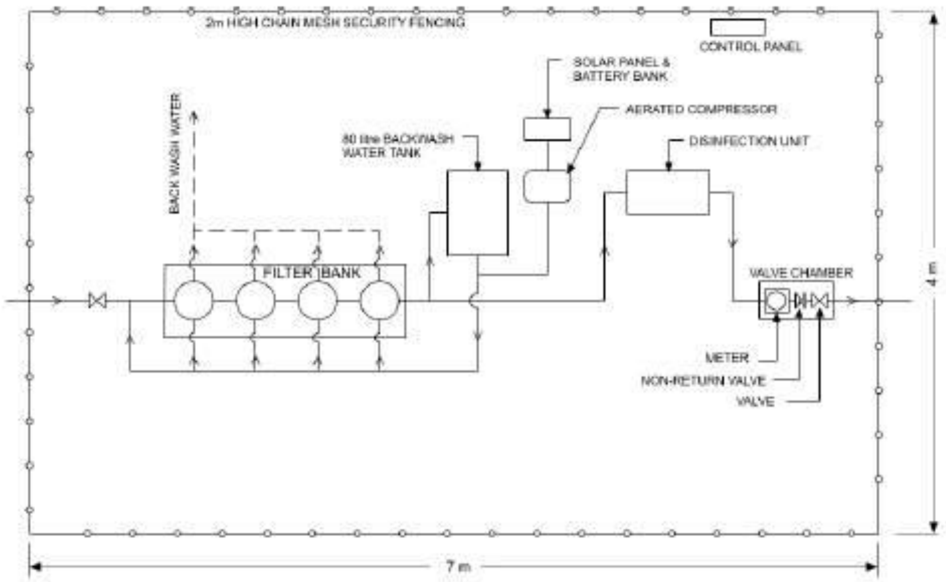
144. Instrumentation and flow control will include a control panel, gate valves, non-return valves, flow meters and a pressure tapping device to enable monitoring production and flow rates. The installation of non-return valves will eliminate inter-catchment transfer of water during low demand periods when water flows from the higher to the lower intakes, and may be a significant current cause of loss from the system.

145. Civil works will include construction of a concrete floor and 2m high chain mesh security fence. In addition a truck equipped with a mobile compressor and diesel powered generator unit will be provided to enable periodical backwash of the screens as necessary.

146. The area required for the installation of each treatment plant will be approximately 30 m^2. A concept layout of a typical water treatment plant is shown in Figure 10 and a photograph of the existing Arkal filter bank (as an illustration of the general layout of the filtration system) is shown in Figure 11.

Volume 3: Water Supply & Sanitation Sector

Figure 10: Concept Layout Typical Water Treatment Plant



TYPICAL WATER TREATMENT PLANT LAYOUT PLAN (NTS)

8.1.2 CSIRO report (2005) – Economic Valuation of Watershed Pollution in Rarotonga

Testing of Rarotonga's water supply has found that the quality of tap water falls below international safety standards in two categories with faecal and total coliform, types of bacteria also harmful to humans, exceeding acceptable levels at water intakes around the island. The presence of faecal coliform provides a threat with the possibility of an outbreak of Giardia.

Identified watershed issues to be managed to control catchment water quality -

- *Soil erosion and stream sedimentation.*
- *Herbicide and pesticide run-off.*
- *Fertiliser run-off.*
- *Livestock and animal waste.*
- *Septic tank leakage.*
- *Mosquito outbreaks from stream blockage and poor waste disposal.*
- *Liquid and solid waste disposal.*

8.1.3 Overview of current water quality

Both the reports from CSIRO and the ADB have identified water samples with high total coliform, faecal coliform and E-coli counts. Data is limited, but Sections 102 to 105 of the ADB report confirm that bacterial pathogens have been measured in the water sources. This information coupled with site visits and discussions with local field staff, identifying wild pigs and birds in the catchment areas and other human activity in the vicinity of the intakes, confirm the catchments are not protected.

The presence of animals and human activity near the intakes and data described in the ADB report strongly suggests that pathogens can be present in the source waters. Raw water sampling could be conducted to confirm these earlier data and identify which pathogens are present (e.g. whether protozoa such as Cryptosporidium or Giardia are present), but this data would need to be used carefully as they would rely on isolated samples that would represent only a very small fraction of the flow. Moreover, analytical techniques used to evaluate the presence of protozoa have limited sensitivity. Thus, it is not because no protozoa would be detected during the samplings that these pathogens are not present in the intakes.

8.2 Basis of design

The proposed treatment strategies presented in this document offer a multi-barrier approach to remove contaminants from the water source and maintain quality after treatment and prior to delivery to consumers. The proposed treatment processes are aimed at the following objectives, and are further detailed below:

- Particle removal that can withstand storm events which cause highly turbid water;
- Removal (by filtration) and inactivation (by primary disinfection) of microorganisms, and most importantly, pathogens;
- Residual disinfection to protect the treated water against pathogen introduction into the network during water distribution and also inhibit microbial regrowth;
- Distribution system control and water quality monitoring to ensure compliance with water quality goals and the ability for operations staff to know when quality degrades; and
- Water storage to ensure that peak demand is met, but also to stop treatment during storm events that bring overly turbid water that may compromise the treatment steps.

The intent of the proposed water treatment is to provide treated water to meet the WHO standards of 2011.

Options are proposed for both mechanical filtration and disinfection. These options are categorised as the minimum or optimum level required.

- The minimum level of treatment sets out that which should be installed to meet minimum water quality needs;
- The optimum option is the recommended level of treatment which should be installed to allow for a more robust level of treatment and more stable protection of water quality. This option is in addition to the minimum treatment to provide a strong multi-barrier approach with redundancy to minimise the risk of failure.

Further considerations which are presented include treatment waste residual management, backflow prevention, network system operation, water quality monitoring and operator training.

8.2.1 Storage

Storage of untreated water is proposed and offers the possibility of shutting down the intake during storms and high-turbidity events. The agreed concept for the water supply network sets out a required raw water storage of 36,000m^3.

Storage of untreated water is preferred to the storage of treated water because this will offer primary sedimentation of particles prior to water treatment, even during normal operation. Some storm events may be short lived, but high turbidity can continue for several days thereafter. Raw water sedimentation would decrease operating costs for treatment and disinfection, including lower chemical dosages. However, it would still require maintenance and cleaning to ensure the settled matter does not re-enter the system. In comparison, treated water storage would require higher chlorine doses to ensure a residual during storage and through the entire distribution system.

Also, raw water storage does not require ongoing water quality monitoring as required for treated water, which may become excessive if water is stored for significant periods.

8.2.2 Physical removal

A physical removal process is necessary to remove both large and small particulate material including turbidity, sediments and micro-organisms such as pathogens. This is particularly important in the case of Rarotonga, considering the high turbidity that can occur during storm events. A number of technologies are available to remove particles and microorganisms using physical processes, including:

- Roughing filters / rough screening: Large-pore filtration processes usually used to protect downstream small-pore filters such as membranes.
- Sedimentation: Separation of particles from the water supply using gravity. Depending on particle size and their size distribution, significant particle removal can occur in storage reservoirs. Purposely-designed sedimentation processes are typically reserved for large systems (e.g. clarifiers, but these typically require dosing with a flocculant to assist this process), while smaller systems usually bypass sedimentation and contain one or multiple filtration barriers.
- Filtration: Filtration processes can be separated into two types:
  - Granular-media filtration, which removes particles within and on the surface of a media bed, is one of the most common and oldest techniques used in the water industry. The coarse-aggregate filters and the Arkal filters currently used at some of Rarotonga's intakes can be classified as granular-media filters; and
  - Surface filtration involves particle removal using screening or sieving. Membranes are surface filters.

8.2.3 Pathogen inactivation

Removing and deactivating micro-organisms from water prior to consumption in order to provide potable water is the main goal of water treatment. Micro-organisms, which include pathogens and non-pathogens, are normally inactivated during a disinfection step which may include chemical (e.g. chlorine, chlorine dioxide, ozone) or physical (e.g. UV) treatment. Chlorine-based disinfectants are the most widely applied and can efficiently inactivate bacteria and virus. UV (ultra violet) disinfection is particularly efficient at inactivating protozoa, but must be applied upstream of chlorination as it can destroy residual chlorine. Both types of disinfectants are therefore complementary.

8.2.4 Residual disinfection

Following primary disinfection, residual disinfection is practiced in order to protect drinking water against downstream contamination. This contamination can occur if there is a damaged area of pipe (allowing intrusion of contaminants) or if backflow occurs. Residual disinfectant also helps to prevent microbial regrowth within the distribution system which can lead to aesthetic problems and loss of residual disinfection. Whereas UV and some chemical disinfectants (e.g. ozone, and chlorine dioxide under certain conditions) do not provide a lasting residual in water, chlorine and chloramines are both chlorine-based residual disinfectants. For smaller and less complicated systems such as on Rarotonga, chlorination would be typically practiced instead of chloramination (the combination of chlorine with ammonia).

8.2.5 Distribution system control

The distribution system is a managed barrier between the treated drinking water and the environment. It protects downstream consumers from the potential influx of contaminants downstream of treatment and is therefore of the utmost importance. Recognizing that water quality can degrade the longer water flows in the distribution system, the following approaches are proposed and further discussed below:

- Monitoring: An operational process which allows for the systematic monitoring of water quality (including disinfectant residual) will facilitate the detection of breaches in the integrity of the distribution system and allow operations staff to respond appropriately.
- Residual Disinfection: Maintenance of a residual disinfectant in the distribution system will aid in maintaining high quality water prior to consumption.
- Active System Management: Continued maintenance of the treatment and distribution system will allow it to operate for many years without adversely affecting the consumers. For the distribution system, there are

issues such as minimising water age which can be accomplished using the currently available hydraulic model and therefore appropriate sizing of the mains. Furthermore, routine flushing of pipe sections that are predicted or known to exhibit extended water age (greater than 72 hrs) and low flow rates can be an easy method to maintaining distribution system infrastructure and water quality by eliminating potentially accumulated sediments.

8.3 Process selection

The following treatment strategy, also illustrated below in Figure 25, is proposed at all intakes, and further discussed below:

- Coarse-gravel (roughing) filters
- Storage of untreated water (discussed at the end of this section)
- Mechanical filtration
- Disinfection (by chlorine or UV light)
- Distribution (with chlorine residual and water quality monitoring)

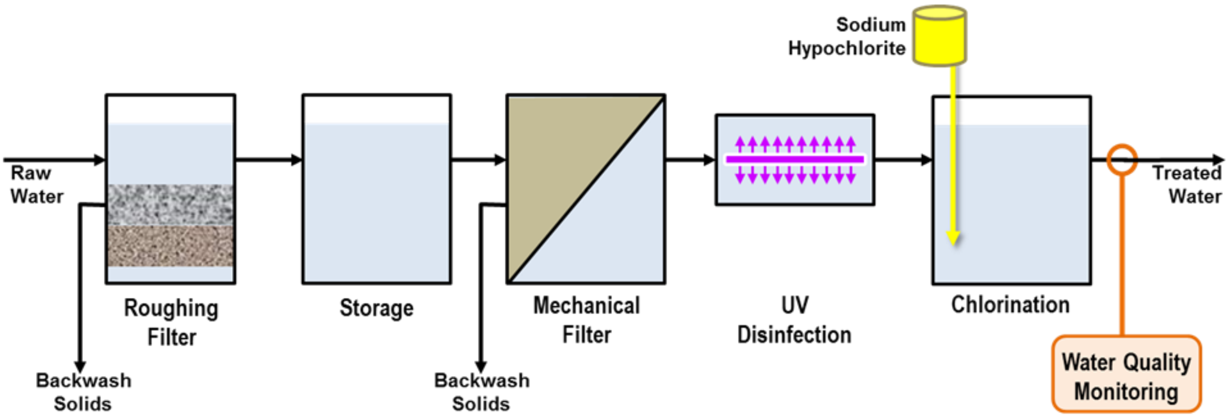


Figure 25 Overall treatment and distribution process recommendation summary

The coarse-gravel filters and the storage reservoirs that immediately follow them are proposed as a minimum and regardless of any additional downstream treatment strategy. Options are proposed for both mechanical filtration and disinfection. These options are categorised as the minimum requirement (that which should be installed to meet minimum water quality needs) and the recommended option (that which should be installed to allow for a more robust level of treatment and more stable protection of water quality).

8.3.1 Coarse-gravel filters

An example of these filters, as proposed in earlier documents, is shown in Figure 26 below. Coarse-gravel filters are present at some of the intakes (Avatiu, Matavera, Ngatoe, Rutaki, Taipara, Takuvaine, Tupapa, and Turangi (Fraser Thomas, 2009), and have been recommended at all intakes in earlier documents. These filters are part of the minimum recommendation in this document. Coarse-gravel filters would be barrier to larger debris and suspended matter that may damage downstream equipment as well as harbour pathogens. These filters will also remove some micro-organisms and pathogens that are attached to larger particulates.

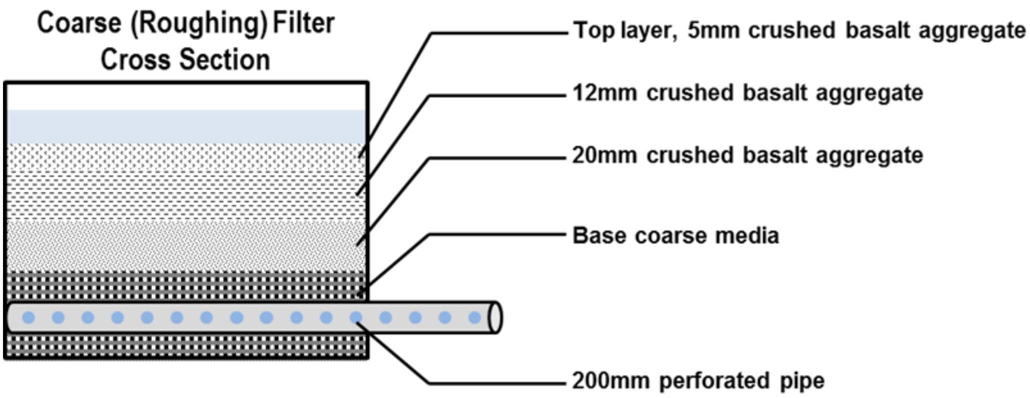


Figure 26 Coarse (roughing) filter cross section diagram showing media layers

The storm events that have damaged some of the intakes indicate the need to review their design and reduce their maintenance requirements. This is particularly important considering the recommendations presented in this document, which propose substantial investments. If the coarse-gravel filters become non-operational, downstream facilities would be at risk to significant damage.

8.3.2 Water storage

Following the coarse filters, water will be stored in reservoirs located at each intake based upon assumptions provided in Table 15. The purpose of the reservoirs is to store water following coarse filtration in order to buffer against flow variations and if the intake is required to be taken off-line (such as during storms and high turbidity events or maintenance).

Guidelines developed during the Te Mato Vai technical workshop set a target of at least 36,000 m³ of raw water storage on Rarotonga, the equivalent of 3 days of supply at peak demand (Te Mato Vai Technical, 2013). Reservoir sizes were derived using an iterative process beginning with a volume equivalent to three times the maximum daily yield of the corresponding intake. Storage was subsequently reduced at intakes where model outputs indicated that the yield of a source was inadequate to fill the tank volume under peak demands. The process was repeated until the target volume of 36,000 m³ was achieved.

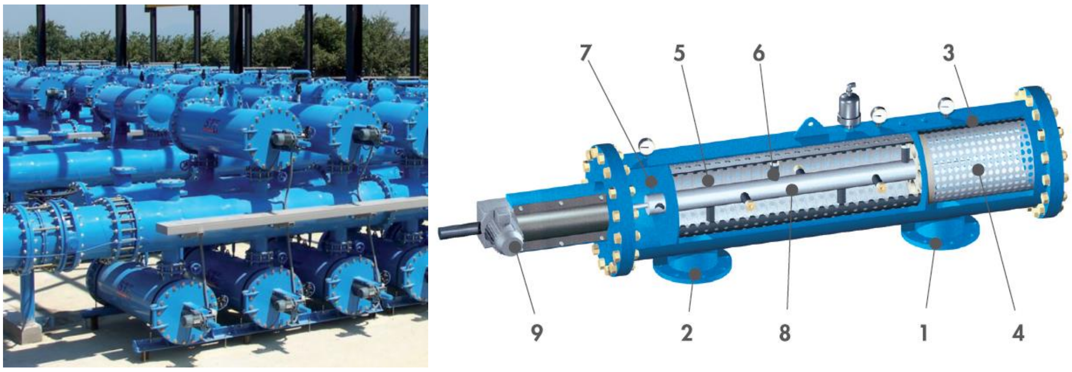
Operations planning should further investigate methods to facilitate water turnover in these reservoirs once they are operational.

8.3.3 Mechanical filtration

Following storage, a mechanical filtration step is likely to be required to further remove fine debris and turbidity from the drinking water. This section describes both the minimum required filter option (screen filters) and an optimum option (membrane filters).

8.3.3.1 Minimum: Existing Arkal filters or new screen filtration

Screen filters can offer self-cleaning, stainless steel screen filters which will remove particulates as small as 10 µm. If the current Arkal filters do not allow for adequate filtration, they should be replaced with the following screen filter equipment. A price quote was obtained from Metaval Consolidated, (FMA 2000 Series) which consists of three distinct chambers, as illustrated below in Figure 27. These chambers include a prefiltration chamber (at the inlet) to remove coarse particles missed by the upstream coarse filters, the main filter chambers, and a backwashing chamber. These filters may be operated automatically with little or no operator attention and minimal maintenance requirements. The backwashing feature for these screens includes full automation of the backwashing sequence (no operator initiation required) and the ability of the equipment to continuously produce treated water flow while the filter is backwashed.



Installation example (left) and filter illustration (right) showing (1) inlet, (2) outlet, (3) prefiltration chamber, (4) coarse screen chamber, (5) filter chamber, (6) fine screen chamber, (7) backwashing chamber, (8) scanner, and (9) motor drive

Figure 27 Metaval FMA 2000 series screen filter

Each unit is detailed in Table 18, and the proposed unit for each intake with associated cost are presented in Table 19. Three design scenarios were considered to address the various flow rates at the 12 intakes which include screen filters operating at 10, 20 or 40 l/s. These screen filters trigger an automatic cleaning when a pressure difference of 0.3 bar (or 4.5 psi) is reached between both sides of the screen. Cleaning can also be set based on operating time period, or a combination of pressure difference and operating time. The minimum and maximum operating pressures are 2 and 10 bar (29 to 145 psi), respectively. Higher pressures can be reached if stainless steel (instead of PVC) support is used.

Table 18 Specifications for Metaval screen filters

Parameter	Values According to Design Condition		
Operating Flow Rate (l/s)	10	20	40
Equipment Name	FMA 2010	FMA 2014	FMA 5000
Inlet/outlet Connector Size (inch)	10	14	20
Operating pressure range required (bar)	2 to 10	2 to 10	2 to 10
Filter Size (µm)	10	10	25
Filtering Surface Area (cm2), PVC	12.25	20.1	N/A
Filtering Surface Area (cm2), Stainless Steel	13.21	21.3	55.0
Backwashing Water Consumption (L)	175	175	N/A
Weight for a PVC Unit (kg)	430	668	N/A
Weight for a Stainless Steel Unit (kg)	495	753	1810

N/A = Information Not available

Table 19 High-level cost opinions (+/- 50 percent) for Metaval screen filters

Intake Location	Average Production and Yield (l/s)	Unit Model	Cost ($AUD)[1]	Cost ($NZ)[1]
Avana	38.2, 39.3	FMA 5000	$71,000	$85,200
Avatiu	19.3, 19.3	FMA 2014	$32,000	$38,400
Matavera	11.3, 15.8	FMA 2010	$22,000	$26,400
Muriavai	4.3, 8.8	FMA 2010	$22,000	$26,400
Ngatoe	22.3, 23.1	FMA 2014	$32,000	$38,400
Papua	4.3, 23.1	FMA 2014	$32,000	$38,400

Intake Location	Average Production and Yield (l/s)	Unit Model	Cost ($AUD)[1]	Cost ($NZ)[1]
Rutaki	9.5, 9.7	FMA 2010	$22,000	$26,400
Taipara	7.1, 25.2	FMA 2014	$32,000	$38,400
Takuvaine	17.4, 17.4	FMA 2014	$32,000	$38,400
Totokoitu	10.8, 10.8	FMA 2010	$22,000	$26,400
Tupapa	13.3, 14.3	FMA 2010	$22,000	$26,400
Turangi	28.7, 28.7	FMA 2014	$32,000	$38,400
Total			**$373,000**	**$447,600**

[1] *Taxes and delivery not included*

8.3.3.2 Optimum filtration: Membranes

It is recommended that membrane filters be installed. These offer the ability to remove finer debris / turbidity from the drinking water as well as pesticides and microorganisms. Removal of these will allow the disinfection stage to be more effective with reduced chlorine dosing / UV required and minimising the possibility of chlorine reacting with organics in the water, producing trihalomethanes (THMs).

The characteristics of microfiltration (MF) and ultrafiltration (UF) membranes, the two options proposed here, are presented in Table 20. Both MF and UF offer high productivity and low pressure operation. When compared with MF, UF would offer an alternative protection against micro-organisms, remove some DBP precursors, and some pesticides, the latter being an advantage in an agricultural environment such as in Rarotonga. UF would also largely meet the requirement to install 5-µm filter at each intake, which was proposed in the Water Safety Plan (Department of Water Works of the Ministry of Infrastructure and Planning, MOIP, 2009). Another argument in favour of membranes is the consideration for using groundwater to supplement the current water supplies during drought events. As salinity in the groundwater supply may be an issue, MF or UF membrane treatment will need to be used as a pre-treatment to reverse-osmosis (RO) treatment for salt removal.

Table 20 Typical membrane filter characteristics

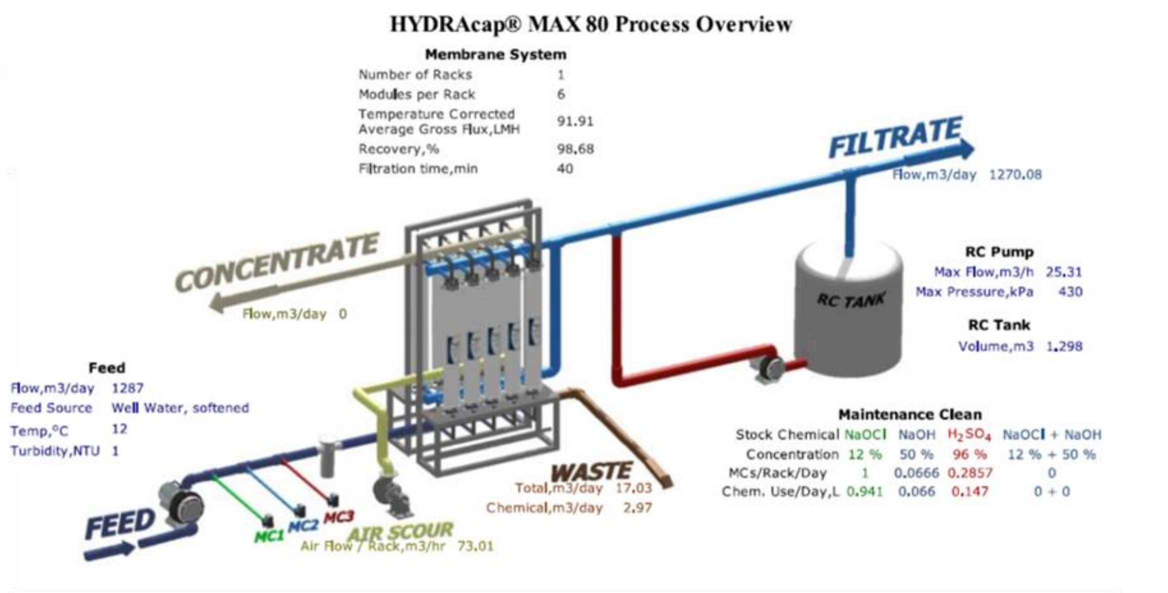
Membrane Type	Pore Size (µm)	Removal Capability	Operating Pressure
Microfiltration (MF)	0.1-10	Algae, colloids, nanoparticles, protozoa, bacteria, pollens, yeasts	0.3-2
Ultrafiltration (UF)	0.001-0.1	Larger organic macromolecules, viruses, some pesticides	0.5-5

In addition to the coarse-gravel filters and shutdown of the intakes during high-turbidity events (as described above), UF membranes may need to be preceded by MF (or by 10-µm sized screen filters), if raw water quality is poor (highly turbid). Many providers now offer packaged membrane systems of various types and sizes that can be operated with minimum supervision, and even remotely. The provider presented here, Hydranautics, can build customized systems for the Rarotonga supply zones.

Figure 28 illustrates a system that can be procured from Hydranautics. This system can provide 1,287 m^3/d (15 l/s) of treated water. This system includes pumps to provide adequate pressure for membrane operations and chemical cleaning equipment which operates automatically with the membrane filter. Additional equipment which would be required to be installed with this system includes the following:

- An discharge containment system for approximately 1.5 L of chemical waste per day.
- Covered, indoor storage.
- To protect against filter failure and off-line maintenance requirements, a one-day supply of water, with pumping to the distribution system, should be allowed in a reservoir immediately after membrane treatment.

Table 21 summarises the costs that are expected with the installation of the membrane systems for each of the catchment areas.



System Summary:

Feed water = 1,287 m^3/day
Treated water = 1,270 m^3/day
Pre-treatment required to provide ≤1 NTU feed water
Daily chemical usage for automated membrane cleaning is approximately 1.2 L/d

Figure 28 Hydranautics HYDRAcap MAX 80 microfiltration system

Table 21 Membrane system equipment and costs summary

Intake Location	Average Production and Yield (l/s)	Number of MAX 80 Systems	Cost ($US)[1]	Cost ($NZ)[1]	Tank Storage Required (x1000 L)	Building Cover Size Required (m^2)
Avana	38.2, 39.3	2	$160,000	$200,000	58	50
Avatiu	19.3, 19.3	1	$80,000	$100,000	29	40
Matavera	11.3, 15.8	1	$80,000	$100,000	29	40
Muriavai	4.3, 8.8	1	$80,000	$100,000	15	30
Ngatoe	22.3, 23.1	2	$160,000	$200,000	29	40
Papua	4.3, 23.1	2	$160,000	$200,000	29	40
Rutaki	9.5, 9.7	1	$80,000	$100,000	15	30
Taipara	7.1, 25.2	2	$160,000	$200,000	29	40
Takuvaine	17.4, 17.4	1	$80,000	$100,000	29	40
Totokoitu	10.8, 10.8	1	$80,000	$100,000	15	30
Tupapa	13.3, 14.3	1	$80,000	$100,000	29	40
Turangi	28.7, 28.7	2	$160,000	$200,000	58	50
Total			**$1,360,000**	**$1,700,000**	*Costs for Tanks and Buildings Not Included*	

[1] *The following items are not included: Taxes, delivery, waste collection, building cover and treated water storage.*

8.3.4 Disinfection

Following mechanical filtration removal of fine debris and turbidity from the drinking water, disinfection is required. This section presents a description of both the minimum required disinfection option (chlorination) and a recommended disinfection option (UV disinfection followed by chlorination). If UV disinfection is incorporated into the design or not, it will not impact chlorine system design requirements. Therefore, the same chlorine system would be required for either option.

8.3.4.1 Minimum disinfection: 30-minutes chlorine contact with downstream residual

At minimum, chlorine should be used following mechanical filtration to provide primary disinfection and residual disinfection in the distribution system. Hydraulic modelling was used to calculate water age throughout the distribution system. Under average and maximum demand conditions, results showed relatively low water ages, i.e. less than 24 hours for most of the pipe sections (Figure 29). The western part of the island in the Arorangi District shows water age up to 48 hours. Throughout the island, a few sections show water ages greater than 96 hours (4 days) where water is delivered to isolated areas in higher elevations.

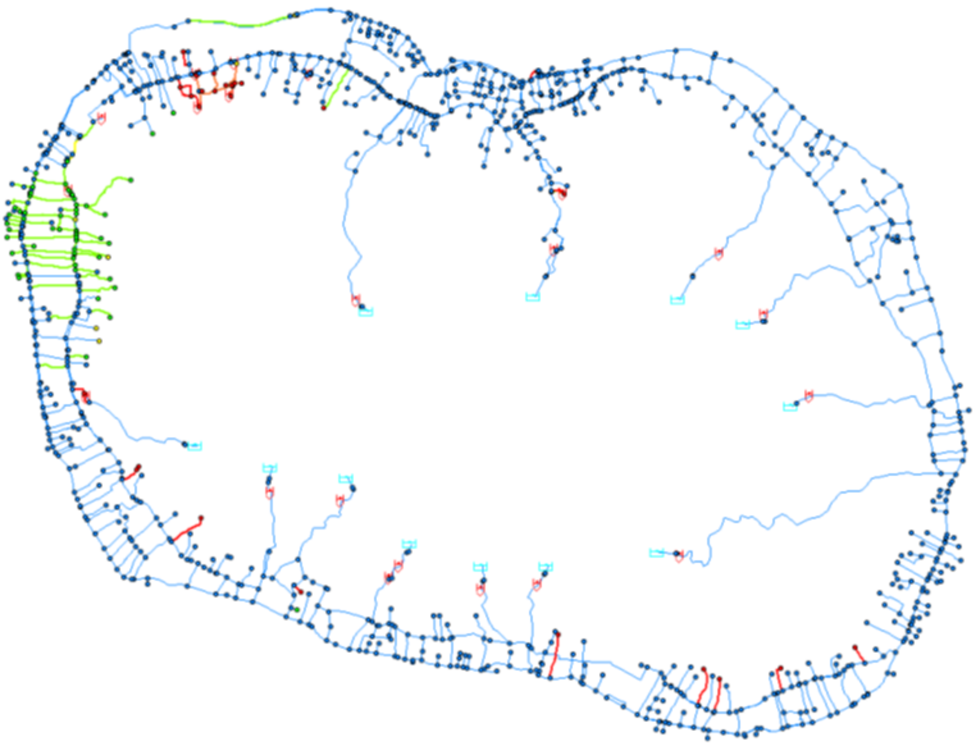


Figure 29 Water age throughout the distribution system under average water demand (Blue: <24 hours; Green: 24-48 hours; Yellow: 48-72 hours; Orange: 72-96 hours; Red: >96 hours)

As a rough estimate, chlorine may need to be dosed up to 2 mg/l into water that is pre-treated by the filters. Chlorine demand tests need to be conducted by operations staff in order to determine the actual chlorine dose required. For the purposes of this document, it will be assumed that there is a 0.5 mg/l chlorine demand and a decay of chlorine of 1.5 mg/l until the furthest reaches of each of the distribution system. Therefore, these assumptions indicate that if 3 mg/l of chlorine is added, the last customer in the system would be provided water with 0 mg/l chlorine residual. Based on these assumptions, a chlorine dose of 2 mg/l is estimated as required in order to achieve at least 0.5 mg/l chlorine residual at the furthest locations in each system (note that Drinking Water Standards New Zealand [DWSNZ] require a 0.2 mg/l residual as a minimum in the distribution system).

The treatment of the water with multiple barriers should considerably reduce the chlorine demand of the water. Likely demand will need to be assessed. If the recommended processes are implemented then the water should be relatively stable which, provided that the distribution system does not have significant ingress should reduce chlorine decay. However, chlorine decay cannot be accurately calculated until disinfectant enters the system. It is recommended that the residual entering the system should be 0.5 mg/L, Residual disinfectant monitoring will then allow this concentration to be modified at a later date. Considering the relatively low water ages modelled throughout the distribution system, re-chlorination should not be necessary.

Most individuals are able to taste or smell chlorine in drinking-water at concentrations well below 5 mg/l, and some at levels as low as 0.3 mg/l (WHO, 2011). The proposed level of disinfection will ensure any taste effects are very limited to the majority of water users.

Table 22 summarises the requirements for water storage after chlorination in order to achieve a 30-minute contact time prior to reaching the first downstream consumers. When using chlorine as a primary disinfectant, this 30-min contact (with a residual of at least 0.5 mg/l) is indicative (as per the Australian Drinking Water Standards [ADWG], 2011 and per DWSNZ) for providing primary disinfection. The C•t (disinfectant residual 'C' multiplied by the contact time 't') achieved for each flow rate and chlorine contact tank size is 15 mg/l•min. It should be further understood that the installation of the optimal filter option (membranes) would allow for the post-membrane water storage tanks to be used as the chlorine contact tanks so that no additional tanks would be necessary.

Table 22 Chlorine dosing and contact time information for primary disinfection (when UV is not used)

Flow Rate (l/s)	Chlorine Dose (mg/l)	Chlorine Contact Tank size (L) Providing 30-min Disinfection*	C•t Achieved**
40	0.5	72,000	15 mg/l•min
20	0.5	36,000	15 mg/l•min
10	0.5	18,000	15 mg/l•min

* *If the optimal membrane option is installed for filtration, the water storage tanks could be used for disinfection rather than adding more tanks as indicated here.*

** *The C•t achieved is assumed that there is a 1 mg/l chlorine demand in 30 minutes*

Example equipment for chlorine dosing and measurement is provided in Figure 30. The combination of the metering pump (a) and the water quality analyser (b) is $7,500 (AUD) (NZ$9,000) per installation. The unit uses amperometric titration for accurate and reliable measurement of chlorine residual.

a)

b)

Figure 30 Chlorine dosing and analysis equipment

The use of sodium hypochlorite (as shown in Figure 25) is recommended, however it is proposed to manufacture this onsite rather than import it to Rarotonga.

Chemical suppliers do not currently export sodium / calcium hypochlorite to Rarotonga, but they can do from existing operations in locations such as Fiji. The costs of transporting these are reasonably significant as they must be treated as dangerous goods with specific handling, transporting and storage requirements.

There are a number of issues with importing sodium / calcium hypochlorite:

- The chlorine content decays over time, meaning the hypochlorite must be monitored to ensure the correct dosage is delivered.

- Whilst there are regular ships between Rarotonga and Fiji, these are not fixed or reliable as they are typically reliant on a full load (i.e. they may be delayed by a week or 2 to allow the ship to be full) and their schedule (i.e. they may be diverted to other Pacific Islands).
- The sodium / calcium hypochlorite must be stored securely – this store may need to be a significant size to ensure adequate supplies on the island.

It is therefore recommended that a single small sodium hypochlorite manufacturing plant will be installed at one of the largest treatment plants (Avana, Avatiu, Ngatoe or Turangi). The produced sodium hypochlorite can be safely transported to the other treatment sites on a trailer with a 1,000 litre tank and a chemical transfer pump, as shown in Figure 31.

Figure 31 Example of sodium hypochlorite transportation

The sodium hypochlorite manufacturing plant uses the process of electrolysis of salt solution to produce a dilute sodium hypochlorite solution. This simplifies storing and handling requirements, minimising any transportation risks and is much safer for staff and operators to deal with, yet is still very effective as a disinfectant.

By manufacturing the sodium hypochlorite on Rarotonga, the issues identified above can be overcome and the import of salt is relatively simple with far smaller quantities required.

Sodium hypochlorite plants are now regarded as being reasonably reliable and simple to run meaning minimal intervention required locally. They are used widely across NZ where in addition to water supply disinfection, they are used at swimming pools, where staff operate the plant but do not have technical knowledge.

Having a single manufacturing plant produces significant cost savings for Rarotonga and reduces the number of plants to maintain. There is obviously an increased risk through having a single plant, the need for storage at each site and the regular transport of sodium hypochlorite, however this can be managed by introducing a robust procedure and ensuring all staff are adequately trained.

Pricing and availability for sodium hypochlorite manufacturing equipment has been provided by Ecological Technologies Ltd, Aquacare Water Treatments Ltd and Liquid Chlorine New Zealand Ltd. The cost of the sodium hypochlorite plant and transportation trailer would be NZ$185,000 not including tax, shipping, installation and any building needs.

8.3.4.2 Optimal disinfection: UV with residual chlorine

UV disinfection inactivates protozoan pathogens that are chlorine resistant (Johnson, 2010) and that may remain following filtration, particularly under suboptimal conditions with the membranes, or with the screen filters that have relatively large pore sizes (10 or 25 µm). UV lamps capable of providing 40 mJ/cm^2 (germicidal dose) at the design flow rate are proposed.

Pricing and availability for UV disinfection equipment has been provided by Aquatec-Maxcon for the Trojan UVSwiftSC reactor and Xylem Water Solutions NZ Ltd for the Wedeco Spektron 50e/90e. This reactor will provide at least 40 mJ/cm^2 UV dose for each of the 12 intake areas for a flow rate up to 40 l/s. Pricing and equipment information is provided here (all prices have been quoted in $AUD, and converted to $NZ, excluding shipping, tax, and building costs):

The total price for all 12 locations would be NZ$215,000 not including tax, shipping, installation and any building needs.

8.3.5 Distribution system water quality monitoring

Water quality monitoring for chlorine residual is recommended in the distribution system. The equipment recommended is a HACH CL17 Chlorine Analyser for free chlorine. This unit uses DPD reagent which needs regular checks each week for its supply, and bottle changes approximately once per month. This equipment requires no equilibration time or regular calibration, however, because it uses reagent it has a waste stream which must be collected and then disposed of properly. Maintenance can be performed monthly only, and consists of replacing the reagents and cleaning the colorimetric cell. The analyser can measure chlorine residuals up to 5 mg/l Cl_2. The unit is approximately 38 cm wide by 45 cm high by 15 cm deep and should be enclosed in a protective cabinet. Cost is approximately $7,800 AUD (NZ$9,400) – this does not include taxes, shipping, installation, or the cost for a protective cabinet.

8.4 Additional considerations

Further cost saving could possibly be made by combining catchments and treatment. There are two options that are identified at this time which include combining Ngatoe (yield of 23.1 l/s) with Rutaki (yield of 9.7 l/s), and combining Taipara (25.2 l/s) with Totokoitu (10.8 l/s). It may be possible to combine untreated water near the distribution system rings, and have 1 treatment unit for 2 intakes. Eventually, these areas could also be good locations to consider installing treated water tanks to balance demand.

8.4.1 Appropriate technology

The process selection outlined above has taken into account where the assets will be sited, how they might reasonably be expected to be operated and their impact upon Rarotonga to identify appropriate solutions. The detailed design phase will revisit these proposed solutions to ensure the most appropriate assets are selected.

The detailed design phase will therefore ensure the final solutions adopted:

- Minimise energy usage;
- Minimise the area of land required to be acquired;
- Are suitably sized to meet current and future demand as identified in this Master Plan;
- Are designed for stand-alone operation and are simple to maintain and operate; and
- Do not require intensive maintenance and operation.

It is envisaged that the treatment plants will require weekly visits of approximately 1 hour to check the performance of all systems and site security. This visit could be combined with delivery of sodium hypochlorite.

8.4.2 Waste residuals management

Many treatment processes create waste residuals that require disposal. These residuals vary widely in quantity and quality based on water quality and treatment strategy. They can be classified in three categories:

- Solids from sedimentation, such as the untreated storage tanks proposed here.
- Spent backwash filter water, such as from the recommended screens.
- Membrane residuals as proposed above.

Typical treatment strategies for residuals include evaporation (e.g. dewatering lagoon, sand drying beds), and mechanical processes (involving either thickening or dewatering technologies such as filter presses, centrifuges, and pressure filters). Final disposal is typically in landfill sites.

There are no easy ways to predict the volumes of residuals produced by a specific treatment strategy as they are highly influenced by the raw water quality (as mentioned above), which varies seasonally. Storm events are also likely to create much greater residual volumes than normal operation. Residual volumes are typically determined in pilot testing.

8.4.3 Distribution system operations

To preserve water quality during distribution, backflow prevention devices are required. At first, these devices could be installed on the largest consumers such as hotels, resorts, and other large institutions. Other locations for installing backflow prevention should include large industrial consumers, public buildings, agriculture supplies and other public or private institutions identified as being a high risk for potential contamination. If the effort to install backflow prevention devices is overwhelming, it should at least be planned to be completed over time if not done all at once.

Procedures and processes should be put in place for maintenance, servicing, renewal and repair of assets. Operators, or service contractors, should be appropriately trained and procurement strategies for the replacement of assets should be implemented.

As mentioned above, a few pipe sections that deliver water to isolated areas in higher elevations appear to show high water ages, i.e. greater than 96 hours (4 days). Routine flushing of these areas should be considered to decrease water age and remove accumulated sediments, which would help restore chlorine residual and preserve water quality. Flushing options should be developed as part of the routine operation of the system. This should be timed to coincide with periods of water abundance to minimise impact upon water availability.

Furthermore, at representative sites of the distribution system (which could be the sampling sites) online pressure readers should be installed. Any significant pressure decreases can be signs of breaches in distribution system integrity, which could be due to leaks and therefore potential intrusion, pipe breaks, or other infrastructure challenges.

8.4.4 Water quality monitoring

Water quality monitoring is of the highest importance to assess water’s potability, and establish trends over time and space (at the various intakes and throughout the distribution system). It is recommended that Rarotonga water supply staff be trained in how to monitor water quality through the multiple systems that supply drinking water on the island. A subset of key parameters is presented below which can be easily analysed using minimum analytical equipment:

- Alkalinity
- Ammonia
- Chlorine dose and residual
- Hardness
- Nitrate
- Nitrite
- pH
- Phosphate
- Sulphate
- Temperature
- Total coliform and Escherichia coli as microbial indicators.
- Total dissolved solids
- Total organic carbon (and dissolved organic carbon)
- Turbidity
- UV absorbance at 254 nm

Other parameters could be added, such as iron and manganese as proposed in the draft Water Safety Plan, as well as other ions. These additional parameters would also allow the calculation of corrosion and aggressiveness indices, an aspect that should be examined to preserve distribution system integrity, particularly considering that the distribution system contains asbestos-cement and steel pipes.

Monitoring could be conducted with commercially-available portable testing kits such as a HACH DR890. These tests should be conducted at the following locations:

- All intakes, prior to treatment.
- All entry points to the distribution system.

- Representative sites throughout the distribution system to capture both the primary and secondary rings, as well as all 6 zones of influence of the water network.
- Selected customer taps.

Monitoring should be conducted no less than weekly, while the on-line instruments recommended above would monitor chlorine residual continuously.

8.4.5 Operator training

Some recommended operator training would include the following:

- General training on water quality
- First training on specific equipment by the manufacturers, including maintenance and operations requirements
- Operations and water quality training refreshers on an annual basis

8.4.6 Accountability and responsibility

Accountability and responsibility for the water supply system should be established through legislation, statements of intent, policy documents, levels of service and standards. This will ensure events that occur in the system e.g. water quality event, equipment malfunction, have clear ownership and can be effectively communicated, managed and resolved.

8.4.7 Security

Part of the scope for renewing the trunkmains includes the construction / upgrade of roads to the sources. These new or improved roads will potentially allow greater access to the water intakes and proposed treatment and storage sites.

In order to minimise risk such as contamination of the water supply or malicious / accidental damage to new assets, the detailed design phase will need to consider security fences or gates to control access.

9.0 Non-revenue water

9.1 What is non-revenue water?

Non-revenue water (NRW) can be defined as the difference between the system input volume (the volume of water produced and supplied into the distribution system) and the billed authorised consumption (the volume of water billed to customers), ie:

NRW = System Input Volume - Billed Authorised Consumption*

* assuming:

- The system input volume has been corrected for known errors such as meter inaccuracies etc.
- The periods for both the billed metered consumption (for customer billing records) and the system input volume are consistent

Table 23 below shows the different components of the overall water balance and how these relate to non-revenue water. The table and terminology has been developed by the International Water Association (IWA) from countries with well-established national procedures and terminology for the Water Balance (France, Germany, Japan, UK and USA). These different terminologies have been compiled to form a standard international water balance structure and terminology.

Table 23 Components of the water balance including NRW

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Commercial Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies & Data Handling Errors</td></tr>
<tr><td rowspan="3">Physical Losses</td><td>Leakage on Transmission & Distribution Mains</td></tr>
<tr><td>Leakage & Overflows from Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the Customer Meter</td></tr>
</table>

Key definitions for terms in the table are:

- **System Input Volume** is the annual volume input into the water supply distribution system.
- **Authorised Consumption** is the annual volume of metered and non-metered water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorised to do so (e.g. fire

fighting, street cleaning, mains flushing). It includes leaks and overflows after the point of customer metering.

- **Water Losses** is the difference between System Input Volume and Authorised Consumption. It is made up of Commercial Losses and Physical Losses
- **Commercial Losses** (also known as 'apparent losses') consist of Unauthorised Consumption and all types of metering inaccuracies
- **Physical Losses** (also called 'real losses') are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

9.2 Methods for determining non-revenue water and leakage levels

9.2.1 Water balance approach

There are four basic steps to conduct a water balance:

Step 1 – Calculate the total system input volume

Step 2 – Determine the authorised consumption (billed & unbilled)

Step 3 – Estimate commercial losses (water theft / fraud, meter under recording and data errors)

Step 4 – Calculate physical losses (bulk mains, distribution mains, reservoirs and customer service connections).

The different components of the water balance can be measured or calculated using a number of techniques. Ideally, all important components will be measured, but this is often not possible. Sometimes key data, such as total system input, are not known, so determining water balances can be inexact. However, a water balance, with elements based on estimates will allow the development of a list of improvement actions required to improve the accuracy of the water balance.

This approach is sometimes regarded as a "top-down" method for calculating non-revenue water and leakage.

9.2.2 Minimum night flow

To determine the level of leakage in an area the system operator needs to calculate the Net Night Flow (NNF), which is determined by subtracting the Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF). Because leakage from the pipes continues 24 hours a day, while customer demand is minimal at night, water operators should monitor leakage during the night.

The MNF is the lowest flow over a 24-hour period, which usually occurs at night when most consumers are inactive (note – when numerous feeds are used, this lowest flow is the lowest total of all feeds). Although customer demand is minimal at night, a small amount of legitimate night flow should be expected, i.e. night-time usage such as toilet flushing, washing machines, etc.

Ideally, LNF is calculated by measuring the hourly night flow for all commercial usage and a selection of domestic meters within the area. For systems without customer metering, water operators can approximate LNF based on estimated per capita night consumption. This can be done by undertaking a survey of all properties, both domestic and commercial and then determining the total number of connections per demand group (domestic, industrial, commercial etc.). Based on data from other areas with customer metering or expected figures, then a night-time flow rate can be estimated for each demand group.

Leakage is proportional to the pressure in the system. System pressures change over a 24-hour period. Pressure is proportional to flow due to frictional headlosses within the system. Therefore a pressure factor must be applied to the NNF to create a true 24 hour leakage rate.

This approach is often termed a "bottom-up" method for calculating leakage.

9.2.3 Infrastructure Leakage Index (ILI)

The ILI is the ratio between the current annual volume of physical losses (CAPL) and the minimum achievable annual volume of physical losses (MAAPL).

The output of the ILI calculation is a figure which can be used to benchmark the area or distribution system against a matrix to direct network development and active leakage control.

As this measure is a ratio, it is more commonly used as a network efficiency indicator. Although this is not the only indicator of its type, it is recommended by the IWA.

9.3 Leakage detection methods

9.3.1 Network monitoring

Network monitoring is the permanent deployment of loggers across the water distribution network where flow or pressure is being monitored. These loggers continuously collect flow and pressure data which can be retrieved to a central control centre by meter readers, radio transmissions or automated meter reading solutions.

Some loggers have the capability to automatically send leak alarms to designated phone numbers. Other systems have an alarm capability in the central control centre when the data is retrieved, validated and analysed. These alarms are usually based on:

- Jumps in flow;
- A dramatic reduction in pressure; and
- A gradual increase in flow above a pre-determined level.

Network monitoring provides the first indication that leakage levels are rising to a point where intervention is required or a burst has happened on the network.

9.3.2 Surveying

"Surveying" is the term applied to searching an area for water leaks. Every available fitting (hydrant, valve etc.) and service line is a potential location to identify the sound of water leaks.

Typical methods for leakage surveying are set out in the sections below.

9.3.2.1 Leak noise logging

Leak noise loggers are deployed with each logger placed on a hydrant, meter or other pipe fitting. The loggers listen for the sound of water escaping from pipes when background noise is at a minimum, typically at night. This data can then be transmitted to a passing patrol vehicle or downloaded off the logger upon collection. Noise loggers are considerably more sensitive than the human ear. Noises that are suspected of being caused by leaks are confirmed and located using other location methodologies.

More advanced models of leak noise loggers are also capable of pinpointing the exact location of identified leaks using correlation and cross-correlation techniques between loggers.

Methods of use include:

- Lift and shift – loggers are deployed in an area selected for leakage detection. The loggers are surveyed and areas of interest followed up. After repair of the identified leaks, 1-2 more surveys may be undertaken, depending on the night flow rates into the area.
- Permanent deployment – areas with persistent high levels of leakage or repeated bursts have loggers permanently deployed throughout the area. When flow rates jump indicating a burst or rise above the intervention level, a survey is undertaken to locate areas of interest for further investigation.

9.3.2.2 Listening sticks

Traditional listening sticks for detecting water leaks rely on the user's hearing. Listening sticks are typically inexpensive, comprising a simple wood or metal rod with an earpiece to amplify sounds. This means that the experience and skill of the operator is paramount and typically users are only able to detect leaks that produce loud noises.

9.3.2.3 STEP testing

Step testing is a proven methodology that allows the localisation of water loss within a zoned distribution system. It works by measuring the flow of water into a zone as valves are shut off in sequence. Additional valves may be installed before the test is undertaken to improve the effectiveness of the operation.

Step testing is conducted at night, when water consumption is at a minimum, both for ease of operations as well as the lack of disturbance to occupants. The targeted area is subdivided by the systematic closing of valves during this period of minimum night flow.

The various valve operations are accurately timed, as is the rate of flow through the water meter and the data is analysed to determine the sections of suspected leakage.

Leak pinpointing can then be carried out in the section identified as having high night flows.

9.3.2.4 Drop testing

When testing for leakage it is often worthwhile to check the water-tightness of storage tanks and reservoirs on the pipe system.

There are 2 main methods for understanding storage losses:

- Water meters can be installed to provide an easy check of inflow versus outflow volumes. This method can be improved by use of water level monitoring so the change in storage volume can be assessed against the overall inflow / outflow volume.
- The inflow and outflow from the tank or reservoir can be closed for a period of a few hours to a day (depending on the system supply arrangements). The water level is measured at the start and end of the period and any change can be attributed to storage losses.

Where reservoirs are identified to be leaking, a detailed survey will usually find areas spots for further remedial work to stop this water loss.

9.3.3 Pinpointing

After a potential leak has been identified using leak localisation techniques, the next step for the leakage team is to identify the precise location of the leak.

Digging holes that don't expose the leak (known as dry holes) can be a very costly and time consuming process, and effective methods for pinpointing leaks will keep these to the minimum.

9.3.3.1 Listening sticks and acoustic microphones

Acoustic Microphones are used to detect and amplify the noise created by water escaping from buried pipes under pressure. The two basic options to use as microphone are the listening stick (to search for leaks on fittings) or the ground microphone (to search for leaks along lengths of pipeline).

They are an essential part of a leak detection team's operating equipment and are used to easily pinpoint exact locations of suspected leaks. As part of an Intelligent Water Loss Management process, Acoustic Microphones are used to validate already pinpointed leak locations.

9.3.3.2 Leak noise correlation

Correlators are electronic devices used to locate leaks on pressurised pipes, where the rough location of the leak is unknown and the distances relatively high. Two (or more) sensors are placed in contact with the pipe (or pipe fittings) on either side of the suspected leak. These sensors record and transmit the leak noise to the main processing unit. This unit uses mathematical algorithms to determine the exact location of certain noise profiles (e.g. a hissing leak sound) on the pipe, by correlating the noises that reach both sensors and measuring the difference it takes to travel on the pipe from the leak location to each sensor. The effectiveness of this process is dependent on the strength of the leak noise and the sound conductivity of the pipe material.

9.4 Customer side leakage

As seen recently in Avana there will be issues with leakage on the private pipework once the water system renewals have been completed. Much of this pipework is old and its condition is unknown. This issue has occurred as a result of the Project City upgrade (Cook Islands News, 2013).

9.4.1 Understanding demand and customer side leakage

Metering trials and assessments of consumption to date ((ADB, 2009)) would appear to have been for total consumption and was not broken down into its constituent parts.

The BRANZ End-User survey (Heinrich M. &., 2010) determined the following breakdown in water use for homes in Auckland. However, similar patterns of use would have to be verified for the Cook Island communities. Key findings from the study were the discovery of large leaks on customer pipes and increases in water for garden irrigation during the summer period (about 17% of total summer demand).

Table 24 BRANZ End-User survey breakdown in water use for homes

	All uses		Indoor uses	
Usage	Dry	Wet	Dry	Wet
Tap	12%	16%	15%	18%
Shower	25%	30%	31%	32%
Washing machine	23%	24%	27%	27%
Toilet	18%	19%	23%	20%
Dishwasher	1%	1%	2%	1%
Bathtub	2%	1%	1%	1%
Misc	0%	1%	0%	1%
Total indoor	80%	92%		
Outdoor	7%	6%		
Leaks	4%	2%		
Total	100%	100%	100%	100%

* Note: Due to rounding, columns may not add to 100%

It would be recommended to undertake an end use survey of domestic properties to understand where and how water is being used, indoors and outdoors, across a representative group of domestic properties across the island. A similar survey of commercial users could also be undertaken. This would help target water efficiency messages and programmes.

9.4.2 Locating customer side leakage

Leaks on the customer side of the meter can be difficult and time consuming to identify. A range of equipment designed primarily to identify customer side leakage is available.

9.4.2.1 Leak-Finder

Leak-Finder is a tool designed to accurately locate leaks on customer supply pipes. It works by isolating and pressure testing sections of pipe. The base unit identifies whether the section is holding pressure, so therefore confirms a leak is present if not.

To operate, Leak-Finder is connected to an open pipe end or pipe fitting and its hose reeled in to the pipe. A bladder is inflated to block a chosen section, which is then pressurised. The bladder is easily deflated and moved, to change the section under test and to accurately pinpoint the leak. The built in tracing line enables accurate tracing of the line of the pipe to the leak.

The Leak-Finder is designed to work on all smooth bore pipes with an internal diameter up to 50mm – it can therefore be used on other small pipes or domestic pipes.

9.4.2.2 Leak Frog

The Leak Frog is a low cost monitoring device that allows customer side leakage to be identified by monitoring the minimum flow rate. The unit connects to a pulsed water meter and shows the maximum time interval between pulses (ie, the time taken to pass a unit of water). The device is usually reviewed for data overnight to minimise usage and identify unexpected water usage that is likely to be caused by leaks.

9.4.2.3 RD542 Handheld Leak Detector

The RD542 is a small hand held acoustic noise detector. The device identifies noises on pipework and displays a noise level indication on its screen. The device amplifies the noises created by leaks, so an operator can attach headphones to confirm if the sound is a leak. The RD542 is supplied with test rods which allows readings to be taken from hard-to-reach locations.

9.4.3 Case studies

9.4.3.1 United Kingdom

Water companies in the UK have had a duty to promote the efficient use of water by all their customers. The UK water regulator (OFWAT) states that:

As a minimum we expect all companies to provide information to customers about:

- *the sensible use of water in the home and garden*
- *how to conduct a self-audit of household consumption*
- *the availability of cistern and other water saving devices*
- *the availability of supply pipe leakage detection/repair*
- *how to report a leak*
- *how to get further information*

However, we expect companies in areas of water stress to do more than this minimum level.

Severn Trent Water

The Severn Trent Water website gives advice about protecting pipes and how to report a leak. The site provides contact details to provide advice and gives details about how to find a local plumber.

Severn Trent Water provides a free, non-emergency, repair service for straightforward leaks on service pipes. Where the pipe has burst more than twice in the previous 2 years, the owner will need to replace the pipe.

Severn Trent Water grants a leakage allowance where the leak occurs on a customer’s external pipework, on a ‘once only’ basis. If another leak occurs, the customer is not able to claim again. The allowance results in an adjustment to the customer’s bill.

Southern Water

The Southern Water website outlines steps customers should take to determine where the leak is, what help is available and how to report a leak. The website also gives details about how to find a local plumber and how to fix a leaking tap, as well as water efficiency guidance.

Southern Water will make up to 3 repairs to the customer supply pipe free of charge (between the property boundary and the internal stop tap). Where the pipe is in a poor condition, the recommendation will be to replace the whole supply pipe – Southern Water will replace up to 10m of leaking lead piping free of charge.

If the leak is repaired within a reasonable time, any additional charges arising from the leak will be removed from the customer’s bill.

Legal background

With leakage being a high profile performance indicator, water companies are keen to ensure that all sources of leaks are identified and repaired as quickly as possible (particularly on unmetered domestic properties). Upon identification of a leak on private property, most water suppliers will negotiate with the property owner to ensure the repair is completed as soon as possible. These negotiations will include incentives such as:

- Free repairs on the supply pipe between the property boundary and where the pipe enters the property;
- A subsidised replacement of the private supply pipe; and
- Free repairs to toilet cisterns and overflowing water tanks.

Should the above incentives fail to encourage the owner to repair the leak, UK water companies have limited opportunities to disconnect users as water is regarded as a basic need. However, under the Water Act (2003), it is an offence to waste, misuse or make undue consumption of water. Therefore water companies are required to enforce a legal process to obtain a court order to gain entry to repair the leak.

9.4.3.2 New Zealand

Capacity Water Services (Hutt City Council and Wellington City Council)

Capacity monitors daily usage from zones across the cities and when usage trends upwards undertakes leak detection surveys. If a private leak is located, the leak detection contractor sends the property owner a letter. This letter advises where to look for obvious leaks (e.g. leaking taps, overflowing toilet cisterns or tanks, continuous flow into toilet pan etc.) and how under council bylaws the property owner is responsible for maintaining their water service pipe and fittings from the point of supply into their property.

Capacity often asks their leak detection crews to provide some assistance in helping owners locate leaks if required (approx. 1/2hr). No other customer incentives are offered.

Christchurch City Council

Christchurch City Council conducts water surveys across its network and upon identifying high customer usage, issues a letter to the owner notifying them of this. The letter sets out the cause could be leakage, provides a list of indicators of water leaks or unplanned water such as:

- Water leaking out of a hot water cylinder (may create steam in cold weather);
- A leaking toilet overflow pipe (usually a pipe through a wall);
- Continuous dripping or running taps;
- Garden irrigation system taps not fully turned off;
- If your water meter continues to turn when you have zero water usage; and
- A puddle or damp area on a lawn or garden bed which never dries out.

The letter also includes a pamphlet to assist in reading the meter and identifying leaks on the property.

Where the leak is over 1 litre per minute, the letter also indicates that the owner has 10 days to complete the repair and notify the council.

Christchurch City Council does not offer any customer incentives.

9.5 Recommendations for non-revenue water

In order to develop a sustainable potable water supply system, non-revenue water and customer demand should be managed and reduced. From the initial review of non-revenue water practice, AECOM recommends the following actions as a high priority:

- Establish a water balance for the Rarotonga water supply network.
  - Determine the target economic level of leakage / ILI for the Rarotonga water supply network, confirming that the 10% target is an achievable and economic long term target.
- Create district metered areas / supply zones to enable MNF leakage calculations to be undertaken.
- Undertake regular analysis of the data collected from above, to understand leakage levels.
- Purchase leakage control equipment to locate and pinpoint leaks on mains and private supply pipes.
- Target active leakage investigations and control measures at areas of highest leakage.
- Commence a programme for customer side leakage:
  - Benchmark customer usage based on meter data.
    - A process should be developed to allow customers with high usage to have letters issued warning of the possibility of leakage on their property.
    - A process should be developed to allow customers with low / no flows to be programmed for investigation of meter under registration or a potential illegal connection.
  - Carry out a programme to raise the awareness of volumes of water lost through private leakage (internal and external) and water efficiency measures.

- Initiate a free repair programme for supply pipe leaks.
- Engage local plumbers to provide assistance to customers in the location and repair of internal leaks. This is likely to be limited to a set number of hour's work, with materials etc. being the responsibility of the property owner.
- Provide free washers and advice on how to repair dripping taps.

- Illegal connections could be regulated through policy, regulation, byelaws and policing of the water system. It would be recommended that a policy be developed to manage illegal connections. Examples include warnings or fines for illegal connections, reporting of suspected illegal connections by the community.

10.0 Other projects and further work

While the projects identified through previous studies and the Te Mato Vai project will make up a large component of the expenditure identified in the water Master Plan, there are a number of additional components to be included to complete the upgrade of the water supply system. These are:

- Groundwater management. Work will need to be undertaken to ensure the management of the groundwater resources in Rarotonga. This will include legislation and studies to confirm the extent of the aquifers. This has now been integrated into investigations being undertaken by WATSAN to determine the extent of groundwater resources and the long term sustainable yield of this resource.
- Backflow prevention. At the end of 2016, the water supply on Rarotonga will be of a potable standard. To ensure that public health is maintained, it will be important to protect the system from contamination and an important part of this is backflow prevention. This will include legislation and installation of devices on customer supplies
- Non-revenue water management. Projects have been identified to allow for the location and repairs of customers leaks.
- SCADA will be required to control the PRV's and the treatment stations. A scoping study should be prepared to review the level of monitoring required, the level of control and the communications mediums.
- Boosters: It is proposed to install small booster at the high elevations where the model shows the pressure below 10m. These should be reviewed and revised as this has been derived from the model demand allocation.

11.0 Cost estimates

An important part of the Master Plan for Rarotonga is to review the cost estimates for the project, the hydraulic modelling exercise has produced sizes of pipes and other infrastructure. These will be used as the basis for the cost estimates.

The Master Plan has identified a high level cost estimate for the Te Mato Vai water supply project. I

11.1 Cost estimating

When cost estimating it is important to classify the estimate according to its accuracy range. AECOM uses five estimate classes, each class being purposely aligned to standard project life cycle development phases. Estimate accuracy is a measure of confidence in the final cost outcome for a given project being within a range expressed as a ± percentage range around a central cost estimate number.

Cost estimate accuracy is dependent on the quality and maturity of the variables available to develop an estimate. Estimate accuracy is able to be improved in parallel with the development of these variables, which include such things as project scope, design development and site specific data.

Accuracy is to be applied only after contingency is included within the central cost estimate. Contingency is a calculated allowance based upon an assessment of “known unknowns” generally using risk management principles. Contingency is not the same as accuracy in cost estimating.

The key control variables for cost estimate accuracy include:

- Level of scope definition – this is the primary determinant;
- Reliability and quality of pricing sources – supply and install components;
- Project implementation plan including procurement strategy and master development schedule;
- Available time, skill and resources to prepare the estimate; and
- Available time for appropriate quality of quotations from vendors and contractors.

11.1.1 Estimate classes

All cost estimates shall be described as one of the following estimate classes:

- ***Class 5 (Conceptual):*** intended level of accuracy ± 50%. Based on limited project scope definition. Generally used to determine indicative end cost values for comparison of scope or delivery method options and for initial evaluation of project economic viability. Also used for long range planning and project screening.
- ***Class 4 (Pre-Feasibility Estimate):*** intended level of accuracy ± 25%. Based on preliminary engineered project definition where the driving components of the scope are definable in terms of capacity and quantity. Used to determine indicative end costs for pre-feasibility studies, strategic planning; budget approvals and confirm project economic viability.
- ***Class 3 (Feasibility Estimate / Preliminary Design):*** intended level of accuracy ± 15%. Based on a detailed level of project documentation of both scope and project delivery methodology and where meaningful budget quotations of contractor / vendor pricing may be sourced. Represents the minimum standard for client funding requests and bankable feasibility studies.
- ***Class 2 (Detailed Estimate / detailed design):*** intended level of accuracy ± 10%. Based on a detailed level of project documentation where the majority of commitments have been formally tendered or already in place. Generally used to determine final cost control baseline, supplier negotiation support, claims and dispute resolution.
- ***Class 1 (Construction Estimate):*** intended level of accuracy ± 5%. Based on a highly detailed level of project

These accuracy classes are shown in Figure 32 with a degree of accuracy of the estimate class.

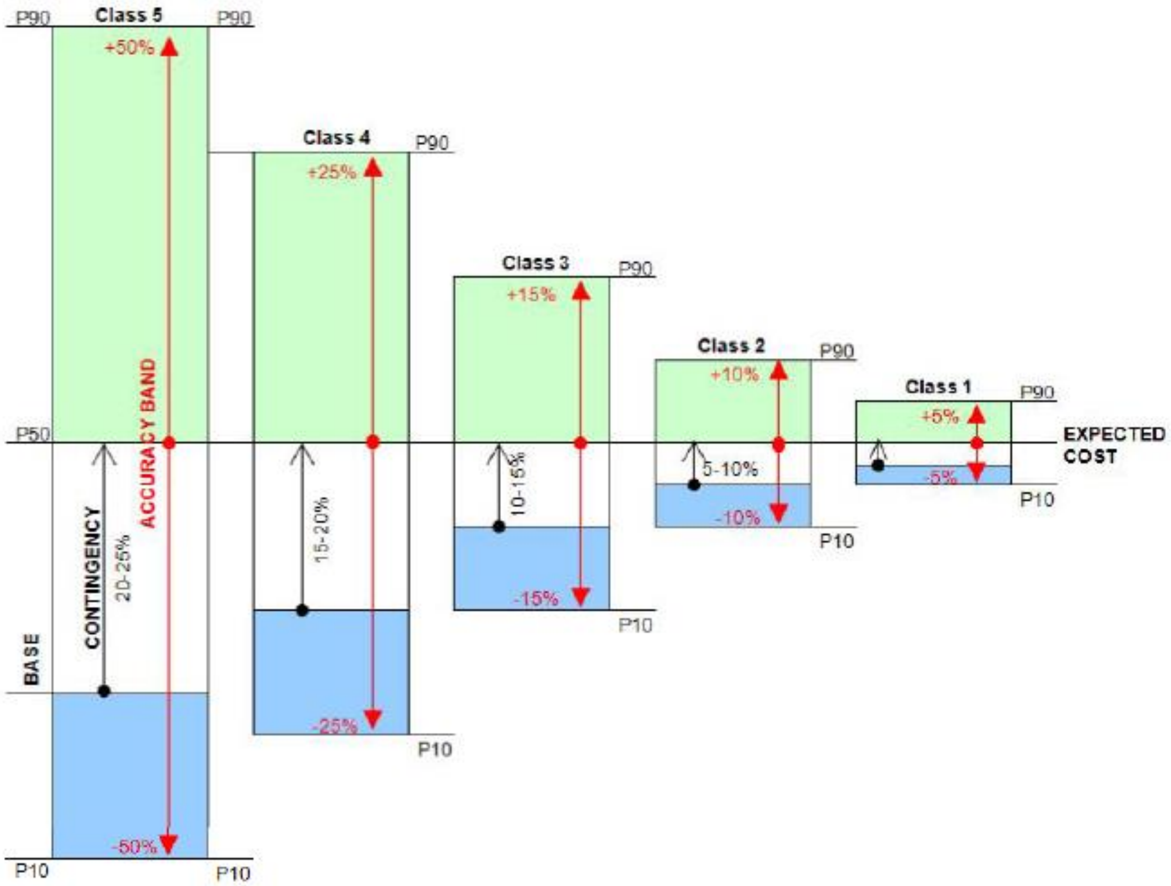


Figure 32 Accuracy bands for estimate classes

Figure 32 demonstrates symmetry around the expected cost value as scope is progressively defined.

Further definition and explanation of these estimate classes is provided in Table 25.

Table 25 Estimate class

Estimate Class	5	4	3	2	1
Name	Conceptual	Prefeasibility	Preliminary Design	Detailed Design	Construction
Expected Accuracy Range	± 50%	± 25%	± 15%	± 10%	± 5%
Usage	- Indicative costs - Comparison of options - Early economic viability - Long range planning	- Pre-feasibility studies - Strategic planning - Budget approval - Economic viability	- Feasibility Studies - Client funding - Bankable Feasibility Studies - Bidding	- Cost control - Final baseline - Bidding - Bid checking - Supplier negotiation - Claims & Dispute support	- Owner's estimate check - Subcontractor's bid - New baseline for cost control / schedule - Evaluate and / or dispute claims

At a master planning level the estimate will be a class 5 / class 4 estimate with some components being more developed and certain i.e. the pipes, whereas the treatment plants at this stage their scope is less defined.

11.2 Project development and associated costs

When estimating the projects it is advisable to allow for other project costs and associated costs that include items such as studies, investigations, design and construction monitoring. The approach that is proposed for this project is contained within the following table (Table 26) and is based upon experience of producing Master Plans. These items are based upon a percentage of the construction value of the project.

Table 26 Project development and associated costs

Other Costs	Percentage of Construction Value	Description of Costs in Relation to Te Mato Vai
Studies	1.0%	Master plan, environmental assessment and further planning studies.
Geotechnical Investigation	2.0%	Trial pits, soil testing, desk top study
Client Costs Design	5.0%	Project Management Unit, WATSAN and MFEM costs related to project, will also include legal and communications costs.
Design	6.0%	Design consultant's fees, includes preliminary design, detailed design and tendering. (ACENZ, 2004)
Client Costs Construction	5.0%	Project Management Unit, WATSAN and MFEM costs related to project, will also include legal and communications costs.
Construction Monitoring	3.0%	This cost is to monitor the contractor's progress. Based upon ACENZ for CM 3 level of monitoring. (ACENZ, 2004).
Contract Administration	3.0%	For processing payments and administering the contract.
Contingency	10.0%	To allow for unforeseen conditions.

11.3 Watermain unit rates

Standard rates for watermain construction can be used from other parts of the world; however it is important that the rates reflect the conditions in Rarotonga, which will include the local labour and the cost of importing the pipes and fittings.

Unit rates have been reviewed and assessed for the provision of a construction cost that includes all costs associated with the provision of assets:

Construction and commissioning costs:

- Reinstatement costs.

The construction rates used are derived from the following sources:

- The material supply tender for Project City, supplied to AECOM by MOIP; and
- The latest actual Engineers costs for the construction.

The rates are generated by analysing the cost components for the installation, including the costs of all pipes / fittings and apportioning provisional and general costs across all installed assets.

The rates assume "brownfields" conditions for construction. That is all other services exist and it is necessary in defining construction rates to expect reinstatement of other assets or services if affected by the installation of the infrastructure asset. It is assumed that all existing pipes will not be removed when they are replaced. The rates exclude Goods and Services Tax.

Part of the scope for renewing the trunk lines includes the construction of roads to the sources. Following discussions with MOIP it was determined that these did not have to be tar sealed roads, but hard fill only. These results are presented in Table 27.

Table 27 Watermain unit rates

Pipe Dia (mm)	Trench Width (mm)	Depth (mm)	Trench Volume (m^3)	Excavation Cost ($/m)	Material Cost ($/m)	Install Cost ($/m)	Total in Berm ($/m)	Road Reinstatement ($/m)	Total in Road ($/m)
63	450	915	0.41	107.5	30.00	5	142.0	109	251
90	450	915	0.41	107.5	53.77	8	169.4	109	279
110	600	935	0.56	146.5	73.26	11	230.8	125	356
125	600	950	0.57	148.9	74.44	11	234.5	125	359
160	600	985	0.59	154.4	77.18	12	243.1	125	368
180	600	1005	0.60	157.5	78.75	12	248.0	125	373
200	600	1025	0.62	160.6	80.31	12	253.0	125	378
225	625	1050	0.66	171.4	85.70	13	270.0	128	398
250	650	1075	0.70	182.5	91.25	14	287.4	130	418
280	680	1105	0.75	196.3	98.13	15	309.1	133	442
315	715	1140	0.82	212.9	106.44	16	335.3	137	472
355	755	1180	0.89	232.7	116.34	17	366.5	141	508
400	800	1225	0.98	256.0	127.98	19	403.1	146	549

From the cost analysis for Project City, an assessment has been made of the road construction; this has been based on a 4m width of road and is estimated at $120/m of road.

11.4 Reservoir unit rates

AECOM undertook research into different types of reservoir construction and three material types were considered: timber tanks, steel tanks and concrete tanks. A high level comparison was undertaken based upon a $ rate per m^3. The comparison is shown in Table 28.

Table 28 Comparative costs for reservoir construction

Material	Cost per m^3
Timber	$200
Steel	$350
Concrete	$500

The steel tanks have an approximate 50% premium over the timber tanks and the concrete tanks have a 150% premium over the timber tanks. Following this assessment, timber tank costs have been used as the basis of the estimate.

The manufacturer of the timber tanks supplied a quotation for different sizes of tanks which include shipping and assembly in Rarotonga. These do provide some advantages, they can be manufactured in New Zealand and shipped over in a 'flat pack format' and once the sites have been cleared and bases constructed they can be erected in two weeks. Allowances have been made in the estimates provided for construction of the hardfill bases and site clearance. These are contained in Table 29.

Table 29 Reservoir unit rates

Volume (m^3)	Height (m)	Diameter (m)	Area (m^2)	Cost ($)
150	4.2	6.9	37.39	$130,000
300	4.6	9.45	70.14	$190,000
400	4.4	11.17	97.99	$210,000
1,500	6.4	18.05	255.88	$400,000
2,500	6.5	23.2	422.73	$590,000

11.5 Water treatment unit rates

AECOM reviewed the water treatment unit processes and distribution system infrastructure and operations strategies to provide and maintain drinking water quality in the Rarotonga water supply system.

To provide safe drinking water to the Rarotonga Island, a number of recommendations are presented in Section 8.0 for the minimum and optimum levels of treatment. These recommendations are based on a multiple-barrier approach to protecting public health consisting of particulate removal and disinfection. Accompanying the treatment processes are storage recommendations and distribution system monitoring recommendations that will assist in protecting the treated product water. The treatment processes presented were selected so that safe drinking water could be conveyed throughout the island during both low rainfall periods as well as during storm events.

Pricing and equipment information is provided here based on quotes supplied directly from suppliers in either $AUD or $US. These have then been converted to $NZ, excluding shipping, tax, and building costs. In our project costing calculations, we have applied an additional 30% allowance to cover these excluded costs.

Table 30 High-level cost rates (+/- 50 percent) for Metaval screen filters

Unit Model	Cost ($AUD)[1]	Cost ($NZ)[1]
FMA 5000	$71,000	$85,200
FMA 2014	$32,000	$38,400
FMA 2010	$22,000	$26,400

[1] Taxes and delivery not included

The expected cost for the installation of the Hydranautics MAX 80 membrane systems is $100,000 for each system.

Pricing and availability for UV disinfection equipment has been provided by Aquatec-Maxcon for the Trojan UVSwiftSC reactor. Pricing and equipment information is provided here (all prices have been quoted in $AUD, and converted to $NZ, excluding shipping, tax, and building costs):

- UV reactor: Trojan UVSwiftSC D03 System, $40,700 (NZ$48,900) each;
- SCADA Communication (Modbus RS485), $960 (NZ$1,160) for each reactor; and
- Replacement lamps, $350 (NZ$420) each.

The pricing for the HACH CL17 Chlorine Analyser for free chlorine is approximately $7,800 AUD (NZ$9,400) – this does not include taxes, shipping, installation, or cost for protective cabinet.

11.5.1 Proposed treatment system costs

Table 31 below outlines the difference in base construction cost estimate for the minimum treatment against the additional costs required for the optimum treatment option.

Table 31 Minimum system vs optimum system treatment costs

Treatment Plant	Minimum System costs (NZ$)	Optimum System Costs (NZ$)
Avana	$436,690+	$198,536
Avatiu	$90,149	$112,275
Matavera	$72,209	$130,215
Muriavai	$72,209	$130,215
Ngatoe	$90,149	$268,502
Papua	$90,149	$268,502
Rutaki	$72,209	$130,215
Taipara	$90,149	$268,502
Takuvaine	$90,149	$112,275
Totokoitu	$72,209	$130,215
Tupapa	$72,209	$130,215
Turangi	$90,149	$268,502
Total	**$1,338,623**	**$2,148,166**

Note: The optimum system costs assume certain elements of the minimum system are no longer required, so not installed.

+ It has been assumed that the sodium hypochlorite plant will be installed at Avana for the purposes of calculating the treatment system costs.

11.6 Intake costs

Part of the project is to refurbish / reconstruction of the water intakes and new screens to prevent debris entering the system. The level of rehabilitation required for each intake will be confirmed at the detailed design phase, but it has been assumed that all intakes will require extensive works. From the analysis of the Takuvaine intake it is estimated this base construction cost is $120,000.

11.7 Water meters and other infrastructure costs

As part of the Te Mato Vai project, water meters will be fitted to all properties to monitor usage, calculate water losses and encourage the efficient use of water.

From analysing the Project City costs an estimate of $700 per unit will be used.

Due to the risk of contamination of the system due to backflow, it was envisaged that 20% of commercial and agricultural connections would have reduced pressure zone (RPZ) devices to prevent this. From discussions with a water supplier in New Zealand it is estimated that these will cost $2,000 per unit to install.

Other costs included in the project are:

- Pressure reducing valves (PRV) to regulate the demand from the 12 intakes and these are $30,000 each;
- Booster pumps an allowance of $150,000 for the installation of small booster pumps to boost the pressures on high elevation areas;
- Customer side leakage, an allowance of $1,000,000 has been included over 5 years. This will cover the purchase of equipment to detect the leaks, allow funding to assist consumers with the repair of leaking pipework and the repair of leaking taps and cisterns.

12.0 Identified Projects for Te Mato Vai

Through hydraulic analysis and after consultation with the different stakeholder groups of Te Mato Vai AECOM has identified the 64 projects set out in Table 32 as part of the renewal and upgrade of Rarotonga's water distribution network. Identified projects include the ringmain upgrades proposed by CCECC and subsequent network upgrade projects as follows:

- All of Rarotonga's intakes and trunkmains have been recommended for refurbishment and replacement with the exception of the Takuvaine intake which was completed as part of the project city upgrades.
- Treatment works and storage reservoirs are required at each of the 12 intakes.
- The installation of PRVs on the intake lines, flow meters and backflow prevention devices is recommended to facilitate effective management of the network.

A number of smaller and peripheral projects have been identified including:

- Detailed investigation into Rarotonga's groundwater resources. This has now been integrated into investigations being undertaken by WATSAN under the Integrated Water Resources Management programme to determine the extent of groundwater resources and the long term sustainable yield of this resource;
- The installation of local booster pumps to supply properties with low pressure over 30m above mean sea level;
- Initiatives to address customer side leakage across Rarotonga; and
- The implementation of supervisory control and data acquisition systems.

Refer to drawing 60303623_00_012_01 in Appendix E for an indication of project locations.

Table 32 Te Mato Vai projects summary

Project Number	Project Name	Project Type	Total Project Cost ($NZ)
Avatui			
1	Avatiu Trunkmain Replacement	Trunkmains	1,603,000
2	Avatiu WTP	Treatment Plant	123,000
3	Avatiu Storage Reservoirs	Water Storage	593,000
4	Avatiu Inlet Refurbishment	Inlet Refurbishment	162,000
5	Avatiu PRV	PRV	42,000
Sub-total			**2,523,000**
Takavaine			
6	Takuvaine Storage Reservoirs	Water Storage	1,350,000
7	Takuvaine WTP	Treatment Plant	123,000
8	Takuvaine PRV	PRV	42,000
Sub-total			**1,515,000**

Project Number	Project Name	Project Type	Total Project Cost ($NZ)
Tupapa			
9	Tupapa Trunkmain Replacement	Trunkmains	1,165,000
10	Tupapa WTP	Treatment Plant	97,000
11	Tupapa Storage Reservoirs	Water Storage	837,000
12	Tupapa Inlet Refurbishment	Inlet Refurbishment	162,000
13	Tupapa PRV	PRV	42,000
Sub-total			2,303,000
Matavera			
14	Matavera Trunkmain Replacement	Trunkmains	1,009,000
15	Matavera WTP	Treatment Plant	97,000
16	Matavera Storage Reservoirs	Water Storage	593,000
17	Matavera Inlet Refurbishment	Inlet Refurbishment	162,000
18	Matavera PRV	PRV	42,000
Sub-total			1,903,000
Turangi			
19	Turangi Trunkmain Replacement	Trunkmains	1,022,000
20	Turangi WTP	Treatment Plant	123,000
21	Turangi Storage Reservoirs	Water Storage	3,672,000
22	Turangi Inlet Refurbishment	Inlet Refurbishment	162,000
23	Turangi PRV	PRV	42,000
Sub-total			5,021,000
Avana			
24	Avana Trunkmain Replacement	Trunkmains	2,574,000
25	Avana WTP	Treatment Plant	458,000
26	Avana Storage Reservoirs	Water Storage	3,672,000
27	Avana Inlet Refurbishment	Inlet Refurbishment	162,000
28	Avana PRV	PRV	42,000
Sub-total			6,908,000
Totokoitu			
29	Totokoitu Trunkmain Replacement	Trunkmains	515,000
30	Totokoitu WTP	Treatment Plant	97,000
31	Totokoitu Storage Reservoirs	Water Storage	243,000
32	Totokoitu Inlet Refurbishment	Inlet Refurbishment	162,000
33	Totokoitu PRV	PRV	42,000
Sub-total			1,059,000

Project Number	Project Name	Project Type	Total Project Cost ($NZ)
Taipara			
34	Taipara Trunkmain Replacement	Trunkmains	549,000
35	Taipara WTP	Treatment Plant	123,000
36	Taipara Storage Reservoirs	Water Storage	1,350,000
37	Taipara Inlet Refurbishment	Inlet Refurbishment	162,000
38	Taipara PRV	PRV	42,000
Sub-total			2,226,000
Papua			
39	Papua Trunkmain Replacement	Trunkmains	577,000
40	Papua WTP	Treatment Plant	123,000
41	Papua Storage Reservoirs	Water Storage	540,000
42	Papua Inlet Refurbishment	Inlet Refurbishment	162,000
43	Papua PRV	PRV	42,000
Sub-total			1,444,000
Ngatoe			
44	Ngatoe Trunkmain Replacement	Trunkmains	679,000
45	Ngatoe WTP	Treatment Plant	123,000
46	Ngatoe Storage Reservoirs	Water Storage	217,000
47	Ngatoe Inlet Refurbishment	Inlet Refurbishment	162,000
48	Ngatoe PRV	PRV	42,000
Sub-total			1,223,000
Rutaki			
49	Rutaki Trunkmain Replacement	Trunkmains	689,000
50	Rutaki WTP	Treatment Plant	97,000
51	Rutaki Storage Reservoirs	Water Storage	837,000
52	Rutaki Inlet Refurbishment	Inlet Refurbishment	162,000
53	Rutaki PRV	PRV	42,000
Sub-total			1,827,000
Muriavai			
54	Muriavai Trunkmain Replacement	Trunkmains	920,000
55	Muriavai WTP	Treatment Plant	97,000
56	Muriavai Storage Reservoirs	Water Storage	217,000
57	Muriavai Inlet Refurbishment	Inlet Refurbishment	162,000
58	Muriavai PRV	PRV	42,000
Sub-total			1,438,000

Project Number	Project Name	Project Type	Total Project Cost ($NZ)
Other Projects			
59	Ringmain	Ringmain	22,584,000
60	SCADA	Other	1,350,000
61	Water Meters and Backflow Installation	Meters and Backflow	4,251,000
62	Customer Side Leakage	Other	1,000,000
63	Ringmain Project Management (CCECC)	Ringmain	577,000
64	Local Booster Pumps	Other	205,000
Sub-total			29,967,000
Total			59,357,000

13.0 Staging and implementation plan

For a programme of work of this cost, scale and complexity it is important to phase the project, this is needed for the following reasons:

- Manage disruption;
- Resources; and
- Management of funds.

If additional flexibility for the delivery date is included, this may minimise the disruption caused by intensive island wide construction works and keep project costs down by removing the high demand for and increased workload on suitable contractors.

13.1 Current project funding

MFEM have published their funding requirements for the Te Mato Vai project which have been based upon previous estimates of the construction costs. These are presented in Table 33.

Table 33 MFEM Budgets

	$NZ				
Project	2012/13*	2013/14*	2014/15*	2015/16*	Total
TMV Contract administration and project management unit	-	$354,000	$1,302,000	$771,000	$2,427,000
TMV CIGov PM of CCECC (Local administration fee)	-	$200,000	$200,000	$177,000	$577,000
TMV Master plan, studies and project oversight	$250,000	$533,000	$450,000	-	$1,233,000
TMV Remaining Tupapa to Aquarius watermains and roads (PRC) including design and project management	-	$5,591,000	$11,182,000	$3,574,000	$20,347,000
TMV Intakes (Reservoirs and slow sand filtration)	-	-	$6,399,000	$6,398,000	$12,797,000
TMV Treatment	-	-	$500,000	$499,000	$999,000
TMV Rarotonga water tanks	$250,000	$1,000,000	$1,000,000	$750,000	$3,000,000
TMV Storage, rehabilitate existing / new water storage capacity	-	-	$784,000	$783,000	$1,567,000
TMV Trunk (Link to water treatment to distribution)	-	-	$3,305,000	$3,304,000	$6,609,000
TMV meters	-	-	-	$169,000	$169,000
	$500,000	$7,678,000	$25,122,000	$16,425,000	$49,725,000

*The budget years in the Cook Islands run from the 1st of July to the 30th June.

13.2 Estimates of project costs

The components of the project have all been estimated and cost estimate calculation sheets have been included in Appendix F along with a summary by project.

In the estimating procedure and design the following was assumed:

- There is no refurbishment of the existing storage due to the expense of refurbishing these;
- Kia Orana is demolished and the new storage is installed at this site; and
- There is no impact upon the project costs from the high demand for and increased workload on suitable contractors.

Maps of all of the projects are contained in Appendix E.

A summary of the estimates is shown in Table 34 with all the costs presented in 2013 $NZ. In producing the cost estimates, no allowance has been made for inflation.

Table 34 Summary of project costs (including all other costs)

Project type	Total Project Cost ($NZ)
Trunkmains	11,302,000
Treatment Plants - Minimum	1,681,000
Water Storage	14,121,000
Inlet Refurbishment	1,782,000
PRV	504,000
Meters and Backflow	4,251,000
Ringmain	23,161,000
Other	2,555,000
	59,357,000

The estimates produced above are a class 5 estimate and are plus or minus 50%. Further project definition and scoping will allow the accuracy of these estimates to be better defined.

These estimates exclude additional projects which were identified by the Water Partnership; these are:

- Additional storage at Takuvaine; due to the plentiful water supply at Takuvaine it is proposed to build another trunkline and tanks at the site of the existing tank to provide additional storage. This would capture surplus water and have it available in times of drought. In times of drought this would be pumped up to the treatment plant and put into supply. Funding for this scheme could be investigated through its potential for pumped storage for hydroelectric and use of the untreated water for irrigation. The cost of this scheme is approximately $3 million.
- Additional storage at Turangi; due to the plentiful water supply at Turangi it is proposed to build another trunkline and tanks near to the inner ringmain. This would capture surplus water and have it available in times of drought. In times of drought this would be pumped up to the treatment plant and put into supply. Funding for this scheme could be investigated through its potential for pumped storage for hydroelectric and use of the untreated water for irrigation. The cost of this scheme is approximately $3 million.

In addition to the minimum level of treatment included in the above summary of project costs, the costs to increase the treatment to the recommended optimum level are listed in Table 35. As final costings become clear through the detailed design phase and the need for all trunkmains to be upgraded is confirmed through hydraulic modelling and pressure testing, then installation of the optimum treatment may be able to be implemented.

Table 35 Te Mato Vai optimum treatment projects summary

Project Number	Project Name	Project Type	Total Project Cost ($NZ)
Optimum treatment			
2a	Avatiu WTP - Optimum	Treatment Plant - Optimum	151,000
7a	Takuvaine WTP - Optimum	Treatment Plant - Optimum	151,000
10a	Tupapa WTP - Optimum	Treatment Plant - Optimum	177,000
15a	Matavera WTP - Optimum	Treatment Plant - Optimum	177,000
20a	Turangi WTP - Optimum	Treatment Plant - Optimum	362,000
25a	Avana WTP - Optimum	Treatment Plant - Optimum	269,000
30a	Totokoitu WTP - Optimum	Treatment Plant - Optimum	177,000
35a	Taipara WTP - Optimum	Treatment Plant - Optimum	362,000
40a	Papua WTP - Optimum	Treatment Plant - Optimum	362,000
45a	Ngatoe WTP - Optimum	Treatment Plant - Optimum	362,000
50a	Rutaki WTP - Optimum	Treatment Plant - Optimum	177,000
55a	Muriavai WTP - Optimum	Treatment Plant - Optimum	177,000
Total			2,904,000

13.3 Project priority

The objective of Te Mato Vai is to supply safe, reliable potable water to all properties connected to the water network by 2016. Based on this, the first priority is to increase the reliability of supply. This will be achieved through the construction of the storage reservoirs at the intake sites. Furthermore, the first 4 storage reservoirs to be constructed should be at Avana, Turangi, Takuvaine and Taipara as per the recommendations from the hydraulic analysis.

The commissioning of the reservoirs is not dependent on the completion of the other proposed works. Therefore each reservoir can be commissioned after they have been constructed, providing a more reliable supply of water prior to 2016.

Following this the replacement of the trunkmains, ringmains and installation of PRV's would then further increase the reliability of supply and provide the required level of service for the supplied pressure.

The next priority would then be to provide a safe potable water supply. This would essentially be provided with the construction of the water treatment plants (WTP). However, before the WTP's are commissioned the replacement of the ringmains and trunkmains needs to be completed and ancillary fittings such as those preventing backflow will need to be installed to prevent the risk of contamination of the supply.

During the design and construction of the new water supply system, it is recommended that leakage control equipment is purchased to allow the location and pinpoint leaks on mains and private supply pipes. It is important that these identified leaks are repaired as soon as practicable to reduce the system demand in advance of the full commissioning of the new system. The active leakage investigations and control measures should be targeted at the areas of highest leakage and those areas serviced from the new reservoirs which will be brought on line first.

In order to further reduce the system demand, an information and awareness programme should be commenced to explain of volumes of water lost through private leakage (internal and external) and water efficiency measures.

Based on this project priority, the spend for the proposed works between 2013 and 2016 has been forecast. This can be seen in Table 36 below. It also shows the spend forecast beyond 2016 for the projects that are not considered as critical for meeting the immediate objective of Te Mato Vai.

Table 36 Forecast spend for proposed works

Component	Total Cost ($)	Cost ($)						
		2012/13	2013/14	2014/15	2015/16	2016/21	2021/26	2026/31
Investigation and studies	717,000	0	540,000	99,000	0	0	0	78,000
Design	1,369,000	0	956,000	255,000	48,000	0	0	111,000
Client costs	3,501,000	0	1,052,000	1,467,000	732,000	0	0	252,000
Construction	53,770,000	0	5,737,000	28,381,000	16,472,000	300,000	0	2,887,000
Total	59,357,000	0	8,285,000	30,202,000	17,252,000	300,000	0	3,328,000

13.4 Project timeline

An anticipated project timeline has been produced based on the project priority set out in the previous section. The project timeline can be found in Appendix G.

In order to produce the timeline some assumptions needed to be made on the procurement of works, the availability of crews and construction times. This section sets out the key assumptions made and goes through the proposed order of works.

13.4.1 Note on project priority and timeline

This Master Plan makes recommendations to meet the Government of the Cook Islands' commitment to supply reliable potable water to all properties connected to the water network by 2015 / 2016. It is understood that certain elements of the proposed system may be perceived as contentious and require additional community engagement and consultation before they are adopted and installed. The final decision regarding which elements of the Master Plan design are to be installed lies with the GoCI.

During the detailed design phase, the system should be designed to include all aspects included within this Master Plan, but allowing sufficient flexibility to allow elements to be removed as desired, whilst maintaining the ability to retrofit install them at a later date.

13.4.2 Assumptions for procurement of works

AECOM is not proposing the procurement strategy, but for the purpose of this program it is envisaged that the following process will take place:

- The client will shortlist consultants and contractors;
- The shortlisted consultants will be asked to price projects or packages of works:
  - Consultants will then be appointed for projects or packages of works; and
- The shortlisted contractors will be asked to price projects or packages of works:
  - Contractors will then be appointed for projects or packages of work.

13.4.3 Assumptions for design and construction

A preliminary design stage will be carried out for the storage reservoirs and treatment plants. This will be followed by a period of detailed design. It is assumed that the inlet structures, trunkmains and access roads will only have one design period – detailed design. It has been assumed that new trunkmains will be constructed as close to the existing alignment (preferably within 1 metre) as possible to minimise any land required.

Construction works will commence for packages of design work completed, whilst the detailed design of other packages of works is ongoing. Construction works is assumed to be carried out all year round and therefore not dependent on seasonal weather conditions. It is assumed that there will be the required availability of construction crews and plant for construction of reservoirs, WTP's, trunkmains and ringmains to occur during the same time. However, it has been assumed that only one reservoir project, one trunkmain project and one WTP project will occur at one time. This can be reviewed if it is felt more resources would be made available.

The following assumptions have been made for the rate of construction works:

- One crew of pipelayers can construct pipelines at an approximate rate of 30m per day;
- On average a WTP can be installed in 2 weeks once all enabling works are completed;
- Site clearance for storage reservoir sites is assumed to be 1 week for small areas and 2 weeks for larger areas; and
- The time to construct 1 to 2 storage tanks is 3 weeks and the time to construct 3 to 4 tanks is 6 weeks. These durations have been increased slightly for larger volume tanks.

For all domestic properties, a 20-25mm connection will be installed, whilst for most commercial properties a 50mm connection will be installed. Where larger connections are required, an application will be lodged, detailing the need for the larger size. These are designed and approved on a case by case basis, based on a number of factors, including:

- Peak demand (plus fire flows if required to service firefighting on site);
- Required pressure at the buildings; and
- Length of connection from the ring main.

13.4.4 Proposed order of works

To enable works to be completed within the time frame the client will need to issue Expressions of Interests for the design and construction by early 2014.

The construction of the ringmains will need to commence first as this has the longest duration for construction and the design has already been completed. Due to the length of the ringmains it has been assumed that 3 crews will be required to work on the construction at one time. This means that the installation rate for the ringmains is assumed to be 90m per day.

The next stage is the storage reservoirs. The construction of the storage reservoirs is considered a priority as they can be put in service to increase the reliability of supply before the 2016 deadline. The storage reservoirs would be a priority focus for design.

Once the design for the storage reservoirs is complete the focus can shift to the trunkmains. Construction of the trunkmains will commence whilst the construction of the storage reservoirs is still ongoing. The assumed pipeline installation rate for one crew has been utilised in the program. It has also been assumed that only one trunkmain construction project will be carried out at a time. At five sites, Matavera, Ngatoe, Rutaki, Tupapa and Turangi, due to the relative young age of the trunkmains it has not been considered necessary to replace the trunkmains prior to 2016. They have been programmed in to be replaced, with completion due by 2031, however it is recommended that pressure testing (or similar) is undertaken in addition to hydraulic modelling for the recommended upgrade of the trunkmain size to ascertain the optimum replacement date. This hydraulic modelling will also include a review of the use of groundwater resources and updated system demand. However, the installation of PRVs and construction of access roads has been included as part of the works to be carried out by 2016. This has been programmed in with the construction of the associated storage reservoirs.

Access road construction is required as a permanent access to the intake sites. To optimise the programme of works the access road construction has been tied in with the either construction of the associated trunkmain or associated reservoir works. It has been assumed to take approximately 3 weeks for the construction of 1km of road. This includes site mobilisation and therefore has not been prorated for longer lengths. It is assumed that a 4km road (that required at Avana) would take approximately 5 weeks.

The construction of the treatment plants will be the last to commence and will only be commissioned once all the other components of the network have been completed. As mentioned in Section 13.4.1 above, certain elements of the proposed treatment may be perceived as contentious. The final decision regarding which elements of the Master Plan design are to be installed lies with the GoCI. It is assumed that the minimum plants will be constructed. As final costings become clear through the detailed design phase and the need for all trunkmains to be upgraded is confirmed through hydraulic modelling and pressure testing, then installation of the optimum treatment may be able to be implemented.

Additional projects have been included in the programme as follows:

- Water meters and backflow preventers – These have been assumed as one project with approximately 5,000 units required. It is assumed that 5 water meters could be installed by one crew in one day. It can't be gauged how many crews will be available but it has been assumed that 4 to 5 crews will be used to complete the work within one year.
- SCADA – The scope for SCADA to operate PRV's and WTP's will need to be assessed during the design stage. Any proposed system will then be commissioned with the WTP's.
- Local booster Pumps – The number of booster pump locations required will depend on further investigations. A 10 week installation window has been assumed.

14.0 Quality and materials

The Te Mato Vai project has a huge expenditure and it is important that all the material components are to a high quality, correct specification and installed correctly. The ringmain has been designed by CCECC and has been designed to Chinese material specifications and the construction standards proposed are Chinese. The Government of the Cook Islands uses Australian and New Zealand Standards.

MOIP has undertaken substantial work during and after Project City to ensure quality. Standard details have been produced for water supply. The following standards are designed to complement these and be read in conjunction with them.

This Master plan does not set out a complete list of permitted pipes and fittings, due to the commercial / litigative risk of missing a supplier that meets the standard (e.g. a supplier from a non-established country). Where a supplier can provide the documentation to demonstrate their product meets the relevant standard and evidence of the appropriate quality and compliance systems being in place, then their products should be accepted for use in Rarotonga.

14.1 Material standards

Within the Te Mato Vai project the following major components of the pipelines will need to have an assessment made of their quality prior to accepting them as a material for use in the Cook Islands, these are:

- PE Pipes and associated fittings;
- Valves;
- Fire Hydrants;
- Steel Pipes; and
- Bolts and Gaskets.

Currently the Government of the Cook Islands requires all pipelines adhere to AS / NZS standards, ensuring that these products meet the required standards is of vital importance to this project.

There are different levels of checking that can be undertaken to verify quality, some examples of these are:

- Standards, it is assumed that everything supplied is to the specification and the standards within;
- Manufacturers Documentation, requesting certificates of conformance from the suppliers and wholesalers; and
- Quality audit of the factories by suitably qualified experts, auditing the factories and carrying out independent testing on the products. Reviewing their quality and compliance systems that ensure quality and traceability.

The Ministry of Infrastructure and Planning (MOIP) has been installing PE 100 SDR 17 pipes. CCECC confirmed in 2012 in correspondence this is the material they would purchase and install. This has changed earlier this year to a higher pressure rating of pipe which is 12.5 bar pressure rating, and has a SDR of 13.6. If this has not already been communicated to CCECC they will need to be informed of this change. As a result the pressure testing regime within their methodology will also have to be amended.

14.1.1 PE pipes

The Government of the Cook Islands has approved the use of polyethylene pipe of the following grade; PE 100 SDR 13.6 (PN 12.5) for use as a material for pipeline construction on the Cook Islands for pipes larger than 63 mm OD and for pipes 63 mm or smaller PE 80 SDR 11 (PN12.5). This is an appropriate standard for the Cook Islands.

Table 37 sets out the standards that all PE pipes should conform to.

Standards

Table 37 Standards relating to PE pipe

Standard	Description
AS/ NZS 4129:2008	Fittings for polythene (PE) pipes for pressure applications.
AS/ NZS 4130:2009	Polyethylene pipes for pressure applications.
AS/ NZS 4131 2010	Polyethylene (PE) compounds for pressure pipes and fittings.
WIS 4-24-01	Specification for Mechanical Fittings and Joints for Polyethylene Pipes of Nominal Sizes 90 – 1000 – Issue 2, July 1998.
PIPA POP004	Polyethylene Pipe Compounds Issue 8.7, 27 June, 2012

Pipe purchased out of Australasia shall conform to ISO 4427.

Manufacturers Documentation

The following documentation is required:

a) A legible copy of the Resin manufacturers batch certificates clearly stating:

i. Resin batch number;

ii. Resin model number;

iii. Pipe manufacturers name and address;

iv. Quantity of resin supplied;

v. Date resin was dispatched;

vi. Analysis of resin properties including:

- Melt flow rate (MFR);
- Density;
- Pigment dispersion level;
- Oxygen induction time (OIT); and
- Volatile content.

b) Manufacturers' legible production and inspection records in English for all pipes supplied. Each pipe record shall comply with the requirements of AS/NZS 4131 and AS/NZS 4130 and:

i. Sequential individual pipe numbers allocated to each pipe and pipe batch;

ii. Unique batch numbers applicable to each specific batch of pipe;

iii. Resin manufacturers Model number/s linked to each batch number for pipe; and

iv. Resin manufacturers batch numbers – linked to each individual pipe number.

c) A test report for each batch of pipe shall be provided demonstrating compliance with AS/NZS 4130 sections:

i. Section 10.1, Hydrostatic strength test at 80°C, 5.4 Mpa stress for 165 hours;

ii. Section 10.2, Reversion; and

iii. Section 10.3, Thermal stability - > 20 minutes @ 200°C

d) Details of the source and type of the proposed polyethylene resin and pipes for this contract shall be submitted this shall include:

i. Name and address of Resin supplier;

ii. Resin ,model number and location of resin manufacture ;

iii. Pipe manufacturer and location of pipe extrusion plant;

iv. Manufacturers' quality assurance certification;

v. Supporting technical information to be supplied in advance of materials;

- Manufactures technical data sheet for all proposed pipe resins; and
- Manufacturer's technical data sheet for proposed pipe.

Inspection

The inspection of the manufacturing process of the PE pipe should be undertaken by an experienced specialist in polymers and be familiar with the processes of ISO 9001.

Compliance and verification testing to AS/NZS 4130 and 4131 may include but are not limited to:

a) Melt flow rate (MFR);

b) Material density;

c) Pigment dispersion;

d) Oxygen induction time on samples taken from outside of pipe wall, middle of pipe wall and inside of pipe wall;

e) >3300 Hr Slow crack growth test; and

f) Resin manufacturer verification that the resin used in the pipe matches the resin certificate.

14.1.2 Resilient seated sluice valves (Larger than 50mm)

All valves used in the Cook Islands shall be resilient seated and constructed from Ductile Iron and flanges shall be raised and drilled to PN 16. The pressure rating shall be 16 bar. The direction of closing shall be **anti-clockwise** closing.

Table 38 below sets out the standards that all gate valves should conform to.

Standards

Table 38 Standards relating to gate valves

Standard	Description
AS 2638.2-2011	Gate valves for waterworks purposes
AS/NZS 4158: 2003	Thermal-bonded polymeric coatings on valves and fittings for water industry purposes.
AS 1831: 2007	Ductile Cast Iron
AS 4087: 2011	Metallic flanges for waterworks purposes
AS 2837 1986:	Wrought alloy steels

Manufacturers Documentation

The supplier shall supply the following information in table 39.

Table 39 Sluice valve data sheet

<table>
<tr><th colspan="5">Valve Details</th></tr>
<tr><td colspan="2">Manufacturer</td><td colspan="3"></td></tr>
<tr><td colspan="2">Make/ Model</td><td colspan="3"></td></tr>
<tr><td colspan="2">Country of manufacture</td><td colspan="3"></td></tr>
<tr><td colspan="2">Nominal size (mm)</td><td colspan="3"></td></tr>
<tr><th colspan="5">Valve Characteristics and materials</th></tr>
<tr><th>Parameter</th><th colspan="2">CI Government Requirement</th><th colspan="2">Supplier to complete</th></tr>
<tr><td>Valve Specification</td><td colspan="2">AS 2638.2-2011</td><td colspan="2"></td></tr>
<tr><td>Valve type</td><td colspan="2">Gate Valve</td><td colspan="2"></td></tr>
<tr><td>Valve Seat</td><td colspan="2">Resilient seat</td><td colspan="2"></td></tr>
<tr><td>Valve closure direction</td><td colspan="2">Anti-clockwise</td><td colspan="2"></td></tr>
<tr><td>Pressure rating</td><td colspan="2">PN 16</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Connection Flange Details</td><td colspan="2">Raised face and drilled to AS 4087: 2011</td><td colspan="2"></td></tr>
<tr><td>Flange OD (mm)</td><td></td><td>Flange OD (mm)</td><td></td></tr>
<tr><td>Flange ID (mm)</td><td></td><td>Flange ID (mm)</td><td></td></tr>
<tr><td>Valve body material</td><td colspan="2">Ductile iron to AS 1831: 2007</td><td colspan="2"></td></tr>
<tr><td>Spindle</td><td colspan="2">Stainless steel complying with AS 2837 grade 431</td><td colspan="2"></td></tr>
<tr><td>Stem Seals</td><td colspan="2">Nitrile or comparable approved rubber ‘o’ ring type</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Valve body and bonnet coating</td><td colspan="2" rowspan="2">Encapsulated in thermally bonded coating system to AS/ NZS 4158 Part 1.</td><td>Internal</td><td></td></tr>
<tr><td>External</td><td></td></tr>
<tr><td>Spindle Cap</td><td colspan="2">Ductile iron secured with set screw.</td><td colspan="2"></td></tr>
<tr><td>Approvals</td><td colspan="2">Potable water contact NSF/ ANSI 61 or AS 4020</td><td colspan="2"></td></tr>
<tr><td>Valve product details</td><td colspan="2">Valve assembly drawings with dimensions</td><td colspan="2"></td></tr>
</table>

A certificate of conformance with AS 2638.2-2011 shall be supplied with every valve and certification that the castings have been manufactured, sampled, tested and inspected in accordance with AS 1831-2007.

A signature is required on all certification indicating the name, position and qualification of the person with signature rights. The document shall clearly identify the organisation submitting the certification and its authorised agent. Any membership of a quality accreditation within the country of origin needs to be clearly identified.

Inspection

The inspection of the manufacturing process of the valve should be undertaken by an experienced metallurgist and be familiar with the processes of ISO 9001.

The following inspection and testing may occur, may include but is not limited to:

a) Foundry Audit; and

b) Microstructural analysis; and

c) Mechanical Testing.

14.1.3 Fire hydrants

All fire hydrants used in the Cook Islands shall be constructed from Ductile Iron. The pressure rating shall be 16 bar. The direction of closing shall be **clockwise** closing.

Table 40 below sets out the standards that all fire hydrants should conform to.

Standards

Table 40 Standards relating to fire hydrants

Standard	Description
NZS 4522 2010	Underground Fire Hydrants
AS 1831:2007	Ductile Cast Iron
AS/ NZS 4087: 2011	Metallic Flanges for waterworks purposes
AS 2129: 2000	Flanges for pipes, valves and fittings
AS/NZS 4158: 2003	Thermal-bonded polymeric coatings on valves and fittings for water industry purposes.
As 1565: 1996	Copper and Copper allows, ingots and castings

Manufacturers Documentation

The supplier shall supply the following information in table 41 below.

Table 41 Fire hydrant data sheet

<table>
<tr><th colspan="5">Hydrant Details</th></tr>
<tr><td>Manufacturer</td><td colspan="4"></td></tr>
<tr><td>Make/ Model</td><td colspan="4"></td></tr>
<tr><td>Country of manufacture</td><td colspan="4"></td></tr>
<tr><td>Nominal size (mm)</td><td colspan="4"></td></tr>
<tr><th colspan="5">Valve Characteristics and materials</th></tr>
<tr><th>Parameter</th><th colspan="2">CI Government Requirement</th><th colspan="2">Supplier to complete</th></tr>
<tr><td>Hydrant Type Specification</td><td colspan="2">NZS 4522: 2010</td><td colspan="2"></td></tr>
<tr><td>Hydrant type</td><td colspan="2">Squat</td><td colspan="2"></td></tr>
<tr><td>Valve Stopper</td><td colspan="2">EDPM or nitrile rubber resilient seat.</td><td colspan="2"></td></tr>
<tr><td>Valve closure direction</td><td colspan="2">Clockwise Close</td><td colspan="2"></td></tr>
<tr><td>Pressure rating</td><td colspan="2">PN 16</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Connection Flange Details</td><td colspan="2">Slotted hole compatible with 80 mm AS 4087 2011 and 90mm AS 2129 (Table D)</td><td colspan="2"></td></tr>
<tr><td>Flange OD (mm)</td><td></td><td>Flange OD (mm)</td><td></td></tr>
<tr><td>Flange ID (mm)</td><td></td><td>Flange ID (mm)</td><td></td></tr>
</table>

Hydrant body material	Ductile iron to AS 1831: 2007		
Hydrant outlet	Threaded outlet complying with NZS 4522 2010, made from copper alloy complying with AS 1565 material grade C83600		
Stem Seals	Nitrile or comparable approved rubber 'o' ring type		
Hydrant body and bonnet coating	Encapsulated in thermally bonded coating system to AS/ NZS 4158 Part 1.	Internal	
		External	
Spindle Cap	Ductile iron secured with set screw.		
Approvals	Potable water contact NSF/ ANSI 61 or AS 4020		
Hydrant product details	Valve assembly drawings with dimensions		

A certificate of conformance with NZS 4522: 2010shall be supplied with every valve and certification that the castings have been manufactured, sampled, tested and inspected in accordance with AS 1831-2007.

A signature is required on all certification indicating the name, position and qualification of the person with signature rights. The document shall clearly identify the organisation submitting the certification and its authorised agent. Any membership of a quality accreditation within the country of origin needs to be clearly identified.

Inspection

The manufacturing process of the hydrant should be undertaken by an experienced metallurgist and be familiar with the processes of ISO 9001.

The following inspection and testing may occur, may include but is not limited to:

a) Foundry Audit;

b) Microstructural analysis; and

c) Mechanical Testing.

14.1.4 Steel pipe

The Government of the Cook Islands has approved steel pipe to NZS 4442: 1998.

Table 42 below sets out the standards that all steel pipes should conform to.

Standards

Table 42 Steel pipe standards

Standard	Description
NZS 4442; 1998	Specification for welded steel pipes, fittings for water, sewage and medium pressure gas

Manufacturers Documentation

The supplier shall supply the following information in table 43 below.

Table 43 Steel pipe documentation

<table>
<tr><th colspan="5">Pipe Details</th></tr>
<tr><td colspan="2">Manufacturer</td><td colspan="3"></td></tr>
<tr><td colspan="2">Make/ Model</td><td colspan="3"></td></tr>
<tr><td colspan="2">Country of manufacture</td><td colspan="3"></td></tr>
<tr><td colspan="2">Nominal size (mm)</td><td colspan="3"></td></tr>
<tr><th colspan="5">Pipe Characteristics and materials</th></tr>
<tr><th>Parameter</th><th colspan="2">CI Government Requirement</th><th colspan="2">Supplier to complete</th></tr>
<tr><td>Steel Pipe Specification</td><td colspan="2">NZS 4442; 1998</td><td colspan="2"></td></tr>
<tr><td>Pressure rating</td><td colspan="2">PN 16 (MIN)</td><td colspan="2"></td></tr>
<tr><td>Lining:</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Coating:</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="3">Dimensions</td><td colspan="2">Dimensions as per clause 102 in NZS 4442</td><td colspan="2"></td></tr>
<tr><td>Pipe OD (mm)</td><td></td><td>Pipe OD (mm)</td><td></td></tr>
<tr><td>Pipe ID (mm)</td><td></td><td>Pipe ID (mm)</td><td></td></tr>
<tr><td></td><td>Wall Thickness (mm)</td><td></td><td>Wall Thickness (mm)</td><td></td></tr>
</table>

A certificate of conformance with NZS 4522: 2010 shall be supplied with every valve and certification that the castings have been manufactured, sampled, tested and inspected in accordance with NZS 4522: 2010.

A signature is required on all certification indicating the name, position and qualification of the person with signature rights. The document shall clearly identify the organisation submitting the certification and its authorised agent. Any membership of a quality accreditation within the country of origin needs to be clearly identified.

Inspection

The inspection of the manufacturing process of the valve should be undertaken by an experienced metallurgist and be familiar with the processes of ISO 9001.

The following inspection and testing may occur, may include but is not limited to:

a) Factory Audit;

b) Microstructural analysis including testing of the welds:

- Dye penetrant; or
- Magnetic particle; or
- X-ray; or
- Ultra-sonic methods.

c) Mechanical Testing.

14.1.5 Bolts, washers and gaskets

The following sections detail the type of bolts and washers that are permitted for use in the Cook Islands.

Table 44 below sets out the standards that all bolts, washers and gaskets should conform to.

Standards

Table 44 Bolts washers and gaskets standards

Standard	Description
AS 1111.1 2000	ISO metric hexagon bolts and screws - Bolts
AS 11112.3:2000	ISO Metric hexagon nuts
AS/NZS 1252:1996	High strength steel bolts with associated nuts and washers for structural engineering
AS/NZS 3679.1: 2010	Structural Steel – Hot rolled bars and sections
AS 1214;1983	Hot-dip galvanized (zinc) coatings on fabricated ferrous articles

Hexagon bolts and nuts shall be manufactured to AS 1111 and AS 1112, grade 4.6 mild steel or to AS/NZS 1252 for high tensile steel to grade 8.8.

Stainless steel bolts and nuts shall be Grade 316 (S31600), or as specified by the Engineer.

Hexagon bolts and nuts may be produced by either hot or cold forging, and with or without secondary machining. Alternatively, they may be machined from bar stock.

Dimensions for hexagon bolts shall be as per table 1 of 1111.1 and nuts as per table 1 of AS 1112.3.

Washers shall be manufactured from mild steel to AS/NZS 3679.1, or 316 stainless steel, unless otherwise specified by the Engineer.

Washers may be produced either by stamping or by machining from bar stock. Each Washer's internal diameter and outside diameter shall be concentric. Washers shall be flat and be free of burrs.

Two washers are to be provided for each nut and bolt. The outside diameter of the washer shall be less than the diameter of any spot face provided on the flanges. Galvanised steel washers shall be used with steel bolts, and stainless washer shall be used with stainless bolts.

Hexagon nuts, bolts and washers shall be hot dip galvanised in accordance with AS 1214.

Hexagon bolts shall be hot dip galvanised after the external thread has formed to the correct dimensions.

Hexagon nuts shall be hot dip galvanised before the internal thread is formed. Internal threads shall be formed using an oversize tap to allow for galvanising on the bolt thread.

Gaskets materials shall be suitable for a 16 bar pipeline. Gaskets shall be 2 or 3mm thick and be approved by the Engineer. Natural and nitrile insertion rubber shall have hardness in the range between 60 and 75 IRHD units, and shall have a cotton reinforcing layer.

Nuts and bolts shall be stored in dry and clean conditions prior to use. The bolt thread and internal threads of the nuts shall be coated with an approved lubricant for corrosion protection.

14.2 Construction standards

14.2.1 Management of community effects

14.2.1.1 Working site

Construction operations and material and equipment storage shall be confined to the minimum area required for the contract and shall adequately indicate and protect all opened up portions of the works.

No soil or other debris is to be deposited on the roads outside construction areas and any accidental spillage shall be removed immediately.

Any work affecting access to private property shall be carried out to completion as quickly as possible after starting construction there. During construction consideration shall be given to the needs of the residents / property owners with regard to access and use of the property.

14.2.1.2 Notifications

The contractor must keep affected parties appropriately informed of proposed works and works in progress.

A written communication strategy should be prepared where the Engineer specifies. A written strategy may be appropriate where major works or project works may have a significant effect on the public / property owners / occupiers. Reasonable conditions may also specify communications such as:

- production and distribution of a suitable leaflet advising the public of the forthcoming project at least one month before work starts;
- advertisement / public notice in specified local newspapers at least two working days before work is started; and
- advertisement / public notice on specified local radio stations in advance of the work and throughout the period of the work (typically before and during peak traffic times).

The contractor must display signs for works, unless otherwise agreed with the Engineer, as follows:

- placed at each end of the Work Site;
- erected a minimum of two days prior to construction;
- minimum dimensions of 1200 mm by 800 mm;
- clearly visible to pedestrians and other traffic;
- include the name of the contractor, the nature of the works, the likely duration and contact details; and
- with colour and font size conforming to the Corridor Manager's requirements.

The signs must, where practicable:

- be at right angles to the Road centreline;
- not obstruct access to private property;
- not obstruct visibility at pedestrian crossings or intersections;
- not be on a handrail, fence or tree;
- not be on a pole or Structure without first obtaining the agreement of the owner;
- not obstruct the visibility of road users, particularly at or near intersections or entrances;
- not physically obstruct road users including pedestrians and cyclists; and
- be at least 2.4m above ground level if mounted above pedestrian areas.

The contractor must remove signs immediately the work has been finished and the site cleared.

14.2.1.3 Traffic management

The contractor must prepare and have approved a traffic management plan (TMP) prior to commencing works. The contractor must implement the approved TMP.

If an audit shows that the traffic management does not comply with the above or any other condition, the contractor must remedy the non-compliance immediately, or cease working until authorised to recommence, except for that work required to ensure the safety of the work site.

The contractor must follow all instructions given by an officer of the Cook Islands Police in respect of traffic management, except that any work site ordered closed must be made safe before it is vacated.

14.2.1.4 Hours of work

The normal hours of work shall be between 7:00 am and 6:00 pm (subject to loud noise restrictions), Monday to Saturday. Work outside these hours will only be with the specific approval of the Engineer.

For any work carried out in a residential area, no work shall be carried out between the hours of 6:00 pm and 7:00 am on any day, or on Sundays or public holidays without the written approval from the Engineer.

Hours of work may be restricted to limit interference with property access, or to minimise noise, other environmental impacts and traffic congestion. Where the hours of work may be severely restricted the Parties may agree on special arrangements to work extended hours.

14.2.1.5 Noise, vibration and dust management

The continuous noise level at residential and commercial property boundaries shall not exceed the ambient level by more than 10 dB (A). The best practical means of reducing the noise of continuous use equipment to affected people shall be adopted.

The contractor shall

- resolve excessive noise and vibration conditions where they occur as a result of the works;
- address noise management in its work planning;
- minimise dust affecting private properties and visibility for road users;
- muffle all plant and equipment in accordance with good industry practice;
- avoid unreasonable nuisance and use methods that minimise noise levels, such as avoiding the use of breakers and other similar loud noise when required to work at night; and
- take additional care when undertaking work adjacent to asbestos pipes, as these are prone to failure when subjected to vibration.

14.2.1.6 Work in private property

The contractor shall notify private property owners at least one week prior to starting construction on their property. The contractor must comply with any Private Property Reinstatement Agreements in place.

No trench shall be open for longer than 2 weeks on an individual property.

The contractor is to inform all residents/ property owners in the event of a variation to the original programme of works, in writing within 24 hours of the variation.

All requests for information by the property owner shall be attended to by the contractor within 24 hours,

The contractor is to complete all works in private property by the deadlines supplied on their submitted programme for the works

All reinstatements shall be completed within 2 weeks of the trench being backfilled.

Work on each property shall be carried out to completion as quickly as possible after starting construction there. During construction consideration shall be given to the needs of the residents/ property owners with regard to access and use of the property. The working site shall be tidy and silt or debris deposited in the property shall be cleaned up as soon as practically possible.

14.2.2 Delivery and inspection

14.2.2.1 Transportation of pipes

Pipes shall be transported by a flat decked vehicle free from nails or other sharp projections.

Pipes shall be inspected upon delivery and may be rejected if damaged or deformed in any way. All pipes delivered to site and accepted shall be signed for on the delivery docket, including the date, time, name, and organisation of the person accepting delivery. The delivery dockets and pipe inspection report are to be submitted to the Engineer within two working days of the delivery.

Pipes shall be visually inspected before incorporating into a pipeline, and shall satisfy the requirements in Table 45.

Table 45 Visual inspection requirements

Condition	Requirement
Branding	The pipe material, size and SDR details on the drawings agrees with the pipe branding. The pipe shall branded in accordance with the relevant standard and in accordance with this specification.
Out of roundness	≤ 2% of mean diameter
Reversion	The pipe shall not exhibit strong reversion at the pipe ends.
Eccentricity	Pipe wall thickness measured at any point shall be within the dimensional limits of the relevant standard.
Surface finish	There shall be no extrusion die marks or spider-lines, or evidence of crazing, flaking, indication of disintegration, pitting, or discolouration.
Scratches	None on the internal surface. External surfaces shall be free from longitudinal or circumferential sharp scratches deeper than 10% of the pipe wall thickness.
Cracks	The pipe shall be completely free from cracks
Voids or inclusions	There shall be no visible voids, material discontinuities, or inclusions of extraneous matter.
Protuberances	Ridges or ripples shall not exceed 0.5mm in height.

The Engineer shall be advised of any of the pipes or fittings delivered to site that do not meet the requirements of the visual inspection.

Fittings and accessories shall be stored in their original containers or suitable protective bins.

Pipes shall be lifted using a centrally placed nylon sling or as per the manufacturer's instructions. Pipes shall not be placed directly on the ground. Timber cradles shall be used to keep the pipes clear of the ground.

During pipe lifting the pipe shall be kept under control by the use of tag lines, for example, to avoid bumping the pipe against hard or sharp obstacles. Loads shall not be suspended over trafficked areas that have not been closed to vehicles.

The trench floor or bedding at the position of slinging of each pipe shall be cut out sufficiently by the contractor to permit the removal of the slings.

14.2.2.2 Material storage

All materials should be stored and handled in accordance with the manufacturer's recommendations and in such a manner that no damage or degradation to the component parts occurs. All materials should be protected from the elements and other potential sources of damage or degradation.

Pipe handling, transportation and stacking shall comply with AS/NZS 2566.2. Pipes cut and squared for butt welding shall be handled, particularly in transport, in a manner that keeps the pipe ends free from damage.

Pipes shall not be dragged across sharp or abrasive surfaces or subjected to rough usage. Soft strops are preferred for pipe lifting, but when wire ropes or chains are employed pipes shall be suitably protected against scoring of the pipes.

Pipe stacks shall be supported on a continuous base or on flat ground free from stones. Vertical side supports shall have a bearing width of at least 75 mm and be spaced no further than 2m centres. Pipes on the bottom layers of a stack may become distorted. The height of pipe stacks shall be limited to minimise ovality and distortion while stored. In any case, pipe stacks shall not be greater than 10 pipes high.

Pipes with end treatment such as flanging, belled, or preassembled fittings shall be stacked or supported so that the ends are free from carrying any loading.

14.2.3 Excavation and backfilling

14.2.3.1 Surveying and setting out

It will be necessary to establish all levels, construction marks and set outs in order to ensure the accuracy of all survey pegs and marks that are used for determining the location of the components of the works.

Full records of all set-out and as-built measurements as well as any observations must be maintained in order to prepare as-built drawings.

The contractor shall arrange for all underground services adjacent to the construction site to be traced, using electronic location equipment where applicable, and marked out on site prior to construction. Where this marking out is not done by the utility operator, the contractor shall arrange for mark out by a competent person using reliable equipment where applicable.

The contractor shall take measures to ensure existing underground utility assets are not damaged during the course of the works, and carry out the works in a manner that protects the separation requirements of other utility operators as provided for in relevant codes and regulations.

The contractor shall follow the instructions of the respective utility operators when excavating near existing services. These instructions may include that a representative of the authority is on site while excavations are undertaken and that machinery shall not be used for excavation within a defined distance of the service.

14.2.3.2 Excavation

All trenches deeper than 1.0m should be shored and the excavated materials tested for any contamination, if suspected contaminated materials are encountered. If contaminated materials are found, these should be extracted, excavated, contained and disposed of at an approved land fill.

14.2.3.3 Backfilling

The backfill material around and to 200mm above the pipe shall be 5mm to 14mm well graded gravel for PE pipe and shall be well compacted.

The backfill shall be placed uniformly and not dropped from a height greater than 300mm, over the full width of the trench, on both sides of the pipe. Lifts of not more than 100mm thick shall be compacted to a relative density of between 95 and 98 percent (Proctor) according to BS 1377 Test 11, Standard Method of Compaction.

The contractor shall install the pipe surround cover to pipe to 200mm (minimum). Above the pipe surround a regulating base course of approved material shall be placed and compacted, followed by a 300mm depth of compacted base course material.

Tests to verify compaction should be made by the Engineer. Material that is found to be compacted to standards below that specified shall be removed at the discretion of the Engineer and replaced by the contractor, as specified until the required compaction standards have been met.

14.2.4 Installation

14.2.4.1 Pipe laying

All pipes must be laid true to line / grade and pipes shall be uniformly bedded along their entire length. All pipelines, fittings, and fixtures shall be installed in accordance with the manufacturer's specifications and recommendations.

Any PE pipe surface notched greater than 10 percent of the wall thickness will be rejected. Where a pipe or fitting is damaged prior to installation or while installing, it will be rejected or the defect repaired and installed to the manufacturer's specifications. The contractor shall forward details of the manufacturer's serial/batch numbers of all pipes and fittings to the Engineer prior to starting any work on site.

For PE pipes, the minimum trench width of the trench excavated shall be the pipe outside diameter plus 75 mm each side of the pipe. Where two pipes are to laid in a common trench a clear separation of 300mm minimum must be provided. The bottom of the trench shall conform to grade with the side walls cut vertically to provide sufficient width to enable compaction of side fill at each side of the pipeline at the horizontal diameter of the pipe.

Where the stability of the trench side walls, whether supported or unsupported, results in trench widths greater than the minimum width specified on the drawings then all costs of extra excavation, backfilling and reinstatement shall be the responsibility of the contractor.

Where pipes are laid on curves of large radius the trench shall, without extra charge be widened by the contractor to ensure that no point of the pipe shall be nearer than 75mm to the side of the trench wall.

14.2.4.2 Pipe bedding (PE pipes)

The trench shall be excavated to grade, with a flat bottom 100mm below the pipeline invert level. The bedding material shall be well graded gravel, 5mm to 14mm, for pipe diameters above 100mm nominal bore.

The bedding material shall be placed in the trench by the contractor to a compacted depth of 100mm. The contractor shall use a vibrating plate or small vibrating rollers to achieve the compaction standard.

The contractor shall profile the bedding and shall provide a uniform bedding surface for the pipe barrel except at joint position. Where PE pipe is to be laid, extreme care should be taken in preparing the trench bedding.

Should the material at the bottom of the trench be unsuitable, the excavation shall be carried to such a depth as directed by the Engineer. The bottom of the trench shall be backfilled to pipeline invert level with 5mm to 14mm well graded bedding material in uniform layers not exceeding 100mm in thickness. Each layer should be thoroughly compacted before the next layer is placed.

14.2.4.3 Depth to pipes

The contractor shall install pipes with a minimum cover of 750mm. The PE pipe cover should be adjusted to allow valves and fire hydrants to be installed with clearances as specified.

14.2.4.4 Installation

The accommodation of thermal expansion and contraction of the polyethylene during installation should be considered. Connection of joints should be completed when thermal movement is minimal. Polyethylene pipe can be either butt welded or electrofusion welded.

Polyethylene (PE) pipe welding

The Engineer must approve the test weld results before commencement of further welding or any pipe installation can occur. Acceptance or rejection of the weld test results will be available within 3 working days of the results being given to the Engineer.

All polyethylene pipes shall be jointed to the manufacturer's recommendations, in compliance with NZSA/AS 4131.

Experienced and suitably qualified personnel must undertake the welding procedure. It is required that the pipe welder will have a recognised PE welding certificate from a technical institution or an equivalent. A copy of the certificate is to be provided to the Engineer before any welds are made.

A detailed methodology stating the times, pressures and temperatures that are to be used for each diameter of pipe welded must be submitted to the Engineer prior to welding commencing on site. These will generally be consistent with the manufacturer's recommendations but may be modified to achieve consistently good welds.

Butt welding shall be carried out in accordance with the conditions specified in WIS 4-32-08 and weld parameters to POP003.

There are two separate phases relating to the testing of Polyethylene welds. The first phase must occur prior to construction of the pipeline and is used to define the welding parameters that will be used for the duration of the works. The second phase is quality assurance testing during construction of the pipeline.

The contractor shall make sure that during the Bead Pressure time the pipe ends are not quickly pulled together causing the heated material to disperse away from the pipe ends. The pipes ends must be slowly brought together until they touch and then brought up to full pressure.

Weld beads are not required to be removed for water supply applications. Every butt weld is each to be stamped with a weld number and the welder's certification number before the weld cools. The stamp depth must not exceed 5mm. a welding log stating the weld pressures, temperatures and times corresponding to each weld number and certification number must be submitted to the Engineer before the pipe is installed.

Prior to construction the contractor must undertake a series of test welds to demonstrate that the welding parameters being used will produce acceptable weld results. The welds must be undertaken on the specific machine and by the specific operator as will undertake the construction welding.

The weld parameters contained in the latest version of POP003 “Industry Guidelines for Butt Fusion Jointing of PE Pipes and Fittings - Recommended Parameters" should form the basis of the methodology.

Where the pipe wall thickness is less than 20mm, two (2) pre-construction welds must be carried out at the same weld parameters. Where the pipe wall thickness is equal to or greater than 20mm, five (5) pre-construction welds must be carried out at varied weld parameters. Where the pipe wall thickness is equal or greater than 20mm, it is the contractors responsibility to vary the weld parameters in order to obtain a weld that meets the acceptance requirements.

During construction the Engineer will randomly select welds from the pipeline. The contractor must remove the welds and arrange to have them tested.

The Engineer may take quality assurance test welds, in addition to those scheduled, if:

- The contractor changes the machine, operator, pipe source or resin source during construction;
- Previous weld test results have not met the acceptance criteria; and
- In the opinion of the Engineer, a weld is not of an acceptable quality standard.

The contractor must cut out sample welds and arrange for the welds to be tested by an IANZ Registered Laboratory or one approved by the Engineer. These welds are to be a minimum length of 300mm either side of the weld.

A tensile test of a longitudinal strip of pipe including the weld taken from equidistant sites in the weld must be undertaken on the samples. Refer to table 2 of ISO standard 13953 for the correct number of test pieces per weld for each pipe diameter. Tensile testing of a longitudinal strip will generally be carried out in accordance with IRS/FDIS13953 but must be modified as follows:

a) The type A test specimen must only be used for all samples exceeding 20mm in thickness.

b) All test strips for Type A tests must be machines down to 20mm thickness by removing material evenly from each side of the pipe and then tested in the Type A test apparatus. Samples tested in the above manner are referred to as Modified Type A testing to avoid confusion with ISO/FDIS 13953.

c) For polyethylene pipes with a wall thickness less than 20mm a Type B test must be carried out.

A graph of load verses tensile extension must be supplied with each test specimen to assist in interpretation of ductile and brittle failures. It is acceptable for the tensile extension to be measured on the machine clamps and not on the pipe itself if desired.

It is recognised that it is difficult to achieve consistent ductile ruptures of PE welds, from the Type A Tensile Test, when the wall thickness is greater than about 20mm. Random brittle results do occur in the thicker walled Type A test specimens, irrespective of the weld parameters used. The acceptance of tensile results will be based on the following:

- The weld record sheet must show that the weld has been carried out within the tolerances of the weld procedure;
- The visual inspection of the weld must confirm that the weld is acceptable;
- Ultimate tensile strength of the weld must be no less than 90% of the pipe strength;
- Modified Type A test specimens must rupture in a generally ductile manner. Some degree of brittleness will be accepted provided that:
    - It occurs in no more than half of the test coupons for any given weld;
    - The nature of the brittleness does not extend over more than 25% of the surface of the weld area tested; and
- The Type B test specimens must rupture in a generally ductile manner.

Welds will be evaluated on the following criteria:

- Visual inspection of welds;
- Welding within agreed welding procedures;

- Weld records to be maintained so that checking of actual weld parameters used can be made against target weld parameters;
- Any welds that are made without the required records being made and supplied to the Engineer will be rejected; and
- Until the results of the weld testing to define construction parameters have been approved by the Engineer the contractor may, entirely at their own risk, weld pipes but may not install any pipe.

Each joint will be visually inspected to check that:

- Both fusion beads are of the same size and shape and project evenly above the outside diameter of the pipe;
- The bead width is within the parameters shown in Table 46 below;
- There are no cracks in the beads; and
- There are no obvious inclusions or other faults present.

A check sheet must be kept by the welder for each weld to show that the above items have been checked.

- Visual inspection of welds; and
- Welding within agreed welding procedures.

Table 46 Bead width

Wall Thickness (mm)	Overall Bead Width (mm)
11 or less	9-12
13	10-14
16	11-15
18	12-16
19	12-18
22	13-18
24	14-19
28	15-20

Note: The width of bead is the total width of the bead measured across both pipe ends.

Any welds that are made without the required documentation being supplied to the Engineer will not be accepted and will have to be redone.

All welding machines used must have automatic logging facilities incorporated in them. The contractor must submit the welding log to the Engineer before the pipe is installed. As a minimum these will record the following:

- Pipeline and location (accurate enough so that the weld location can be determined).
- Weld number
- Weld date
- Welder ID number
- Pipe Size
- Pipe SDR
- Wall Thickness (e)
- Annular Area (A)
- Cylinder Area (a)

- Fusion Pressure (Po)
- Plate (T1)
- Drag Pressure (Dp)
- Bead Pressure (P1)
- Soak Pressure (P2)
- Soak Time (T2)
- Changeover Time – T3 – ref Auspoly POP 003 Recommended Parameters
- Time to Achieve Welding Pressure (Ramping Pressure Time) – T4
- Weld Pressure 1 (P3 1)
- Cooling time 1 (t31)
- Weld Pressure 2 (P32) if applicable
- Cooling time 1 (t32) if applicable

The results must be given in tabular form. Graphical results are not acceptable

If a tensile tested weld fails in a brittle mode before the pipe wall yields then, the test will be classified as a failure.

- Failure of a weld during the definition of construction parameters stage of proving of the strength of the welds – No further welding or pipe installation may be carried out until the Engineer has been provided with acceptable rest results. If a tensile weld is found to fail at this construction parameters testing stage, the Engineer require the supply of another two welds for testing. If these additional two welds fail then the welder must submit a report to the Engineer indicating the reasons why welds are failing.
- Failure of a weld during construction – During Construction the Engineer may select two random welds for testing. If one or both tensile welds fail during construction, the Engineer will instruct the welder to supply another two welds for testing. The Engineer will select these next two welds. If either of the additional two welds fails then every weld constructed up to this point in the Contract must be exposed and re-welded to the satisfaction of the Engineer. The welder must also submit a report to the Engineer indicating the reasons why the welds failed.

Electrofusion Welding

Electrofusion jointing shall be carried out using automatic machinery designed for the pipe size. Manually operated welding machines are not acceptable. The machine shall not be changed without the Engineer's approval.

Two clamps supported on a frame shall ensure the alignment of the components and mating of the component ends. Re-rounding clamps of the appropriate size shall be used where necessary. The clamping system shall not be removed until after the manufacturer’s specified cooling time for the electrofusion fitting

All equipment shall be well maintained and kept in a clean condition at all times. The equipment shall be serviced and calibrated regularly. The frequency at which this is carried out will be different for individual items of equipment and will also depend on usage, but should be at least once every 12 months.

Suitable protection against inclement weather shall be provided, to prevent water, dirt and dust contamination and differential cooling of the pipes and couplings.

The spigot end of the component shall be cut square and all rough edges and swarf shall be removed from the pipe ends.

The maximum ‘out of roundness’ of the pipe shall be 1.5% of the internal diameter. The maximum allowable gap between butted ends within an electrofusion fitting shall comply with the fitting Manufacturer’s requirements. The pipe diameter and wall thickness shall be measured for compliance using the appropriate tools. Sections of the pipe experiencing pipe end reversion will be removed.

After cleaning pipe ends shall be peeled to 0.3mm depth and for a distance equal to half the length of the coupling plus 40mm to remove dirt and oxidation. This should be peeled to a smooth profile using a sharp rotational peeler. The exposed ends of the pipe strings shall be covered until cooling is complete, to prevent any air flow which may heat or cool the pipe. Covers on fittings shall be retained until immediately before welding.

All jointing surfaces shall be clean, dry and free of all contamination before being assembled. Iso-propyl alcohol complying with the manufacturer's concentration requirements and a lint free disposable wipe shall be used to remove any oil, or grease films. Mark witness marks with a non-contaminating marker at half the fitting length plus about 40mm to enable visual checking of the scraped area after jointing is complete.

For pipes with nominal diameters 90mm and larger, joints shall be tested in accordance with ISO 13954 Peel decohesion test. Two joints for each pipe diameter and material shall be completed, using the machine and operator named in their submitted methodology. Results shall include a commentary on and photos of the failure mechanism, including: peel depth and quality, ovality, gaps and insertion into the coupler, joint alignment, melt flow into cavity.

Failed joint samples shall be made available to the Engineer if requested. The relevant jointing log sheet and a graphical plot of the load versus extension shall be supplied for each test. Ductility shall be evident through the plot showing a rounded top and an extended sloping recession leg. The load extension graph may be used by the Engineer in assessing the results of the test.

Welds shall be inspected in the field and assessed in accordance with the requirements of AS/NZS 2033 "Installation of polyethylene pipe systems". One site constructed joint shall be tested for each 20 joints constructed for each differing diameter or material. Where the length is between 50m and 100m, one joint shall be tested. Lengths less than 50m shall require only pre-construction testing.

Any test joint failures shall be informed to the Engineer immediately of. Failure of any joint test will require the removal of the previous joint for testing, as per the chronological order of jointing. The section of pipe from the location of the failed test joint to the last passing test shall be quarantined and not installed. If the previous joint(s) are at a tee, these shall not be removed for testing and the next through (straight) joint shall be testing.

If the second joint test is unsatisfactory welding shall cease and no further pipe installation shall be carried out. The jointing process shall be reviewed to determine the cause of the unsatisfactory joints and report to the Engineer. Jointing shall not recommence until the Engineer accepts the corrective action and receives these complying test results. Installation and backfill of pipe joints made prior to the test failure may not occur until the Engineer is satisfied that the joints in this pipe are satisfactory. This may require that all the suspect joints are cut out and re-welded.

A site welding log sheet template shall be prepared and used to provide a detailed record of all joints carried out. As a minimum, the site welding log sheet shall provide the actual fusion and cooling times, ambient conditions and the actual temperature of the pipe and coupler prior to jointing, corresponding to each weld number and certification number. The log shall also clearly identify the location of each joint. The completed welding log shall be submitted to the Engineer as an as-built record.

Each electrofusion joint shall be identified with the operator's certification number, applied in a legible and durable form. Individual joint details shall be recorded on the log sheet The manufacturer's recommended Standard Fusion Times (SFT) shall be entered into the control box using the appropriate methods required by the type and model of control box.

- For automated systems, the resistor lead shall be connected to the resistor terminal pin of the coupling;
- For bar code systems, the light pen shall be wiped across the code panel to enter the fusion times; and
- For magnetic card systems, the card shall be placed into the control unit reader to enter the fusion times.

The pipe and fittings shall be pre-heated to manufacturer's requirements if required.

The pipes shall be restrained in position during welding at the centreline height of the coupling, to prevent movement and the application of stress during the fusion process. The pipes shall be horizontal either side of the clamps to prevent both pulling away from the coupling joint and the entry of water or dirt into the pipe, which may contaminate the weld zone. The welded joint shall be kept immobile for the full cooling times, before removing clamps or moving the joint assembly. No attempts shall be made to accelerate the rate of cooling.

The polyethylene pipeline shall be allowed to recover from the effects of thermal expansion and installation stretching. The pipeline shall not be restrained by rigid connections until the pipeline temperature reaches ground or service temperature.

The Engineer shall inspect the pipes before they are placed in the trench. The contractor shall provide assistance to the Engineer to enable these inspections to be undertaken by lifting the pipe clear of the ground or by rotating the pipe on timber bearers on the ground.

No foreign matter will be allowed to enter the pipe at any stage of storage or pipe laying. Outside of working hours the pipeline shall be temporarily sealed with fixed covers or bungs to prevent any entry of foreign matter or groundwater.

14.2.5 Testing and commissioning

Maximum allowable operating pressure

For pipelines less than 400m Long and up to DN315 testing should be undertaken as follows:

Care shall be taken to expel all air from the pipeline when filling, and to ensure that fittings such as air release or anti-vacuum valves are functioning and sealing properly.

Pipelines shall be tested to the pressure nominated in the Particular section, which shall not be less than 1.5 times working pressure, or greater than 1.25 times the maximum allowable operating pressure (MAOP) at the lowest point of the pipe. If ambient temperature is above 20 degrees Celsius the maximum pressure shall be reduced accordingly.

The following test procedure shall be utilised unless an alternative test is approved by the Engineer before installation commences.

- Prepare the pipeline by sealing both ends with flanged connections. The uphill end shall have a valve to enable air to be expelled from the pipeline. The lower end shall be fitted with separate tappings for the filling point control valve and for the pressure gauge.
- Fill the pipe, taking care to expel all the air.
- Apply the required test pressure, taking care not to exceed 1.5 times the rated pressure for the pipe.
- Maintain the pressure for 30 minutes by additional pumping as required.
- Check for obvious leaks.
- After 30 minutes at the test pressure, reduce this pressure rapidly by bleeding water from the system, to a nominal pressure of not less than 6 bar at the test gauge.
- Close the control valve and isolate the pipeline.
- Record the pressure at 5 minute intervals for one hour after the pressure has been reduced.

In a leak free system the gauge pressure would be expected to rise from its reduced setting as the polyethylene attempts to contract to its original diameter. The system should then retain this slightly higher pressure.

If the pressure does not rise, or if it falls after an initial rise, then a leak must be suspected and the test is failed. The line shall be repaired and the test shall be repeated until a satisfactory result is achieved. Tabulated results of the test are to be provided to the Engineer as soon as possible after completion the test. In a leak free system the gauge pressure would be expected to rise from its reduced setting as the polyethylene attempts to contract to its original diameter. The system should then retain this slightly higher pressure. If this is the case, the test is considered as satisfactory.

If the pressure does not rise or falls after an initial rise, then a leak must be suspected and the test has failed. The line shall be repaired and the test shall be repeated until a satisfactory result is achieved.

PE pipelines shall be sterilised before commissioning.

14.2.6 Standards and specification

The installation of all pipes should comply with the standards and industry guidelines shown in Table 47, except as modified herein:

Table 47 Pipeline industry standards and guidelines

Standards	
AS/NZS 1260:2009	PVC-U Pipes and fittings for drain, waste and vent applications.
AS/NZS 2033:2008	Installation of polyethylene pipe systems
AS/NZS 2280:2004	Ductile Iron Pipes and Fittings
AS/NZS 2566.1:1998	Buried flexible pipelines - Structural design
AS/NZS 2566.2:2002	Buried flexible pipelines - Installation
AS/NZS 4129:2008	Fittings for Polyethylene (PE) Pipes for Pressure Applications
AS/NZS 4130:2009	PE Pipes for Pressure Application
AS/NZS 4131:2010	Polyethylene (PE) Compounds for Pressure Pipes and Fittings
AS/NZS 5065:2005	Polyethylene and polypropylene pipes and fittings for drainage and sewerage application
BS 1377:1990	Methods of Test for Soils for Civil Engineering Purposes
BS EN 12201 Part 3:2003	Plastic piping systems for water supply, polyethylene (PE) fitting
ISO 9624:1997	Thermoplastic Pipes for Fluids Under Pressure – Mating Dimensions of Flange Adapters and Loose Backing RingsISO 13953:2001
ISO 13954	Plastic Pipes and Fittings – Peel Decohesion Test for Polyethylene (PE) Electrofusion Assemblies of Nominal Outside Diameter Greater Than or Equal to 90 mm
ISO 13957	Plastic Pipes and Fittings – Polyethylene (PE) Tapping Tees – Test Method for Impact Resistance
AWWA M11	Steel Pipe – A guide for Design and Installation
BS EN 1092-1:2007	Flanges and their joints – Circular flanges for pipes, valves, fittings and accessories, PN designated – Part 1: Steel Flanges
WIS 4-32-08 Issue 3; 2002	Specification for the fusion jointing of pressure pipeline systems PE 80/100
WIS 4-32-15, Issue 1, 1995	Specifications for polyethylene PE100 spigot fittings, saddles and drawn bends, for fusion jointing for use with PE100 cold potable water pressure pipes, nominal sizes up to including 500
Plastic Industry Pipe Association of Australia guidelines	
POP003	Butt fusion jointing of PE pipes and fittings – recommended parameters – Issue 6.1
POP006	De-rating requirements for fittings – Issue 5.01
POP010A	Part 1: Polyethylene Pressure Pipes Design for Dynamic Stresses – Issue 5.1
POP010B	Part 2: Fusion Fittings for Use With Polyethylene Pressure Pipes Design for Dynamic Stresses – Issue 5.1
POP013	Temperature Rerating of PE Pipes – Series 2.0

14.3 Maintenance and operations

To ensure that the water supply is potable and meets drinking water standards a commitment must be made to manage, maintain and operate the system as intended. This will require a management structure, for example Figure 4, maintenance programmes, operations procedures and operator training, data capture and analysis, contingency and response procedures for events throughout the system (from water catchment to customer tap).

14.3.1 Treatment

Initial training on water quality and specific equipment by the manufacturers will set out maintenance and operations requirements. As these assets are operated, these can be further developed into procedures and processes for Rarotonga. These should include maintenance, servicing, renewal and repair of assets.

Water supply staff will be trained in how to monitor water quality through the multiple systems that supply drinking water on the island – the results in these tests will feedback into maintenance and operations works required to maintain a potable water supply system.

Staff will be required to regularly deliver sodium hypochlorite to the treatment plants where it is not produced. This visit can be combined with a regular system check and collection of the water quality monitoring reagent for safe disposal.

14.3.2 Distribution system

Actively caring for the treatment and distribution system will allow it to operate for many years. For the distribution system, there are issues such as minimising water age which can be accomplished using the currently available hydraulic model. Furthermore, routine flushing of pipe sections that are known to exhibit high water age can be an easy method to maintaining distribution system infrastructure and water quality by eliminating potentially accumulated sediments.

Once the system is operational and better understood, processes to facilitate water turnover in reservoirs should be developed and undertaken.

In order to manage non-revenue water, an ongoing programme of active leakage control should be set up, including active leakage investigations and control measures, a programme for customer side leakage and management of illegal connections.

Initial training on PRVs and backflow prevention will set out maintenance and operations requirements.

15.0 Conclusions and recommendations

15.1 Te Mato Vai projects

Through hydraulic analysis and after consultation with the different stakeholder groups of Te Mato Vai AECOM has identified 64 projects as part of the renewal and upgrade of Rarotonga's water distribution network. Identified projects include the ringmain upgrades proposed by CCECC and subsequent network upgrade projects and are listed in Section 12.0.

This Master Plan's recommendations have been formulated to meet the Government of the Cook Islands' commitment to supplying reliable potable water to all properties connected to the water network by 2015 / 2016. It is understood that elements of this Master Plan, particularly treatment options, remain of concern to some stakeholders. It is recommended that the GoCI determines the programme of works to be completed to upgrade the water system to meet its commitment to potable water supply.

15.2 Further investigation

A number of issues requiring additional projects or further investigation beyond the scope of this Master Plan have been identified throughout this plan. These have been grouped into 6 main areas of improvement and summarised below:

Legislation, regulation and policies

- Legislation should be enacted to:
  - Protect public health through backflow prevention and plumbing bylaws.
  - Prevent water wastage by updating the Rarotonga Waterworks Ordinance (1960) and developing a strategy to address non-revenue water.
  - Manage Rarotonga's groundwater resources by introducing a system of permitting or licensing to allow the government to manage these resources on behalf of the citizens of Rarotonga.
- The national policy for water should be updated to ensure the stated principles and objectives are aligned with decisions that have been made in connection with Te Mato Vai and to remove duplication with other policies.
- A policy should be developed establishing the level of service to customers where there is non-payment of water bills.
- Strict regulations need to be developed around how water tanks are connected to the public mains supply, backflow prevention and maintenance of the tank system.
- Consideration should be given to future demand and the certainty of future revenue when considering end user charging and tariff structures.

Accountability and responsibility for the water supply system

- Accountability and responsibility for the water supply system should be established through legislation, statements of intent, policy documents, levels of service and standards.
- A commitment must be made to manage, maintain and operate the system as intended. This will require a management structure, maintenance programmes, operations procedures and operator training, data capture and analysis, contingency and response procedures for events throughout the system (from water catchment to customer tap).

Catchment management plans

- It is recommended that catchment management plans be considered to provide for the management of catchments supplying water for the potable supply.

Investigations

- Further work should be undertaken to understand the health and water quality issues of connecting the tanks from the Water Tank Subsidy programme to the public potable supply.
- Further assessment of the theoretical yield of each catchment based on recent rainfall data and intake flow metering must be undertaken to verify the data presented by the ADB. Theoretical source yields should then be compared with measured flow meter data as it becomes available.
- Once the field studies and flow monitoring equipment has been installed, it is recommended the model is refreshed with the new system flow and pressure values and if necessary the proposed works are updated with the changes.
- As flow meter data becomes available, customer demand profiles specific to Rarotonga should be derived to replace the standard demand profiles used within the hydraulic model.
- Pressure testing (or similar) is undertaken in addition to hydraulic modelling for the recommended upgrade of the trunkmain size to ascertain the optimum replacement date for the newer trunkmains installed in the 1990's.
- The processes and measures introduced to reduce the demand should be documented in a water demand management plan to maximise the availability of water during periods of low flows to the water intakes.
- It is recommended that a drought management plan and contingency water sources are developed to ensure the long term security of supply for Rarotonga.
- It is recommended that an end use survey of domestic properties be undertaken to understand where and how water is being used, indoors and outdoors, across a representative group of domestic properties across the island.
    - A similar survey of commercial users could also be undertaken.
- Further refinement of the cost estimates should be undertaken as improved project definition becomes available.
- It may be possible to carry out raw water quality monitoring with some guidance from Watercare labs, or samples could be air freighted to Auckland for analysis. We would recommend doing this over the next year in preparation for the detailed treatment design solution at each site – including following storm events.
- Although the addition of fluoride sits outside the scope of this Master Plan, we recommend the Government of the Cook Islands reviews the health benefits of this. A decision on whether to include this in the water system could be made during the detailed design phase.

Training, processes and procedures

- Plans for the routine flushing of mains with high water ages should be developed as part of the routine operation of the system.
- Procedures and processes should be put in place for maintenance, servicing, renewal and repair of assets.
- The introduction of a robust procedure and ensuring all staff are adequately trained will minimise the risk from the transport of sodium hypochlorite to the treatment plants.
- It is recommended that Rarotonga water supply staff be trained in how to monitor water quality through the multiple systems that supply drinking water on the island.
- It is recommended that a comprehensive non-revenue water programme is developed.
    - Establish a water balance for the Rarotonga water supply network.
        - Determine the target economic level of leakage / ILI for the Rarotonga water supply network, confirming that the 10% target is an achievable and economic long term target.
    - Create district metered areas / supply zones to enable minimum night flow leakage calculations to be undertaken.
    - Undertake regular analysis of data collected to understand leakage levels.

- It is recommended that a policy be developed to manage illegal connections. Examples include warnings or fines for illegal connections, reporting of suspected illegal connections by the community.

- Operations planning should further investigate methods to facilitate water turnover in reservoirs once they are operational.
- Operators, or service contractors, should be appropriately trained and procurement strategies for the replacement of assets should be implemented.
- Adequate construction supervision must be implemented to ensure adequate material and construction standards are followed during the construction phase of the Te Mato Vai project.

Stakeholder and customer communication

- Stakeholder and customer communication will be an important component in establishing a commitment to use of the potable water supply by demonstrating the additional benefits it may provide e.g. reduced public health risk, fire-fighting supply.
- During the detailed design phase, community engagement and consultation will be required to ensure public acceptance of the system as recommended. This consultation should also identify any aspects of the Master Plan that will need to be modified or removed.
- Further community engagement and consultation will be required during the detailed design phase around land acquisition for the Te Mato Vai project.

16.0 Abbreviations

AC	Asbestos Cement
ACENZ	The Association of Consulting Engineers NZ
ADB	Asian Development Bank
ADWS	Australian Drinking Water Standards
AM	Asset Management
AMIS	Asset Management Information System
AMSL	Above Mean Sea Level
CAPL	Current annual volume of physical losses
CCECC	China Civil Engineering Construction Corporation
CI	Cast Iron
CIIC	Cook Islands Investment Corporation
DEM	Digital Elevation Model
DI	Ductile Iron
DWSNZ	Drinking Water Standards New Zealand
EIB	European Investment Bank
EU	European Union
GI	Galvanised Iron
GIS	Geographic Information System
GoCI	Government of the Cook Islands
Ha	Hectare
ILI	Infrastructure Leakage Index
IPENZ	The Institution of Professional Engineers NZ
IWA	International Water Association
LNF	Legitimate Night Flow
m	metre
m^3	Cubic metres
MAAPL	Minimum achievable annual volume of physical losses
MAOP	Maximum allowable operating pressure
MF	Microfiltration
MFAT	Ministry of Foreign Affairs and Trade
MFEM	Ministry of Finance and Economic Management
mm	Millimetre
MNF	Minimum night flow
MOIP	Ministry of Infrastructure and Planning
NNF	Net Night Flow
NRW	Non-revenue water
NSDP	National Sustainable Development Plan
NZ	New Zealand
NZCIC	New Zealand Construction Industry Council
NZDOS	NZ Department of Survey
PE	Polyethylene
PRV	Pressure reducing valve
PUA	Public Utilities Authority
RO	Reverse osmosis
RPZ	Reduced Pressure Zone device
SDR	Standard Dimensional Ratio
SOE	State Owned Enterprise
TAU	Te Aponga Uria
TMP	Traffic management plan
TMV	Te Mato Vai
UF	Ultrafiltration
uPVC	Unplasticised Poly Vinyl Chloride
UV	Ultra violet
WATSAN	Water, Waste and Sanitation unit
WHO	World Health Organisation
WTP	Water treatment plant

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Appendix A

Technical workshop summary outcomes

Appendix B

Model results

Appendix C

Water system options

Appendix C Water system options

In the review of the suitability of the options available to design the concept water system in this Master Plan a number of options were considered and a decision made to exclude these from the final Master Plan. Table 48 below outlines the high level reasons for the exclusion of these options.

Table 48 Water system options considered and high level reasons for non-inclusion in Master Plan

Water system option	High level reasoning for non-inclusion in Master Plan
No treatment of raw waters	The intent of the water treatment is to provide treated water to meet the WHO standards of 2011. With the reported presence of contamination from humans and animals with total coliform, faecal coliform and E-coli levels well above WHO standards for drinking water (ADB, 2009). The raw water is unsafe for potable use and therefore not able to provide clean water to meet the Government of the Cook Islands goal of potable water without treatment.
Centralised treatment plants	Centralised treatment plants offer the benefit of a single plant treating water from multiple sources and economies through avoiding duplication of treatment. However, due to the topography of Rarotonga, the new treatment plants would need to be sited towards the level of the inner ring main. The construction of centralised treatment at this level would require the installation of additional raw water pipes to the treatment plant (from the raw trunkmains) and new potable watermains to provide water back to properties situated along the trunkmains. Each plant would also require a pump station to ensure potable water could be delivered to these properties. Therefore the additional pipe laying and pumping costs make this option uneconomic in general. As outlined in the Master Plan, there are two options that are identified which include combining Ngatoe with Rutaki, and combining Taipara with Totokoitu. It may be possible to combine untreated water near the distribution system rings, and have 1 treatment unit for 2 intakes.
Sand filtration	The sand on Rarotonga is not suitable for rapid slow sand filters. Therefore the sand would need to be imported – this would be an expensive investment (backed up by the 2009 ADB report). Were sand filters to be installed, a store of sand would also be required on the island to allow for the rapid restoration of the filters following damage (e.g. storm washout). Sand filters may require significant space if they are designed to operate as slow-sand filters rather than rapid-sand filters. Slow-sand filtration normally operates at 0.1-0.3 m/h. With intakes that vary from 10 to 40 L/sec, they would require filters with surfaces ranging from 36 m2 to 144 m2. With the availability of land and topographical limitations, the necessary space may not be available at all 12 intakes. For other additional reasons, the ADB (ADB, 2009) also came to the conclusion that slow-sand filters would not be appropriate for Rarotonga.
Non-chlorination of potable water	As outlined above, the source waters have reported presence of contamination from humans and animals with total coliform, faecal coliform and E-coli levels well above WHO standards for drinking water (ADB, 2009). The ADB report states "*All sources are bacteriologically contaminated*

Water system option	High level reasoning for non-inclusion in Master Plan
	and therefore the raw water is unsafe for potable use without disinfection……. There is strong risk therefore of transmission of water-borne bacteria and related disease." With an array of contaminants, a fairly thorough treatment strategy was required in order tom ensure the water supplied protected public health. In addition, the risk of contamination being introduced into the water supply network (through backflow or other route e.g. depressurisation of the network in the vicinity of leaking pipes etc.) will be minimised through maintaining a chlorine residual through the distribution system.
Import of sodium hypochlorite for disinfection	Sodium hypochlorite degrades with time, heat & sunlight. As it is classified as a dangerous good, it would need to be physically separated from other cargo which makes shipping very expensive. In addition a large volume would be required on a regular basis.
Import of calcium hypochlorite for disinfection	Calcium hypochlorite must be kept dry during shipping and storage. If it should it be contaminated with organic material it is likely to be combustible. As it is classified as a dangerous good, it would need to be physically separated from other cargo which makes shipping very expensive. However, a volume of around 20% of the sodium hypochlorite volume would be required.
Use of UV as the sole disinfection at the treatment plants	UV and some chemical disinfectants (e.g. ozone, and chlorine dioxide under certain conditions) do not provide a lasting residual disinfection in water. Residual disinfection is practiced in order to protect drinking water against downstream contamination. This contamination can occur if there is a damaged area of pipe (allowing intrusion of contaminants) or if backflow occurs. Residual disinfectant also helps to prevent microbial regrowth within the distribution system which can lead to aesthetic problems and loss of residual.
UV units fitted at individual properties to disinfect supplied water	It has been estimated that the installation cost of an individual household UV unit would be approximately $3,000. The cost of these across 3,000 properties would exceed the proposed treatment costs, so this option was discounted on economic grounds.
Use of fluoride as a disinfection	Fluoride is added to water to reduce tooth decay. It is not used as a disinfection agent. Water fluoridation, where fluoride is added to the water system is a widespread method for the prevention of dental decay. Although the addition of fluoride sits outside the scope of this Master Plan, we recommend the Government of the Cook Islands reviews the health benefits of this. A decision on whether to include this in the water system could be made during the detailed design phase.
Separation of agricultural supply from potable supply	Separation would require additional trunk mains to deliver water from the intakes, bypassing the treatment plants. Additional ring mains and local reticulation would also be required, at a significant additional cost. Use of the existing ring main has been discounted as one of the drivers for its replacement is to reduce leakage.
Use of trenchless technologies such as slip lining or pipe bursting to replace existing ring / trunkmains	Each trenchless technology requires specialist equipment, the import of which will necessarily raise the cost, bringing it significantly closer to that of a conventional trenched methodology. Pipes situated above ground are not suitable for pipe bursting and those that require upsizing are not compatible with slip lining. Therefore a number of different specialist machines would be required to complete all the replacement works. This would eliminate the potential cost savings through use of trenchless technologies.

Water system option	High level reasoning for non-inclusion in Master Plan
	With no local technical backup, the use of the specialist equipment would be at risk of technological failure, which would in turn cease pipe laying operations. New trunkmains will be constructed as close to the existing alignment (preferably within 1 metre) as possible to minimise land required.

Appendix D

Project cost summary

Appendix E

Project maps

Appendix F

Cost estimate sheets

Appendix G

Project program