Safe and sustainable drinking water for Kiritimati Island
Republic of Kiribati

Costed Concept Designs for

Upgraded Water Supplies at Tabwakea, Banana-Bamboo-Main Camp and Poland

Prepared for
the Pacific Community (SPC)

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Table of Contents

List of Tables

List of Figures

List of Abbreviations and Units

AC	alternating current
DC	direct current
EU	European Union
GGT	gallery ground tank
GPO	general purpose outlet
IDWSKIP	Improved Drinking Water Supply for Kiritimati Island Project, 2014-18
kL	kilolitres (= 1,000 litres = 1 m^3)
kL/day	kilolitres per day (=m^3/day)
km	kilometre
KWASP	Kiritimati Water and Sanitation Project
L	litre
L/p/day	litres per person per day
L/s	litres per second
m	metre (=1,000 mm)
m/s	metre per second
MELAD	Ministry of Environment, Lands and Agriculture Development
MLPID	Ministry of Line and Phoenix Islands Development
mm	millimetre
MSL	mean sea level
PE	polyethylene
PVC	polyvinyl chloride
RAPS	Remote Area Power Supply
SCADA	Supervisory Control and Data Acquisition
SPC	Pacific Community
TOR	Terms of Reference
WSD	Water and Sanitation Division (of MLPID, Government of Kiribati)

1. Summary

Operation of London Tanks and Pumps

- The operation of the transfer pumps that supply water to the London head tank has been changed from its original specification. It now operates automatically in response to the water level in the ground tank and no provision is made to isolate the underground tank while the transfer pumps are operating. This results in excessive operation of the pumps and wastes electricity and should be rectified as soon as possible.

Possible Continuous Pressurised Water Supply

- The provision of a continuously pressurised water supply to customers is not possible if the supply to each village is limited to the very low design water allowance of 60 L/p/day that has been set in the TOR to apply to all the village centres being considered in this report. The most equitable method of limiting the demand to these low levels is to supply all customers with water for only a few hours each day.
- Having an intermittent supply makes it important that householders have a safe and convenient method of storing water for use when the town supply is depressurised.

Possible Use of Mains Electricity for Gallery Pumping

- Having access to mains electricity allows a greater range of pump types and daily pumping hours to be considered leading to cost savings for the expansion of the water supply system to other centres.
- There are few if any advantages to be gained by changing the Decca solar powered pumping system to a mains-powered one as it was designed and built to operate without mains electricity.
- The current diesel pump at Decca gallery DG3W should be replaced with a mains-powered version of the currently used Lorentz solar pumps.
- The Lorentz solar pumps installed at Decca and Four Wells have had a disappointing track record since their installation. However, the pumps have a generally good name in the industry and it is recommended that, given the sophistication of these pumps, additional training in their maintenance and repair should be provided.
- While mains power isn't available at New Zealand Airfield, Lorentz solar pumps are recommended when upgrading that facility for compatibility with the Decca solar pumps and ease of maintenance.
- With the availability of mains electricity in the vicinity of the Decca, Four Wells and the Banana well fields, the use of low head, readily available, reliable and cheap submersible sump pumps should be thoroughly investigated for use in these areas.
- The proposed sump pumps require changes to the hydraulic setup from those used to date and include:
  - Use of a single, centrally located pump on each gallery.
  - The provision of a gallery ground tank (GGT) to service a group of galleries in order to provide a low discharge head for the sump pumps.
  - The GGTs also act as a buffer storage for the mismatch between the relatively high discharge rate from the gallery sump pumps and the lower flow requirements of the long supply pipelines to the villages.
  - Tuning of the daily flow from each gallery can be achieved by using simple electric timers at each gallery. It is expected that pumps will operate with a duty cycle of between 30 and 40 percent. A cycle of 3 hours is anticipated

but consideration of a shorter cycle (of 1.5 hours say) should be considered which could halve the volume of the GGTs although the water hammer implications of that needs to be considered.

- The elevations of the GGTs and the pipelines connecting the galleries to the GGTs need special consideration in order to maintain a low discharge head on the sump pumps. These include:
  - GGTs to be located at lowest practical elevation.
  - The connecting pipeline to have a unit head loss of less than 1 per 1000.
  - Connecting pipelines to maintain a positive head at all times with no high points along their length.
  - 80 or 100mm Helix flow meters without sand filters should be installed.
  - The flexible hose connecting the submersible pump to the PVC pipeline should have a minimum diameter of 32 mm.
- Below ground meter pits containing the flow meter, pressure gauge tapping and reflux valve and fitted with a fire resistant, vandal proof cover should be used.
- A buried isolating valve should be installed downstream of the meter pit.
- Class 12 pressure pipe should be used in areas when insufficient cover over the pipe can be provided.
- Standard 3-pin domestic electrical sockets should be used for the sump pumps and provision needs to be made for installing a standard household electrical timer also into this socket.

GGT and Transfer Pump Considerations

- GGTs are required to have sufficient volume to be able to buffer out the difference in flow rate between the gallery sump pumps and the transfer pumps at each GGT.
- GGTs should be as low as practical with a top water level no more than 1.8 m above the floor level.
- All pipe connections to GGTs except the overflow pipe should be located at the bottom of the tank and fitted with an isolating valve.
- Each tank is fitted with a single suitably rated transfer pump controlled by float switches in the tank.
- The overflow pipe should discharge visibly away from the tank without causing any pooling.
- Each tank should be fitted with an external water level gauge.

Control System Alternatives

- Control systems for monitoring and controlling the starting and stopping of pumps can range from simple household timers and float switches to sophisticated computer-based Supervisory Control and Data Acquisition (SCADA) systems. While there are advantages and disadvantages of each, it is recommended that, at least initially, the simplest and most readily understandable system is employed.

Pumping Options for New Zealand Airfield Galleries

- Mains electricity is unlikely to be available at this site in the near future so Lorentz pumps similar to those currently in use at Decca are recommended in the short term.
- In the longer term, however, mains electricity could be provided allowing consideration of systems similar to those discussed in this report for the Four Wells & Banana well fields.

Estimate of Converting Solar Pumps at Decca to Mains Electricity

- The cost of converting the current Lorentz solar pumping system at Decca to a mains-powered submersible sump pump system would be substantial. It would require mains electricity to be reticulated to each gallery and the replacement of much of the pipe collection system. Modifications to the existing galleries and the construction of at least one GGT would also be required. The estimated cost of conversion would be expected to exceed AU$600,000.

Solar Energy Offsets

- The amount of energy required to pump water from the galleries to the villages is relatively small. The total calculated energy requirements for all new mains-powered pumps at the Decca, Four Wells and Banana well fields, when fully developed as recommended in this concept design is about 130 kWh per day. If averaged over the year, it would be expected that this amount of energy could be delivered by a solar array with a capacity of 25 kW.

Concept Designs

Detailed concept designs were carried out for 4 village centres: Tabwakea, Main Camp, Banana Village and Poland. The designs determined the ultimate population that could be anticipated for each centre based on information contained in the TOR for this project (Annex A), historical and projected populations and Development Plans provided by MELAD.

The analysis carried out at each centre included EPANET pipe network modelling of the gallery supplies and the village reticulation networks. Diagrams and maps of the findings are presented in the report.

Water hammer analyses of the transmission pipelines at each centre were also carried out. While water hammer during pump starts were not found to be a problem, negative pressures of up to minus 5 m were found to occur under some circumstances following pump shutdowns although these could be reduced by increasing the number of GGTs.

It was recommended that each village should have both a village ground tank and a head tank similar to that employed currently in London, although the underground tank installed there is not required.

It is expected that the reticulation will be pressurised for only about 4 hours each day and it is recommended that this should occur at specified times in both a morning and an afternoon session of about 2 hours each.

Table 1 summarises some of the assumptions and findings of various parameters that apply to each of the four centres.

Table 1 Concept Design Parameter Details

	Tabwakea	Main Camp	Banana Village	Poland
Design Population	8,600	6,450	1,050	2,610
Bulk Water Supply Rate (kL/day)	440 +	510	84	207
Design Year	2045	2053	2022	2090
No. of Supply Galleries	11 +	13	3	6
Transmission pipeline augmentation	Yes	Yes	Yes	No
Village water Storage (kL)	285 +	340	75	135
Head Tank Volume (kL)	22.5 +	45	22.5	22.5
Reticulation Peak Demand (L/s)	95	72	12	29

+ Alternatively sourced water supply supplement required after year 2034

Costed Ultimate Designs

Table 2 below shows the estimated cost of the Concept Designs for the ultimate populations at the four village centres that are discussed in detail in this report. Note that the Tabwakea estimate does not include the cost of alternatively sourced water supply required when the population exceeds 5,500 people.

Table 2 Costed Concept Design Systems for Ultimate Populations

Village		**Tabwakea**		**Main Camp**		**Banana**		**Poand**	
Population		8600		6450		1050		2610	
Bulk Water Supply Rate (kL/day)		440		510		84		207	
Item	**Unit Rate**	**No.**	**Cost**	**No.**	**Cost**	**No.**	**Cost**	**No.**	**Cost**
Contractor Establishment Overheads			$950,000		$800,000		$200,000		$600,000
Supervision (local and external)			$500,000		$600,000		$150,000		$300,000
Gallery Construction including Fencing	$135,000	8	$1,080,000	8	$1,080,000			5	$675,000
Gallery Rehabilitation plus Fencing	$25,000			5	$125,000	3	$75,000	1	$25,000
Gallery Instrumentation & Fittings	$4,000	8	$32,000	13	$52,000	3	$12,000	6	$24,000
Mains Power Connection to Galleries and GGT's			$170,000		$180,000		$50,000		
Sump Pumps	$1,500	8	$12,000	13	$19,500	3	$4,500	6	$9,000
Gallery Ground Tanks, Transfer Pumps & Fittings			$100,000		$160,000		$40,000		$80,000
Mains Power Connection to Village Transfer Pumps			$32,500		$35,000		$20,000		$25,000
Gallery Collection Pipelines - 100mm	$60	1,500	$90,000	4240	$254,400	780	$46,800	580	$34,800
Gallery Collection Pipelines - 150mm	$80	4,400	$352,000	6280	$502,400	3940	$315,200	600	$48,000
Chlorination			$120,000		$135,000		$135,000		$135,000
Village Ground Storage Tank & Pumps			$880,000		$650,000		$100,000		$250,000
Village Head Tank Upgrade			$50,000		$50,000		$50,000		$20,000
Village Reticulation - Pipe 50mm	$50					2003	$100,173	2156	$107,820
Village Reticulation - Pipe 100mm	$60	12,247	$734,820	14,862	$891,718	1384	$83,054	4671	$280,265
Village Reticulation - Pipe 150mm	$80	3,691	$295,280	2,504	$200,341	1082	$86,521	2963	$237,035
Village Reticulation - Pipe 200mm	$115	1,157	$133,055	3,381	$388,846			498	$57,213
Village Reticulation - Pipe 250mm	$150	643	$96,450	2,586	$387,923			298	$44,709
Village Reticulation - Pipe 300mm	$200		$0	1,348	$269,596				
Village Reticulation - Pipe 375mm	$270	57	$15,390	20	$5,400				
Village Reticulation - Valves and Fittings			$210,000		$155,000		$30,000		$65,000
Total Cost			**$5,853,495**		**$6,942,124**		**$1,498,247**		**$3,017,842**

2. Introduction

This report has been written in response to the Terms of Reference (TOR) provided by the the Pacific Community (SPC) (refer Annex A).

The objective of the assignment is to perform feasibility assessments and develop concept designs, preliminary cost estimates and recommendations for potential water supply infrastructure improvements on Kiritimati Island. After this consultancy, prioritised water supply improvements will undergo detailed design, construction and commissioning.

Initially, a review was made of the performance data that had been collected since operation of the Decca to London scheme commenced in 2018. The most obvious standout from this review is that the London pumping system was not built according to the original specification and has been operating very inefficiently. While not strictly part of the TOR for this assignment, the findings from this investigation are included in the next section of this report.

3. Review of Operation of London Tanks and Pumps

3.1 Original possible modes of operation

The original concept design (Bencke, 2015) allowed for 3 possible modes of operation of the London Tanks and Pumps, as described below:

- London reticulation fed directly from Decca. This option would only be possible if the actual demand (including leakage) of London consumers could be kept below the available supply from Decca. The likelihood of maintaining actual London demand through Pay-for-use billing and very tight leakage control to these very low values was always seen as optimistic and hence unlikely to be achieved.
- London ground tank supplied directly from Decca and London consumers supplied intermittently from the head tank using the high-rate transfer pumps. For this option, low pressure water supply could be available to many consumers during the day while the Decca pumps were operating and all consumers would get a higher pressure supply intermittently when the transfer pumps were operating.
- Decca water would be directed to the small underground tank from where it would be pumped and stored in the ground tank. The purpose of the underground tank is to keep the pressure in the supply pipeline, to which many London and Tennessee consumers are connected, as low as practical and so restrict their access to the water from Decca in order to get the maximum amount of this water into the ground tank. Then at pre-defined times of the day, the transfer pump sequence would be initiated manually so that the available water in the ground tank could be distributed equitably to all consumers of London and Tennessee.

As expected, the third mode of operation proved to be the most practical.

3.2 Change to automatic mode of operation

In about May 2018 during the commissioning of the London tanks and pumps, a decision was made by the Project to automate the starting of the transfer pumps. Under this revised control arrangement, the transfer pumps started when the water level in the ground tank reached the high float switch which had been lowered down to less than half of the tank's full capacity. Unfortunately, no provision was made to hydraulically isolate the underground tank during this time which has meant that a considerable amount of water has been recirculating continuously (from head tank to underground tank to ground tank and back to head tank) while ever the transfer pumps are operating. This has wasted and continues to waste a vast amount of electricity over these 4 years of operation and caused excessive wear and tear to all the pumps involved. It has also meant that a lot of the water being pumped is not flowing to consumers.

3.3 Recommended change to manual operation of transfer pumps

It is possible to modify the pump control system to overcome this problem and have the system operate automatically but because of London's unique inlet/outlet pipe arrangement with the head tank, it may take some years before it can be designed and incorporated into the current pump control system. Automation will require the pump controller to be integrated with the submersible pump controller which was part of the original specification but was never implemented.

In the meantime, it is the author's strong recommendation that initiation of the automated London transfer pump system is undertaken manually and that a water supply operator is permanently based at the London tanks and pumps compound. As well as manually controlling the transfer pump operation, this operator would be responsible for recording and making daily reports on flows through the current flow meters and pressures (gauge sites yet to be installed) in the London pipe network as well as daily totals of water consumption and hours for which water is available to all consumers (i.e. when water is available in the head tank). He/she should also be responsible for checking that all mechanical equipment is operating as per specification and to inform the head of Water and Sanitation Division (WSD) regarding any necessary repairs or replacements of defective equipment.

The manual initiation of the transfer pump system should be undertaken as soon as possible so as to stop wasting electricity and excessive wear and tear on the pumps. The following arrangement is recommended.

1. Momentary pushbutton switches are wired up in parallel with the two float switches in the ground tank that currently control the automatic starting and stopping of the transfer pumps (i.e. float switches #1 and #2 in Figure 1).
2. Float switch #2 is raised up to near the top of the tank where it was originally intended to be.
3. Times of the day when water will be available to consumers should be determined in consultation with them.
4. At the agreed time for water to be made available to consumers, the water supply operator should:
   - Set the submersible pumps to manual ("Man" on the control panel for these pumps) and set both pumps to "Off".
   - Start the transfer pumps by using the newly installed momentary pushbutton switch that was wired in parallel with float switch #2 (see item 1 above). This effectively "tricks" the current automated pump controller into thinking that the water level in the ground tank has reached the level of float switch #2.
   - Allow the transfer pump system to adjust the number of pumps required to maintain water in the head tank and let this operate for an agreed time based on how much water is available in the ground tank and how many times each day that water will be made available to all consumers.
   - Stop the transfer pumps by using the momentary pushbutton switch wired in parallel with float switch #1. This effectively "tricks" the current automated pump controller into thinking that the water level has reached the level of float switch #1.
   - Monitor the water level in the head tank using the multitrode indicator on the switchboard and the external float device at the head tank.
   - When the head tank is empty, reset both submersible pumps back to "Auto" on the control panel.
5. The water operator should attempt to keep the water level in the ground tank as high as practical so that water is available early in the mornings if that is found to be a desirable time of day for the transfer pumps to operate. This could also prove to be useful if there is a temporary water supply outage from the Decca lens (e.g. a break in the supply pipeline).

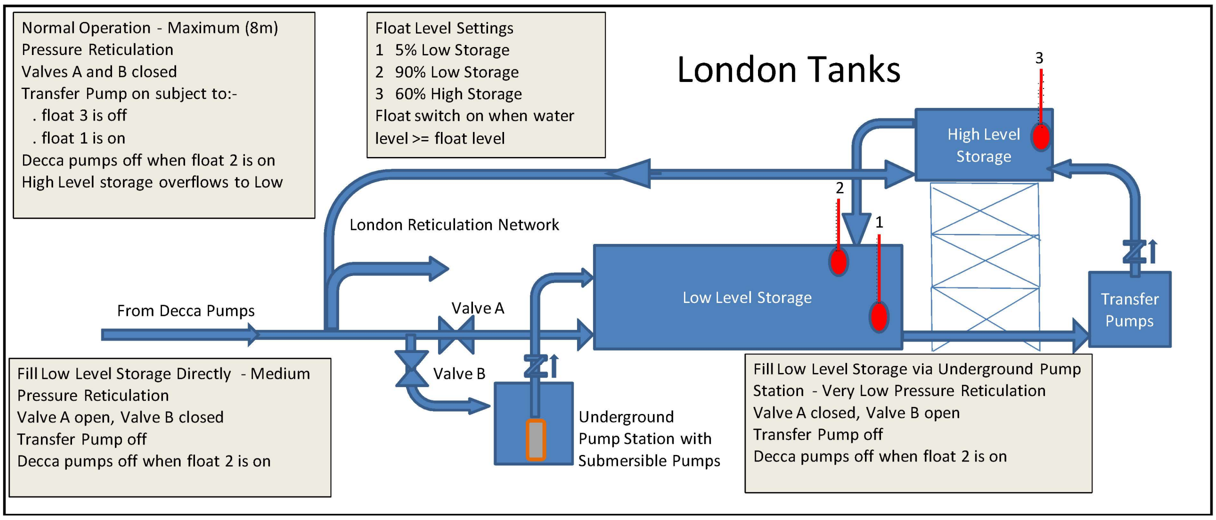

Figure 1 London tanks and pumps operating procedure (modified in 2016 from Bencke, 2015)

4. Feasibility Assessments

4.1 Possible Continuous Pressurised Water Supply

A continuous pressurised water supply is only possible when the available supply of water is equal to or exceeds the actual hydraulic demand on the water supply network.

A distinction needs to be made between an assumed consumer design demand and the actual hydraulic demand on the network as a result of consumers opening their taps plus wastage and leakage from pipe joints and fittings.

For London and Tennessee, the design demand allowance was limited to 90 litres per person per day (L/p/day) in Falkland and White (2008) and Bencke (2015). GHD (2016) recommended 100 L/p/d. This is a very low allowance and consumers would require a very strong incentive to maintain their water demand at or below this allowance. In Australia, this incentive is provided by a pay-for-use water tariff but that incentive is really only effective when it is rigidly enforced and the design demand allowance is considerably greater than has been set for London.

The design situation in Tabwakea is expected to be even worse than it is in London as the current demand allowance in Tabwakea is only 60 L/p/day (Falkland and White, 2008; Bencke, 2015; GHD, 2016). If all the proposed galleries at the Four Wells freshwater lens are in operation by 2025, when the expected Tabwakea population would be about 4,200, the average per capita allowance would be 80 L/p/day which is less than the current London allowance.

While the current population in the Banana-Bamboo-Main Camp area is relatively low, it may be possible to provide a continuous water supply if all the potential galleries in the Banana freshwater lens are developed in the near future. If it is assumed that the current population is 1,450 and the output from all the potential galleries at Banana is made available to the current population, then each consumer could be given an allowance of over 200 L/p/day. At that rate, it may be possible to provide a continuous water supply but the situation would deteriorate if the population in this area increases and no new sources of supply are found to maintain their high allowance.

Leakage from the pipe network is also high in Kiritimati. Leaks in the sandy soil are difficult to locate and resources allocated to find and fix them are limited. In an effort to reduce leakage, the pressure in the pipe network is kept as low as practical while still being able to distribute the water across the whole network. This has been achieved by lowering the distribution head tanks at London and Tabwakea from 10 m to 6 m.

No amount of hydraulic design can change the fact that the actual water demand must always be less than or equal to the available supply. As the supply is currently limited to that available from the freshwater lenses, the actual demand needs to be considerably restricted.

In the past, demand has been restricted by the pressure in the network falling considerably below the design value and water being only available to those consumers who were located in a hydraulically favourable position, i.e. usually close to the water source and with a low elevation so water naturally gravitated to that location.

A more equitable way to restrict demand is to make the water available to all consumers but only for a limited time. This also leads to reduced leakage and water wastage from the reticulation system, as most of the time the pressure in the network is close to zero.

It is therefore important that consumers responsibly store water in their homes for times when the pipe network is de-pressurised. The use of consumer header tanks could play a very useful role in this regard so their disconnection is not recommended. For houses without a functioning header tank, smaller and cheaper methods of storing water should be investigated. All consumers should be encouraged to regard their water supply as precious and not to be wasted.

Poland appears to be a centre where provision of a continuous water supply could be possible. While its demand pattern has not been monitored and analysed in detail, it was the author's considered opinion in 2015 that there was greater community ownership and less wastage of water there. Consumer demand appeared to be lower and the water supply system to be well maintained. It also has access to the largest fresh water lens on Kiritimati so there is less need to maintain the very stringent 60 L/p/day design allocation that has been set for all centres except London. More galleries could be constructed to increase the town's total supply which will allow the head tank at Poland to be supplied for a longer period of time each day. However, the need to supply Poland with a greater water allocation than most of the rest of Kiritimati needs to be traded off against the possible use of that large water reserve to supply Tabwakea in the future.

At present Tabwakea has no identified water source to supply more than 5,500 consumers while it is anticipated to grow to 8,600 by the year 2045. Tabwakea's population is expected to exceed 5,500 in 2034 – just 12 years from now. It may be possible to supply London with water from the New Zealand Airfield freshwater lens as an alternative to installing a desalination plant to supplement Tabwakea's water source. Desalination plants are expensive involving advanced technology and extremely high pressures to force brackish water or even seawater through a semi-permeable membrane which is subject to fowling. The operation and maintenance costs are very high. Energy inputs would be expected to be 20 to 30 times higher than pumping water from New Zealand Airfield. If London was supplied from New Zealand Airfield, then both the Decca and Four Wells reserves could be dedicated to supply Tabwakea. New Zealand Airfield water could also supply Tennessee and even contribute to Tabwakea's requirements using the existing pipeline between London and Tabwakea.

In conclusion, a continuous pressurised water supply at any centre is unlikely.

4.2 Possible use of mains electricity for gallery pumping

4.2.1 Overview

Having access to mains electricity considerably increases the range of pumping options available at the freshwater lenses. When the Decca gallery system was upgraded in 2017, mains electricity was not available and solar pumping systems were installed. There have been a number of problems with these pumping systems related to both the pumps and controllers. The current pumping systems should be maintained unless a solution to the current problems cannot be found. However, this is not the case for the proposed new pumping systems at the Four Wells and Banana freshwater lenses.

The water supply system at each freshwater lens is discussed in more detail in the following sections.

4.2.2 Decca freshwater lens

The groundwater at Decca is supplied to London via a new 150 mm PVC and 180 mm polyethylene (PE) pipeline to southern Tabwakea and then onto Tennessee and London via the older 150 mm PVC pipeline. The new pipeline was installed as part of the EU-funded *"Improved Drinking Water Supply for Kiritimati Island Project"*, 2014-18 (hereafter called IDWSKIP).

At the time of the construction of the new section of pipeline during the IDWSKIP, mains electricity was not available at Decca so the majority of pumps use solar energy. There is one diesel pump and some backup wind pumps.

By its nature, solar energy is not continuous so allowances were made in the design for the majority of the pumps at the Decca galleries to deliver the design flow to Tennessee and London during daylight hours.

These allowances included very generously sized solar panel arrays and an oversized delivery pipeline. This means that even on very overcast days, enough solar energy is available to power the pumps. Similarly, the oversized delivery pipeline means that the total daily water allowance can be delivered in less than 10 hours.

Therefore, there is little to be achieved by converting to mains electricity and the cost of providing this to all the gallery pumping sites which are widely dispersed would be considerable. Unless the current problems with the solar pumps prove to be insolvable, using mains electricity solely on the basis of reducing the maintenance of the solar systems is not recommended at this stage.

The above discussion applies to all the Decca gallery pumps except the one diesel pump at gallery pump well DG3W. This gallery pump is conveniently located close to the main road and hence is close to the 11 kV electric power line. A transformer would be required to reduce the voltage down to 240 volts. The cost of this transformer may be able to be shared with other uses. Assuming that electric power can be made available, it is recommended that the diesel pump be replaced with the same solar pump that is used for the other pumping sites but the pump controller is supplied with 240 volts electric power via a time switch rather than a solar panel.

A possibly cheaper and better alternative would be to operate the pump during the night when the solar pumps are not operating. Under this condition, a cheap sump pump could replace the expensive Lorentz pump and be connected directly into the London supply pipeline without a GGT.

4.2.3 Four Wells & Banana freshwater lenses

Access to a continuous electricity supply will significantly affect the design of the future gallery pumping alternatives, making more options available and generally at a lower capital cost.

These include:

- Making better use of existing water pipelines by pumping for more hours each day.
- Selection from a much larger range of pumps.
- Provision of a more complex pump control system (i.e. SCADA) if that can be justified (refer section 4.3.3).

Gallery pumping options are considered in the following section.

4.3 Reassessment of gallery pump types and control systems

4.3.1 Existing Decca and Four Wells Gallery Pumps

The solar pumps installed during the IDWSKIP have had a disappointing track record to date. For each month in the period from November 2019 to September 2021, there were between two and five non-operational pumps of the 12 solar pumps at the Decca galleries with an average of three non-operational pumps. For each month over the same period, there was an average of one non-operational pump of the 6 solar pumps at the Four Wells galleries.

More recent data on the performance of these pumps received very recently and after this analysis was undertaken have shown a significant improvement which bodes well for their continued use where mains electricity is not readily available.

Problems with the Decca solar pumps seem to relate mostly to the pump controllers which often report errors like “low power” or “low water level” when neither of these conditions are apparent. Often, replacing the controller seems to fix the problem which suggests that the problem was with the controller and not the power supply or float switch. Controllers have even burned out for no apparent reason.

Some Decca solar pumps have also needed to be replaced. In one case, a pump was not assembled correctly in the first place and vibrated considerably while operating. In another case, the rotor was stuck which prevented the pump from operating. Problems have also been experienced with the power cable connection to the pump with water leakage shorting out the pump.

The Lorentz solar pumps that were installed at both Decca and Four Wells galleries are positive displacement helical rotor pumps with a sophisticated advanced controller which is an integrated self-managing system that can operate from solar panels and optimize the output power from the solar panels using maximum power point tracking. The controllers at the Decca solar pumps can be programmed to operate under a wide range of conditions.

The company that produces Lorentz pumps is based in Germany and generally the company has a good reputation for providing reliable well-built products but they have not been successful in Kiritimati. Because of their sophistication, there is very little that can be repaired in country so replacement of components is the only practical option.

The Lorentz pumps are expensive, costing over $5,000 in Australia and the current practice of component replacement to effect repairs makes these pumps a very expensive proposition.

4.3.2 Alternative Gallery Pumping at Decca, Four Wells and Banana

The alternative gallery pumps considered here are at the other extreme end of the pumping range. Instead of using expensive positive displacement solar pumps, it is recommended that readily available, low-head submersible drainage pumps powered by mains electricity be used for future gallery pumping.

Mains electricity has recently been extended close to the Decca, Four Wells and Banana freshwater lenses which allow a greater range of pumping options to be explored for the new galleries that will be constructed there.

The Terms of Reference state that the following 40 kL/day galleries can be expected to be available to supply water to their respective centres:

Tabwakea – total of 11 galleries providing a source supply of 440 kL/day.

- 2 potential galleries at Decca
- 3 existing galleries at Four Wells
- 4 new galleries that have been previously identified at Four Wells
- 2 potential extra galleries at the western end of the Four Wells lens

Main Camp, Bamboo and Banana – total of 10 galleries providing 400 kL/day

- 7 existing galleries located in the Banana water lens
- 3 potential galleries located to the north of Banana village.

The alternative gallery pumping system discussed here could apply to all these galleries and replace any current pumps installed there.

At present, there is no mains electricity supplied to the New Zealand Airfield area that could be used to power the alternative pump option being discussed here. The extension of mains electricity into this area just to meet the pumping requirements of Poland in the near future would seem unlikely. However, the situation could change if it was decided to extensively expand the New Zealand Airfield gallery system in order to supplement the current supplies to London and Tabwakea by constructing a pipeline to London.

Gallery Pump Considerations

Low-head submersible drainage pumps are available from a large variety of sources and come with a wide range of costs and reliability. The pumps considered here are the Grundfos Unilift KP250-A-1 and the Grundfos Unilift CC7 AV-1. Both of these pumps can be purchased in Australia for under $500. The KP250 pump has a slightly greater capacity than the CC7 pump but either would be suitable. Grundfos is a reliable brand that makes a good quality pump and it is the popularity of these pumps that make them so relatively cheap. These pumps are not usually used in a municipal water supply for daily use so, to that extent, there would be some experimentation involved with their use in Kiritimati. However, they have a good reputation as a reliable general-purpose drainage pump that continues to operate often under quite adverse conditions. Their low cost means that they can be used as a disposable item when they fail which, in Kiritimati where repair facilities are limited, is a very favourable characteristic.

Other brands of similar pumps are even cheaper starting at under $150 in Australia. As an example, the hardware chain Bunnings sells a “ClayTech EcoSub 7 Clean and Dirty Water Drainage Pump” for $139. However, these very cheap pumps could prove to be false economy if they are found to need frequent replacement. Individual pumps at the gallery sites are expected to operate for about 8 hours each day.

The design of the gallery pumping systems discussed in this report is based on the pumping specifications of the above-mentioned Grundfos pumps. These are centrifugal pumps whose output varies with the discharge head of the receiving pipe network. This is in contrast to the positive displacement solar pumps whose output flow rate is little affected by the pressure characteristics of the receiving pipe network.

The Grundfos pumps have a relatively low maximum discharge head. Both the KP250 and the CC7 have a shut-off head, where the flow is reduced to zero, of about 7.5 m. Their normal operating range is between 3 and 6 m with maximum efficiency occurring at about 4 to 5 m. The efficiency of these pumps is relatively low being in the order of 15%. However, even this efficiency is high compared to the very generously designed solar-powered, positive displacement pumps that are currently used.

The flow rate from these Grundfos pumps is significantly greater than the output of the current solar pumps and range between 1 and 2 L/s depending on the pump and the discharge head.

Hydraulic Considerations

The very low discharge head of the proposed gallery pumps means that double pumping via GGTs located near the Decca, Four Wells and Banana galleries would be required. Unlike the current solar pumps, the proposed gallery pumps cannot be programmed to deliver a set flow rate. Rather, the total daily flow will be set by varying the individual pump operating times.

Gallery, Collector Pipeline and Gallery Ground Tank Design Considerations

The proposed pumping arrangements for Four Wells are discussed below as an example.

Two pumps each with a nominal daily output of 20 kL/day are currently used on each gallery. It would be considerably more economic and efficient to use a single, centrally located pump for each future 400 m long gallery and consideration should be given to modifying the existing three galleries to allow for this.

The calculated drawdown along both of the proposed 200 m long, 100 mm slotted infiltration pipes is less than 8 mm when delivering a flow of about 0.7 L/s. The actual drawdown will be even less as this longitudinal flow is not confined to the pipe itself and much of the flow will be via the gravel and sand bed that surrounds the pipe. It is therefore considered that except for the single central pump well, no other changes need to be made to current infiltration gallery design.

It is anticipated that ultimately there will be 9 galleries at Four Wells, each with a design yield of 40 kL/day which translates to an average flow of 0.46 L/s per gallery over the full 24 hours of the day.

As discussed previously, the anticipated flow rate from the Grundfos pumps is between 1 and 2 L/s. Using a pump flow rate of 1.5 L/s, a duty cycle of 1 in 3 (i.e. 8 hours per day) would result in a daily average flow rate of 0.5 L/s which is close to the required 0.46 L/s. The duty cycle is defined as the percentage of time that the pump is on during a complete on/off cycle. The cycle period is defined as the total of the "on" and "off" periods of the pump. In order that a simple timer can be used to regulate the daily gallery discharge, a cycle period of 3 hours is anticipated with each pump nominally operating for one hour on and two hours off. However, while "one hour on, two hours off" is conceptually simple, the volume of the gallery tank could be significantly reduced if the nominal "on" time was halved to 30 minutes and the "off" time to 1 hour. However, this will result in twice the number of pump starts which could have implications for the simple pump timers as discussed in section 4.3.3. Reduced GGT storage will also increase the number of starts and stops of the transfer pumps which could have water hammer implications. This potential problem could be reduced by increasing the number of GGTs and thereby reducing the number of sump pumps connected to each GGT.

The GGTs at the gallery sites will provide the buffering between the gallery pumps and the transfer pumps which will deliver the water to the destination village ground tanks at Tabwakea, Main Camp and Banana. The most efficient operation of the total pumping system will be achieved when the "on" time of each gallery pump is staggered relative to the other gallery pumps. However, the volume of the GGT will be sized such that any combination of gallery pump run times will not overflow the GGT.

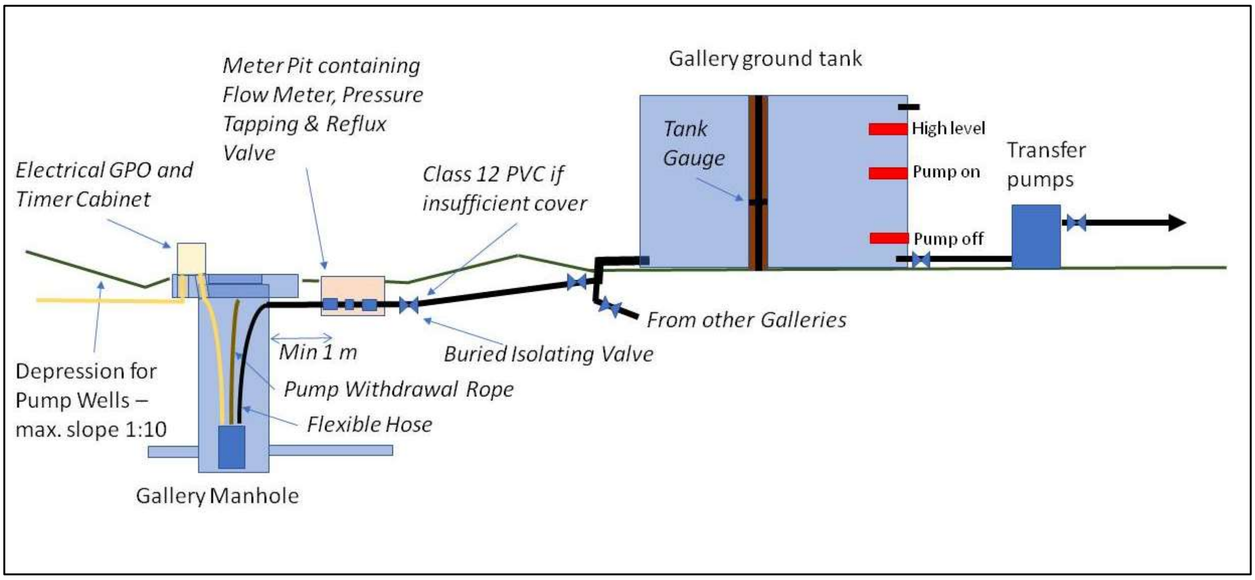

Figure 2 Gallery Pump to GGT Configuration

Conventional transfer pumps will be used to convey water from the GGTs at the gallery sites to the destination village ground tanks. The pumping efficiency of these pumps is considerably better than the gallery pumps and is expected to be about 65%. When combined with an electric motor of 85% efficiency, the overall efficiency of the transfer pumps would be about 55%.

The transfer pumps would be controlled by a simple float switch controller based on the water level in the GGTs, as described below.

The very low discharge head of the proposed gallery pumps places a number of constraints on the pipe arrangement between the galleries and the GGTs.

Firstly, each GGT needs to be located at the lowest practical elevation. A review of gallery monitoring data between 2015 and 2021 suggests that the ground elevation near the existing Gallery 2 East pump well is about 1.8 m above mean sea level (MSL) while the water level in the gallery is normally about 350 mm above MSL and the lowest recorded level was 150 mm above MSL.

This location is also relatively central to the overall extent of the Four Wells freshwater lens. The whole area should be studied to select the best site but for now, this location (Four Wells Gallery 2 East) will be used for the design.

The collection pipelines from each gallery to the GGT needs to generate very little head loss. Also, some galleries could be located some distance from the GGT. In order to minimize friction losses, the unit head loss in all collection pipelines should be kept below 1 per 1,000 which means that the minimum pipe size is 100 mm and if more than one gallery is connected to the pipeline, a 150 mm diameter pipeline will be required.

It is essential that the collection pipes from each gallery maintain a positive pressure and do not have any high points where air could collect and negatively impact the friction losses along the pipe. This means that all the collector pipelines need to be laid at a level equal to or below the level of the base of the GGTs. Also, any slope in the pipelines need to be upwards towards the GGT so any air in the pipelines is expelled at the GGT.

In some cases where the ground level at a gallery pump well is higher than the GGT, this could mean that the collector pipeline from the gallery passes through the wall of the gallery pump well a metre or more below ground level. In this case, consideration should be given to lowering the finished ground level and forming a permanent depression in the vicinity around the manhole. The ground slope of the depression should be no greater than say 1 in 10 and there should be a reverse slope adjacent to the manhole so there is no well contamination from stormwater. If this is not feasible, the flow meter may need to be located away from the manhole. However, the 100 mm gallery discharge pipeline cannot join into pipelines from other galleries until it has passed through a flow meter.

The flow meter will need to be installed in a pit and it would generally be impractical for the pit to be deeper than 500 mm. The recommended flow meter would be either an 80 mm or 100 mm helix meter in order to minimize head loss and remove the need for a filter. The minimum flow rate in the pipeline when the gallery pump is operating will always be above 1 L/s which is about six to seven times the minimum flow rates for these helix meters. To ensure optimum accuracy, there should be at least 1 m of straight 100 mm PVC pipe installed before the meter.

In order to prevent negative pressures being generated in the delivery pipeline, a reflux (check or non-return) valve needs to be installed. Each reflux valve has to be accessible so it can be replaced if it fails. It would normally be placed downstream of the flow meter also within the meter pit. There should be 300 mm of straight 100 mm PVC pipe between the meter and the reflux valve. A pressure gauge tapping should be installed on that piece of pipe. The cover of the meter pit should be able to withstand small grassfires and be lockable or otherwise protected against vandalism.

A key operated 100 mm gate valve fitted with a PVC valve key sleeve should be buried adjacent to the outside of the meter pit to allow for maintenance of all these upstream components.

Each submersible pump should be connected to the 100 mm collector pipeline via a flexible hose of at least 32 mm diameter. The hose connection on the inside wall of the pump well needs to allow for the pump to be pulled out of the pump well and placed on the concrete adjacent to the pump well opening so that a new pump can be installed without the need to enter the pump well. The hose also needs to be kink-proof while in operation.

The electrical connection to the pump should be via a standard 3-pin plug inserted into a waterproof switched general purpose outlet (GPO). Again it needs to be accessible from outside the pump well. There should be sufficient space around the GPO such that a domestic electric timer can be inserted between the GPO and the pump plug. The conduit connecting the GPO cabinet to the pump well needs to be large enough to draw the pump plug up through it from outside the manhole - using a draw wire if necessary.

The maintenance of sufficient cover over the collection pipes between gallery pump wells and the GGTs will be another important consideration. Where this is not possible, other measures to protect the pipelines (e.g. use class 12 PVC pipe) against vehicles and other sources of damage will need to be undertaken.

Gallery Ground Tank and Transfer Pump Considerations

The working volumes of the proposed GGTs at Decca, Four Wells and Banana are shown in Table 3 along with their anticipated floor level. The top water level of the GGTs should be kept as low as practical and not more than 1.8 m above the floor. The working volume is defined as the volume between the top water level and the lowest level that does not cause air to be drawn into the transfer pump. This would be expected to be about 300 mm above the floor.

Table 3 Gallery Ground Tank Details

Location	Total Working Volume (kl)	Floor Level (m above MSL)	Connected Galleries
Decca	9	2.2	2
Four Wells	32	1.8	9
Main Camp	46	2.0	13
Banana	12	2.0	3

All pipe connections to each GGT (except for the overflow pipe) should be located at the bottom of the GGT and fitted with isolating valves.

Each GGT should be fitted with a single transfer pump that is rated for the number of galleries connected to it and the expected downstream head. The pump design duty point flow rate is the total daily pumped gallery flow divided by 18 hours. The design duty point downstream head is the head expected when all transfer pumps feeding into the common supply pipeline are running and the village ground tank is half full. A spare transfer pump with similar ratings could be added to the list of critical components kept in the WSD store as part of an overall maintenance plan for the whole water supply system.

The pump should start when the water level is about half way between top water level and the lowest operating level (say 1 m above the floor) and should stop at the lowest operating level (say 300 mm above the floor).

The overflow pipe should discharge visibly away from each GGT. If necessary, a pit should be dug and filled with gravel to prevent pooling of water on the ground.

All GGTs should be fitted with an external water level gauge.

4.3.3 Control System Alternatives

Control systems for scheduling pump starting and stopping as well as monitoring the performance of the gallery and transfer pumps at the various centres can range from the simplest to the most sophisticated. Each type has its advantages and disadvantages.

At the simplest end of the spectrum, the gallery pumps could be started and stopped by simple household timers of the type shown in Figure 3 Houshold Timer.

Figure 3 Houshold Timer

The advantages of this type of controller are:

- Low initial cost and replacements are readily available
- Minimal cost of installing a replacement unit
- Changes to pump schedule times require minimal training.

However, their prolonged use switching on pumps of this size is somewhat unknown. While their contact rating of 10 amps is well above the 2 amps drawn by the proposed pumps, the starting current of the pumps could approach 10 amps. Heavy-duty versions of the above timer are also available at about 10 times the cost and are usually recommended for starting and stopping household pool pumps. However, it should be noted that a standard pool pump draws considerably more current (3 to 6 times as much) than the pumps proposed here so these heavy-duty timers are not expected to be required.

The other disadvantage of the heavy-duty timers is that the minimum time interval is 30 minutes compared to 15 minutes for the above timer. The minimum time interval is important when adjusting the total daily pumped flow.

At the other end of the spectrum is a Supervisory Control and Data Acquisition (SCADA) system using radio linkage of galleries and GGTs back to the WSD office in London which could contain any or all of the following:

- Remote setting of gallery pump schedules.
- Remote setting of float levels in GGTs.
- Remote real time monitoring of water levels in GGTs.
- Remote real time monitoring of pump performance.
- Remote real time monitoring of flow meters.

- Automatic data logging and review of historic performance.
- Automatic notification when monitored data deviates from normal performance.

The disadvantages of a SCADA system include:

- High initial cost and cost of hardware and software updates.
- Requires specialised training to update pump schedules, respond to notifications etc.
- Requires specialists to install replacement hardware and reset the software.
- Subject to external hacking.

4.3.4 Pumping Options for New Zealand Airfield Galleries

At present, there is no mains electricity at the New Zealand Airfield freshwater lens but that situation may change in the future. In the short term, the proposed pumping system discussed above cannot be installed without extending electricity to the area. It may be possible to provide a Remote Area Power Supply (RAPS) but that is outside the experience of the author and it would also need to be determined who would own and reliably operate such a specialised system.

Alternative solar powered centrifugal pumps or positive displacement pumps from a different supplier could be investigated but again that is a speciality subject and outside the experience of the author.

In the meantime, Lorentz solar pumps are recommended for compatibility with the Decca solar pumps and ease of maintenance. If the existing Lorentz solar pumps at Four Wells are replaced by mains powered submersible pumps, then they could be used at the New Zealand Airfield Galleries.

4.3.5 Estimate of Cost of Converting from Current Pumping Systems

Investigation of Current System

Before considering the conversion of the current solar Lorentz pumps to this newly proposed scheme, a thorough investigation into the reasons that the Lorentz pumps have performed so badly needs to be undertaken. It is possible that many of the failures are due to poor installation of the pumps, controllers and supporting equipment and not directly the fault of the supplied equipment. As an example, a poor electrical connection between the solar panel and the solar pump controller that exhibited a high resistance and resulting voltage drop when the pump was under load would cause the controller to shut down the pump and report that insufficient power was available from the solar panel. In this case, neither the solar panel, nor the pump controller is faulty but simply the electrical connection between the two. Similarly, a sensor fault reported by the solar controller that appeared to be solved by replacing the controller may not mean that the solar controller was faulty. It could be that a poor connection between the sensor and the controller was inadvertently fixed when the new controller was connected.

A thorough troubleshooting and fixing procedure needs to be determined for diagnosing faults with these pumps and local maintenance personnel need to be given the equipment and training to be able to fully undertake the troubleshooting and fixing procedure.

At this stage, the gallery pumping proposed in this report has not been trialled and it may also prove to have unforeseen problems.

Cost of Conversion

The cost of converting the current mostly solar-powered Decca gallery water collection and pumping system to the system described in section 4.3.2 would be substantial and approaching the cost of developing the system from scratch. Not only would it require mains electricity to be reticulated to each gallery, it would also require the current pipe network to be largely replaced as it currently is not suitable for the low-head submersible drainage pumps now recommended. If those pipelines were to be replaced, then consideration should be given to also placing the electrical reticulation underground as that would not only be more aesthetically pleasing but also less expensive to maintain.

The existing galleries would also need to be modified by constructing a new central manhole to replace the two current ones located towards the ends of the galleries.

In addition to these very large capital works, a new GGT and transfer pump installation would be required.

The estimated cost of undertaking these works would be expected to exceed $600,000.

Therefore, converting from the current solar pumping systems at Decca cannot be recommended at this stage.

4.3.6 Solar Energy Offsets

The total amount of energy used by the proposed electric pumps to pump water from the galleries and deliver it to their respective villages is relatively small.

The estimated daily energy requirements for these pumps at the Decca, Four Wells and Banana lenses are listed in Table 4.

If it is assumed that the long-term daily peak solar intensity equivalent (peak sun hours) is 5 to 6 hours, then the total daily estimated energy requirements at all sites can be delivered by a solar panel array with a capacity of about 25 kW.

Table 4 Daily Pump Energy – Solar Offsets

Location	No. of Operating Pumps	Total Daily Pump Energy Requirement (kWh)	Panel Size (assuming 5 peak sun hours) kW
Decca Gallery Pumps	2	5	1
Decca Transfer Pump	1	4	1
Four Wells Gallery Pumps	9	24	5
Four Wells Transfer Pump	1	16	4
Banana Gallery Pumps	16	44	9
Banana Transfer Pumps	5	26	5
TOTAL	**34**	**119**	**25**

However, it is worth noting that solar panels cannot operate the gallery and transfer pumps directly. To operate the pumps from a solar source not connected to the mains electricity requires batteries to provide the energy source when there is insufficient solar output from the panels (e.g. night time) and a suitably rated inverter to convert the DC to AC current with sufficient power to provide the high starting current of the electric motors.

5. Concept Designs

This section of the report sets out detailed concept designs for 4 village centres: Tabwakea, Main Camp, Banana Village and Poland. The designs determined the ultimate population that could be anticipated for each centre based on information contained in the TOR for this project (Annex A), historical and projected populations and Development Plans provided by MELAD.

5.1 Four Wells and Decca Freshwater Lenses to Tabwakea Village

5.1.1 Agreed Design Demand

The currently planned development for Tabwakea to the year 2045 is for a population of 8,600 people. The agreed demand per capita for water design purposes is 60 L/p/d while the agreed non-domestic allowance is an additional 10%. To both of these is added a third agreed planning design assumption of 20% to allow for water leakage from the system.

Simple arithmetic using these figures results in a Tabwakea design demand in 2045 of 681 kL/day.

5.1.2 Assumed Gallery Supply

Figure 4 shows the location of the current and future galleries at the Decca and Four Wells well fields as set out in the TOR.

The galleries that are anticipated to supply Tabwakea are summarised below.

- 3 existing galleries at Four Wells currently supplying Tabwakea (shown in blue)
- 4 planned galleries at Four Wells (shown in yellow)
- 2 possible additional galleries at Four Wells (shown in purple)
- 2 possible additional galleries at Decca (shown in purple).

With each gallery supplying 40 kL/day, the maximum total supply of gallery water to Tabwakea is 440 kL/day which means that additional sources of potable water will need to be found before the assumed 2045 design demand of 681 kL/day can be met.

The maximum population that can be served at the 60 L/p/d design rate by the galleries alone is 5,500 compared to the 2045 population of 8,600. On current projections, this milestone is expected to be reached in the year 2034.

Figure 4 Existing and Future Galleries at Decca and Four Wells

5.1.3 Transmission Pipeline to Tabwakea

At present there is a 100 mm PVC pipeline that connects the three existing galleries at Four Wells to the existing 150 mm PVC pipeline between Decca and Tabwakea. The 100 mm section of this transmission pipeline is the weak link in the overall transfer system. The extension of the pumping hours made possible by the use of 24-hour mains electricity is insufficient to overcome the flow capacity limitations of this pipeline and it will need to be supplemented.

It has been previously recommended (Bencke, 2015) that an additional 150 mm PVC pipeline is laid between Decca and Four Wells and that recommendation is still supported.

It is recommended that the new 150 mm pipeline is connected to the existing 100 mm pipeline at both ends. The exact location of the new pipeline is not important hydraulically and its location is best determined by its ease of construction and future maintenance.

The Four Wells connection point should be adjacent to the location of the planned GGT and isolating valves installed on pipelines at both ends to allow either pipeline to be taken out of service for maintenance while allowing the other to deliver water to Tabwakea.

A flow meter should be installed on the common pipeline as it exits the transfer pump and before it bifurcates to the 100 mm and 150 mm pipelines. This flow meter could be used in the future to help identify a leak in the transmission line and determine the section of pipeline where it is occurring.

5.1.4 Water Storage and Transfer Pumps

It is proposed to split the pumping duty between gallery pumps and a transfer pump. The gallery pump will be a relatively cheap readily available submersible low-head pump while a more efficient higher head transfer pump will be used to deliver this water to Tabwakea. This splitting of the pumping duty would also allow for some future treatment of the gallery water before it is transferred to Tabwakea if this is required.

As new galleries are expected to be constructed at both Decca and Four Wells, GGTs will need to be installed at both locations.

The GGTs need to be located at the lowest practical elevation while still being relatively central to all existing and future galleries. For Decca, this location has been assumed for analysis purposes to be near Gallery 3, while at Four Wells it is located near Gallery 2.

The purpose of these GGTs is to provide buffer storage to allow for the different flow characteristics between the gallery and transfer pumps. The flow rate from the gallery pumps is largely determined by the availability of a relatively cheap submersible pump while the transfer pumps need to be matched to the hydraulic requirements of the pipelines between Four Wells and Tabwakea.

Readily available submersible pumps have a flow rate substantially greater than the existing solar pumps. Also, unlike the existing solar pumps, their flow rate is significantly affected by the downstream head on the pump.

As previously discussed in section 4.3.2, it is proposed to use only one submersible pump for each gallery. However, the pump rate is such that the daily allowance of 40 kL from each gallery will be pumped in about 8 hours. The total daily quantity of water extracted from a particular gallery will be adjusted by altering the pump run time for that gallery pump.

The minimum energy required to deliver the water from the GGT to Tabwakea would occur if the flow rate through the transfer pump is continuous over a 24-hour period. However, it is not practical to assume a 24-hour period for design purposes as, in reality, pumps and pipelines do not always perform exactly as they are modelled. A model must make assumptions about friction factors for pipes and pipe fittings and these can change with time. Similarly, pump performance can change with time. The exact level of GGTs is also not known at this concept time and the level of water in the galleries changes with time depending on the preceding rainfall.

To allow for variation in these factors and also to allow for the possibility that the design yield from the galleries could be revised upwards in the future (especially during and following very wet periods), it has been assumed that the transfer pumps will deliver their design flow (360 kL/day from Four Wells and 80 kL/day from Decca) in a nominal 18-hour period.

5.1.5 Simulation Model of Four Wells, Decca to Tabwakea System

Figure 5 shows a schematic of the modelled pipe network. It comprises 9 galleries at Four Wells and 2 galleries at Decca feeding into their respective GGTs. The outflow from both GGTs is pumped directly into the pipeline to the Tabwakea village ground tank.

The schematic in Figure 5 has been taken from the EPANET modelling package and the following explanations may help with its interpretation.

- The blue rectangles represent the water in the gallery manhole.
- The green symbols to their left represent the sump pumps.
- The next symbols represent the reflux valves.
- The red and yellow “pump” symbols represent the GGT transfer pumps.
- The 3 T-shaped objects represent the 2 proposed GGTs at Four Wells and Decca and the village ground tank at Tabwakea.
- The coloured lines represent pipes and their colour represents the magnitude of the flow in the pipe according to the legend shown on the diagram.
- All the lines are terminated by nodes which include the tanks and galleries and their colour represents the head of water at that point according to the legend on the diagram.

It is noted that the model is an extended period analysis and this diagram shows the flows and pressures at one instant in time during a 24-hour simulation.

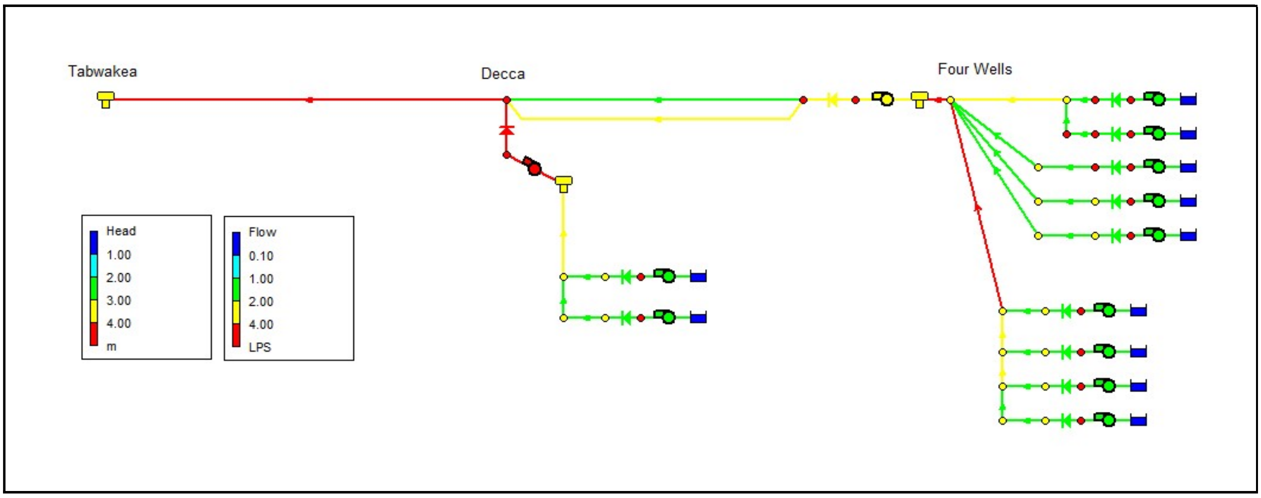

Figure 5 Four Wells to Tabwakea Hydraulic Model Schematic

Annex B contains the data for the Four Wells to Tabwakea EPANET model so that it could be updated in the future if any of the assumptions set out below change.

Model Inputs

Model assumptions include:

- Water level in all galleries set to 0.3 m above MSL.
- Floor level for Four Wells GGT is 1.8 m above MSL.
- Floor level for Decca GGT is 2.2 m above MSL.
- Floor level for Tabwakea village ground tank is 2.5 m above MSL.
- The diameter of the GGTs at Four Wells and Decca are 5 m and 3 m, respectfully.
- The diameter of the village ground tank at Tabwakea is 17 m which corresponds to a volume of 450 kL if the useable height is limited to 2 m.
- The top water level of each GGT is 1.8 m above the floor level.
- The bottom water level of each GGT is 300 mm above the floor level.
- Transfer pumps start when their corresponding GGT water level is 1 m above the floor (pump start float switch level) and stop when the water level drops to 300 mm above the floor (pump stop float switch level).
- Gallery pump characteristics are based on Grundfos CC7-A-1 pump data.
- Four Wells transfer pump characteristics are based on Xylem ESH 50-200 pump coupled to a 4 pole 50 Hz motor. Xylem pumps are currently used to pump water to the London head tank and come in a variety of configurations.
- Decca transfer pump characteristics are based on Xylem ESH 32-250 pump coupled to a 4 pole 50 Hz motor.
- The existing 100 mm Decca to Four wells PVC pipeline is duplicated with a 150 mm PVC pipeline.
- The pipe friction factors are set to a conservative value of 0.3 for the Darcy-Weisbach pipe head loss calculation to allow for pipe deterioration, sand buildup and some air pocket formation in pipelines.
- All gallery pump run times are for exactly one hour starting every 3 hours for the full 24-hour cycle.
- All gallery pumps operate at exactly the same time. Pumps should normally be staggered so as to NOT overlap their run times as much as is practical so this is a worst-case scenario.

Model Results

After a 24-hour extended simulation, the model indicated that the tank at Tabwakea reached a level of just over 2 m above its minimum level corresponding to a volume of 454 kL which is marginally greater than the water source allocation figure of 440 kL specified for Tabwakea in the TOR.

However, the daily volume pumped by the individual pumps varies from 38.7 to 42.6 kL/day. If a result similar to this occurred in the real system, then a small adjustment to the pump timers could bring these daily totals closer to their design figure of 40 kL/day. The 42.6 kL/day pump is over-pumping by 6.5%. This could be corrected by reducing the current total pumping time of 8 hours by 6.5% or 31 minutes. If the household timers discussed in section 4.3.3 are used then this could be achieved by reducing two of the eight one-hour periods by 15 minutes to 45 minutes instead of 1 hour.

While the system modelled has all 9 Four Wells galleries feeding into the one GGT, there is no reason for them all to be brought back to this one point. The two newly proposed galleries at the western end of the Four Wells freshwater lens could be fed to a separate GGT and then pumped into the Tabwakea bulk supply pipelines as proposed for Decca. Splitting up the inflow from the Four Wells galleries like this may have advantages when considering the staging of the works as well as improving the water hammer situation.

5.1.6 Water Hammer Implications

Water hammer can be a problem when there is a sudden change in velocity in the water column of long pipelines which can cause large positive and negative pressure surges to occur. In the case of the Four Wells to Tabwakea pipeline the water column is over 8 km long and the change in velocity is caused by starting and stopping the transfer pumps.

Various water hammer analyses were undertaken for a number of conditions, firstly to determine the magnitude of the problem and then to investigate various methods of alleviating it.

The magnitude of the water hammer pressure surge is less for PVC than for ductile iron because of its relative flexibility. However, this flexibility also reduces the celerity or speed of propagation of the wave. This increases the return period of the pressure wave which can cause an increase in the pressure surges in some situations.

The pipe diameters used here are relatively small and the water velocity in the pipes is quite low so the magnitude of the pressure surges is relatively small being less than 20 m of head. Pump stopping causes the pressure in most of the pipeline to reduce below atmospheric pressure which means that a partial vacuum is formed along nearly the whole length of the pipeline. The lowest pressure occurs in the older section of 150 mm pipeline near Tabwakea where the pressure drops to about minus 4 m of head. At these pressures there is no danger of cavitation causing column separation or pipe collapse due to the partial vacuum. However, there is the possibility of air being drawn into the pipes and getting trapped there. The stopping of the pump will occur many times each day so there is some potential for this trapped air to accumulate. Trapped air pockets will increase the friction losses in the pipe.

Various pipe configurations were tested to see if the magnitude of the negative pressure wave could be reduced. This included installing reflux valves around the pumps to reduce the drag caused by the pumps being “turbined” by the water column that continues to flow but is restricted by the pump. None of the attempted configurations showed any significant improvement.

PVC pipe is subject to fatigue problems when there are a large number of pressure surges over the lifetime of the pipeline. In this particular case, it could be expected that the transfer pumps will start and stop at least 8 times per day. Over a lifetime of say 50 years, that amounts to about 300,000 cycles of a pressure change of about 20 m. According to PVC pipe design information (e.g. Vinidex, 2022), this many cycles would give a fatigue cycle factor of about 0.7 which means that the pipe should have a pressure rating of at least 30 m head. This is comfortably within the rating of the existing Class 6 pipe between Decca and Tabwakea.

The simplest and cheapest method of solving the negative pressure problem is to slowly bring the water column to rest before the pumps are turned off. This is a common practice with larger pipelines and is brought about by slowly closing an in-line valve (or opening a recirculating one in some cases). However, this would significantly complicate the system. It would be prone to failure and is likely to cause more problems than it will solve. It is therefore not recommended at this stage.

5.1.7 Tabwakea Ground Storage and Head Tank Transfer Pumps

Village Ground Tank Volume

The London village ground tank provides sufficient storage for one full day’s water demand. This amount of storage allows for just one period each day when the transfer pumps would operate and pressurise the reticulation network as well as providing minimal emergency storage.

The current practice in London is to have three and sometimes four periods of the day when water is made available to consumers by operating the transfer pumps. The process starts and stops based on two water level float switches – a higher one which starts the pumps and a lower one that stops them.

This means that the actual time of day that water is made available to consumers is somewhat arbitrary and depends on the water level in the London tank when the solar pumps at Decca start up in the morning and the combined pumped flow rate from Decca. Based on the logged performance of the Decca – London system over 4 days in October 2018, water can be first made available to consumers sometime between 7 AM and 9 AM and lasts for less than an hour. The time water is available in the afternoons is more variable and the last water period of the day could start from as early as 3:30 PM or as late as 6 PM. Again the water is normally available for less than an hour.

The current practice uses only about 20% of the available ground storage and a question arises as to whether the previous practice of providing one day's storage should be adopted at Tabwakea.

The current London practice cannot be simply adopted for Tabwakea because water would be delivered from the galleries over the full 24 hours and not just during the daylight hours when London is supplied.

A further question arises about suitable times for the water to be made available to customers and how many times each day should this occur. Another factor that should be considered is that the water allowance for Tabwakea is only 60 L/p/d compared to 90 L/p/d for London. In practice, this will mean that water will be available to Tabwakea consumers each day for only two thirds of the time that water is available to London consumers. Therefore, if water is made available 3 to 4 times each day for Tabwakea consumers, it would be expected to be on for about 30 minutes each time.

It would seem reasonable to assume that a water availability period does not start before 7 AM or after 6 PM. This means that sufficient village ground tank storage needs to be provided to store all the water delivered from the galleries for the 12-hour overnight period.

It also means that the current London practice of starting and stopping of the head tank transfer pumps based on the water level in the tank could not be adopted at Tabwakea as it would not be possible to guarantee that the high-water level float switch would be triggered at exactly 7 AM each day.

If it is assumed that the morning water availability period will start on or before 8 AM and the afternoon availability period will occur no earlier than 4 PM, then the village ground tank working storage could be reduced to 65% of the daily allowance or 285 kL.

It should be noted that this tank volume is dedicated to the gallery water supply. As has been noted previously, the gallery water source can only supply a population of up to 5,500 at the design demand allowance. It is assumed here any new source of water will provide its own tank storage as required.

Transfer Pump Control System

The following algorithm is recommended for controlling the starting and stopping of the watering periods:

- The morning period is started and stopped based on the time of day.
- The mid-day period (if it is deemed to be suitable) is started and stopped based on the time of day.
- The afternoon period is started based on the time of day but only stopped when the low water float switch is triggered.

- At any time, a water period of 10 minutes will commence if the water level in the tank triggers a high float switch level.
- Similarly, at any time, a water period will be terminated if the low float switch level is reached.

At the 60 L/p/d design allowance population of 5,500, it is expected that the total daily watering period will be less than 2 hours. Initially, it would be marginally more than this if all galleries are brought on line initially but the daily water availability period would be expected to fall back to below 2 hours by the early 2030s. For this reason, it is recommended that only two watering periods are provided each day in Tabwakea.

If no new water source is found before the 2045 population of 8,600 is reached, the total daily period when water would be available would be just over an hour.

A system of four transfer pumps similar to those used in London is recommended to pump water from the village ground tank to the head tank. As for London, up to three of the pumps can operate in parallel based on a multitrode level switch in the head tank. Initially, three pumps will start (staggered slightly to reduce starting current draw on the electricity supply) but they are progressively stopped as the water level in the head tank rises towards full.

Unlike London, however, it is recommended that the lead pump of the three duty pumps rotates to the next pump each time a new watering period starts.

It is further recommended that the fourth pump can also be started if the water level drops below a minimum level. This will allow one of the pumps to be not working or out of service.

Head Tank

The current head tank at Tabwakea has a volume of only 22.5 kL. The peak demand or draw from the tank is expected to be up to 95 L/s. At this rate, the head tank provides less than 4 minutes of buffer storage. This is still considered sufficient storage as, by using up to three pumps, the pump flow rate should reasonably match the instantaneous demand rate. It does mean, however, that the transfer pumps could start and stop a number of times during the watering periods.

In order to maximise the useful storage in the head tank, the 375 mm outlet pipe should have anti-vortex vanes or plates installed so that air is not drawn down into the outlet pipe when the water level in the tank is low.

5.1.8 Reticulation Network Design for Tabwakea

Peak Reticulation Demand

Peak reticulation demand was determined using logged performance data from the London reticulation in May 2018. That analysis determined that when the pressure in the reticulation was first raised, the total demand on the reticulation network was 22 L/s or about 7 times the average day rate.

The estimated London population in May 2018 was 2,000 while the design population for Tabwakea is 8,600 in 2045. Assuming that the peak per capita demand in both villages is similar, the design peak demand for Tabwakea is 95 L/s.

EPANET Model

An EPANET model was developed for the Tabwakea reticulation network and a copy of the data file is contained in Annex C.

The design of the reticulation network has been determined using the following assumptions and design principles:

- The 2 m high head tank is half full and placed on a 6 m high tank stand.
- The total water demand of 95 L/s is spatially uniform over the proposed development area. i.e. larger blocks contain more people.
- A water demand allowance of 4 L/s has been applied at the southern end of the network to supply the existing and possible future development of that area.
- A similar water demand allowance of 3 L/s has also been applied to the northern extent of the network.
- All pipes are rubber ring jointed, Class 9 PVC pipe to allow for excessive water hammer generated by entrained air when the system is first pressurised.
- The minimum pipe diameter is 100 mm.
- Ring pipelines allow most areas to be supplied from alternative sources, allowing minimal disruption to supply when maintenance on parts of the network is required.
- A ring pipeline system is not compatible with permanent flow meter installation so they have not been included in the network. District flow meters are only considered useful if sufficiently large resources are devoted to collecting, analysing and acting on the data they produce.
- Valves have been located to allow isolation of areas of the network without disrupting the whole network. Generally, areas of isolation can be limited to less than 50 blocks.

The proposed reticulation network for Tabwakea is shown in Figure 6. The schematic diagram is shown overlaid on a map of the proposed 2045 Development Masterplan for Tabwakea and shows the colour coded calculated residual head at pipe junctions. The pipe network has been designed with a very low unit head loss in order to preserve the low static head from the head tank. The minimum residual head for the network just exceeds 5 m when the head tank is half full.

It is believed that the ground level of the blocks located just above the beach at the northern end of the proposed development is 1 to 2 m above the ground level at the site of the current head tank. This means that the residual pressure at those blocks should not drop below 3 m which should be sufficient for most consumers. If a two-storey building is constructed there, it may require a local pump if water is required on an upper floor of the building.

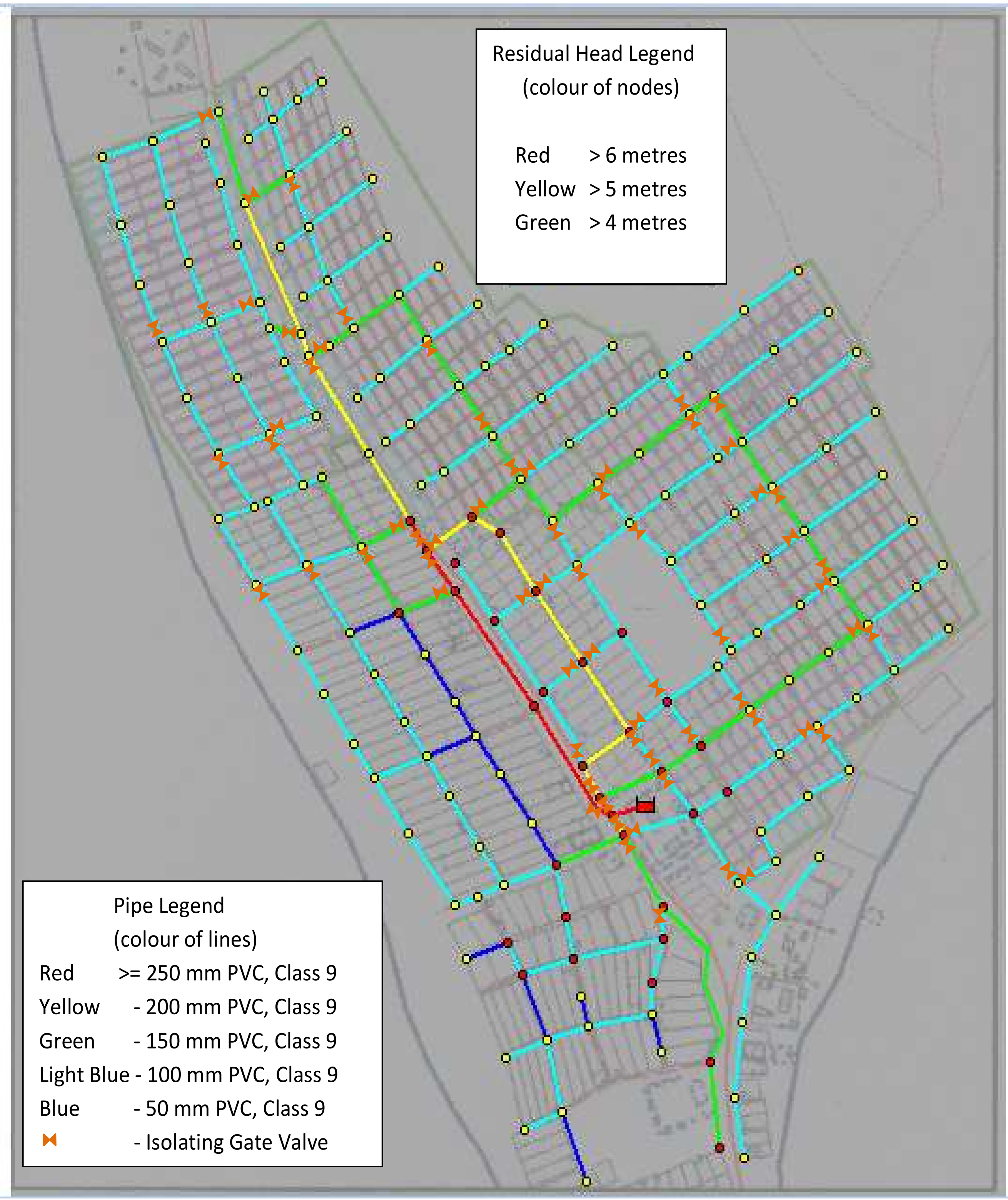

Figure 6 Tabwakea Reticulation Network Schematic

The pipes shown in Figure 6 are also colour coded to reflect their diameter. The minimum pipe diameter for the expanded network is 100 mm. The 50 mm pipes shown in Figure 6 are existing pipes. The diameter of the outlet pipe from the head tank is 375 mm which then connects to two 250 mm pipes and a 200 mm pipe. There are insufficient colours in the legend to distinguish between the 375 mm and 250 mm pipes on the diagram.

It is noted that there is potential to improve this reticulation network if a more central location for the head tank in Tabwakea village could be found – ideally approximately 450m north of the current head tank location, along the main (A1) road. This should be further pursued before implementing the Tabwakea reticulation project.

If there is a preference to use 50 mm PE pipe, it is recommended that its use is limited to the end of dead-end pipelines and that it is limited to serve no more than 6 to 8 blocks. The use of 50 mm pipe will preclude the future extension of the pipeline.

The locations of the proposed isolating gate valves have been added to Figure 6 as an aide for developing future sub-division plans. They are generally located on the pipe tee or a flanged extension of the tee so as to anchor the valve against unbalanced pressures when the valve is closed.

The locations of current isolating valves on the existing pipe network are not shown in Figure 6

5.2 Banana Freshwater Lens to Main Camp, Bamboo and Banana Villages

5.2.1 Agreed Design Demands

The area to be served by the Banana Freshwater Lens is shown in Figure 7. It falls into two development areas:

- The existing Banana village and Airport as well as the proposed new Banana village, all located at the eastern end of the development area.
- The greatly expanded Main Camp and Bamboo villages located on the western side and forming a long ribbon of development adjacent to the main (A1) road which runs through the development.

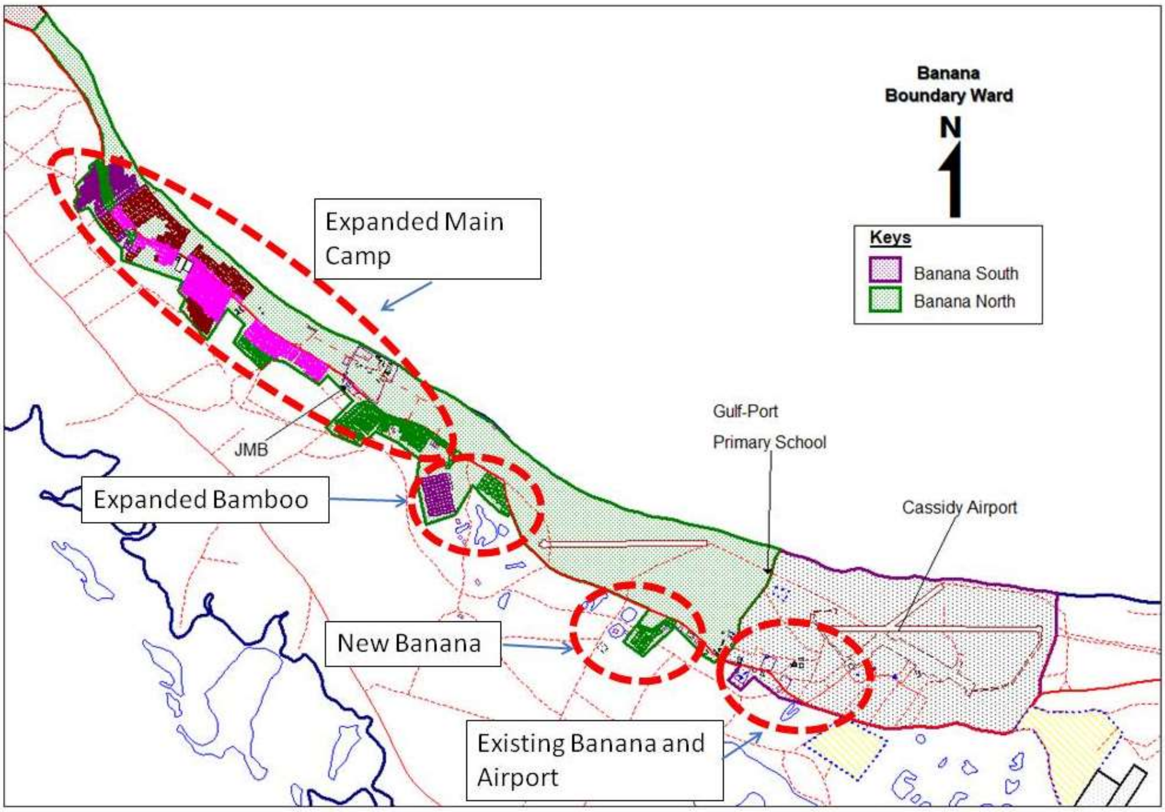

Figure 7 Main Camp, Bamboo and Banana Development Map

The TOR states that the development horizon to be used for design purposes is the year 2045 and the design population is 5,700.

A count of the number of blocks shown on the Ministry of Environment, Lands and Agriculture Development (MELAD) Development Plan and their inferred populations assuming 6 people per household, are as follows:

- Expanded Main Camp – 850 blocks inferring a population of 5,100.
- Expanded Bamboo – 130 blocks inferring a population of 780.
- New Banana – 40 blocks inferring a population of 240.

It is noted that the MELAD Development Plan was released after the TOR was prepared.

The agreed estimate for the current population of Banana Village, Bamboo Village and Main Camp is 1,458 people (as per the 2020 national census) and the assumed household occupancy rate for both permanent and local buildings is 6 people/household. It is further assumed that some of these residents will move to the new development areas.

The design water demand, as set out in the TOR, is 60 L/p/day combined with a 10% addition for non-residential demand and a leakage rate of 20%.

Using these assumptions and that the yield of a standard 400 m long gallery is 40 kL/day, Table 5 shows the design population based on the number of blocks on the development plan plus the current population of the area. A notional allowance of 100 people has also been added for the Airport and the Captain Cook Hotel.

Table 5 Demand Projections based on Banana, Bamboo and Main Camp Development Plan

Location	Blocks	People	Demand (kL/day) @ 60+20%+10%L/p/d	No. of 40 kL/day galleries required
Existing Banana Village	120	720	57.0	1.4
New Banana Village	40	240	19.0	0.5
Airport		100	7.9	0.2
Total Banana Development		1,060	84	2.1
Existing Main Camp & Bamboo	77	462	36.6	0.9
Main Camp	850	5,100	403.9	10.1
New Bamboo	130	780	61.8	1.5
Captain Cook Hotel		100	7.9	0.2
Total Main Camp & Bamboo Development		6,442	510.2	12.8
Grand Total		7,502	594	14.9

It is noted that this revised total design population of 7,502 based on this later information from MELAD is considerably higher than the 5,700 shown in the TOR.

Based on previous population trends, the projected annual growth rate for the current residents is estimated to be 3.4%. Current planning allows for 37.5% of the blocks in the development plan to be occupied by migrants from outside Kiritimati. Using these assumptions, full occupation of the 1,020 blocks indicated on the development plan is not expected to occur until 2053.

5.2.2 Assumed Gallery Flows

The TOR stated that only 10 galleries each with a capacity of 40 kL/day were available to supply all development in this area. The estimated sustainable yield of the Banana gallery made during the Kiritimati Water and Sanitation Project (KWASP) was 555 kL/day (Douglas Partners, 2000) which is 40 kL/day short of what will be required to supply the whole area.

Further studies of the Banana lens are expected to confirm that the sustainable yield can be increased to meet the anticipated demand. In the meantime, the map shown in Figure 8 shows the assumed locations of 17 galleries, only 16 of which are required.

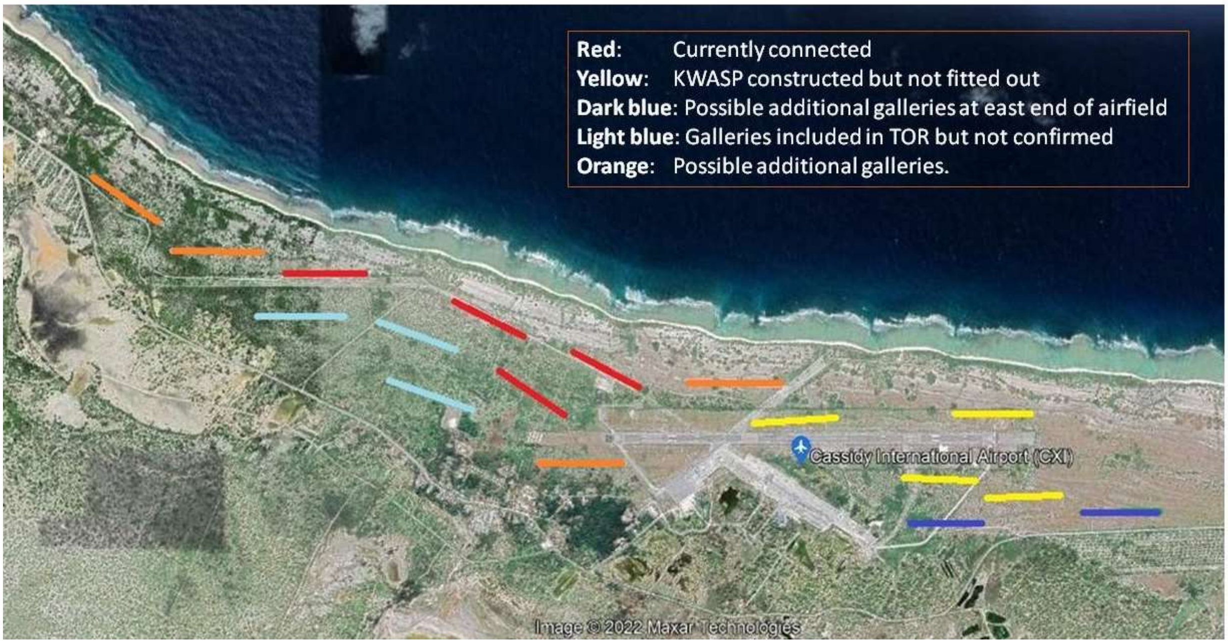

Figure 8 Design Gallery Locations

Referring to Table 5, the total demand of the eastern development zone consisting of old and new Banana is 84 kL/day which requires three galleries. Three galleries on the south of the runway will be assigned to supply this area.

The larger western development of the expanded Main Camp has a total demand of 510 kL/day which will require 13 galleries.

Submersible pumps in each of the galleries will pump water to a series of GGTs located in close proximity to the galleries. Transfer pumps will then deliver this water to village ground tanks located in the existing Banana village and Main Camp through new transmission pipelines.

5.2.3 New Transmission Pipelines to Main Camp and the Existing Banana village

Currently there is a 150 mm PVC pipeline that transports water approximately 6 km from the Banana galleries to Main Camp. This pipeline supplies consumers in Banana village and Main Camp on an intermittent basis by the manual operation of various isolating valves along the way and discharges intermittently to connected households in Main Camp and into a ground tank at the Captain Cook Hotel. Hotel staff pump this water to their privately owned head tanks for use within the hotel.

The existing 150 mm PVC pipeline has sufficient hydraulic capacity to supply water from all 16 proposed galleries to the two proposed zones (Main Camp/Bamboo and Banana) if operated over a 24-hour period. However, it would be difficult to proportionately allocate supply to the two development areas and new distribution pipelines would need to be laid beside this existing main for much of its length.

It is recommended that this pipeline is kept in operation while the new gallery collection system is constructed and two new 150 mm pipelines are laid to deliver water from the proposed GGTs to the new village ground tanks at the existing Banana village and Main Camp.

It is expected that no consumers will be directly connected to these new pipelines. Ultimately, most of the existing 150 mm pipeline will be incorporated into both of the new reticulation networks for the western (e.g. Main Camp, etc) and eastern (e.g. Banana village, etc) developments.

Water will be pumped intermittently from the new village ground tanks at the existing Banana village and Main Camp to adjacent head tanks which will supply their respective consumers on an intermittent basis.

The Captain Cook Hotel has its own head tank which could be supplied intermittently from the Main Camp reticulation network or directly from the village ground tank using its own pump.

Flow meters should be installed downstream of all the transfer pumps located adjacent to the GGTs. Flow meters are required for performance monitoring of the system as well as assisting in identifying leaks in the transmission pipelines.

5.2.4 Water Storage and Transfer Pumps

GGTs are required to provide a buffer storage between the higher capacity submersible gallery pumps and the transfer pumps which operate at a lower flow rate over much of the day and night. The flow rate from the gallery pumps is largely determined by the availability of relatively cheap submersible pumps while the transfer pumps need to be matched to the hydraulic requirements of the pipelines into which they discharge.

The GGTs also provide a lower discharge head for the gallery submersible pumps as discussed in section 4.3.2.

A number of GGTs are expected to be constructed as shown in Figure 9 and Figure 10 in section 5.2.5. GGTs need to be located at the lowest practical elevation while still being relatively central to the galleries they serve.

The minimum energy required to deliver the water from the GGTs occurs if the flow rate through the transfer pump is continuous over a 24-hour period. However, it is not practical to assume a 24-hour period for design purposes as, in reality, pumps and pipelines do not always perform exactly as they are modelled. A model must make assumptions about friction factors for pipes and pipe fittings and these can change with time. Similarly, pump performance can change with time. The exact level of GGTs is also not known at this concept time and the level of water in the galleries changes with time depending on the preceding rainfall.

To allow for variation in these factors and also to allow for the possibility that the design yield from the galleries could be revised upwards in the future (especially during and following very wet periods), it has been assumed that the transfer pumps will deliver their design flow in a nominal 18-hour period.

5.2.5 Simulation Model of the existing Banana village and Main Camp Supply System

Figure 9 and Figure 10 show the modelled pipe network as it appears in the EPANET modelling software. Figure 9 shows the model overlaid on a Google Earth map of the area and gives a general overview of how the 16 galleries are connected to the two village ground tanks at Banana village and at Main Camp.

Figure 10 shows the same model in schematic form. This form shows more clearly how the various components of the system are connected but it is not to scale. As can be seen, there are 4 GGTs fed from 13 galleries for the Main Camp system and one for the Banana Village system which is fed from 3 galleries. Transfer pumps on each of the GGTs feed water to their respective village ground tanks at Main Camp and Banana Village.

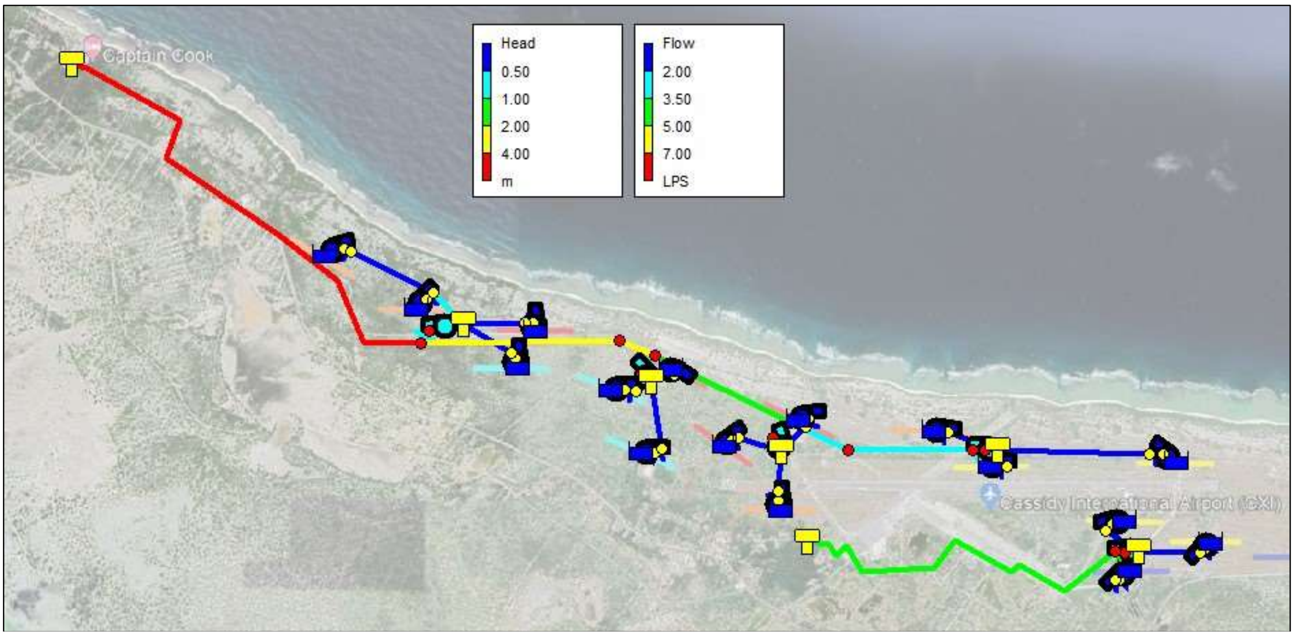

Figure 9 Banana and Main Camp Gallery Supply System Map

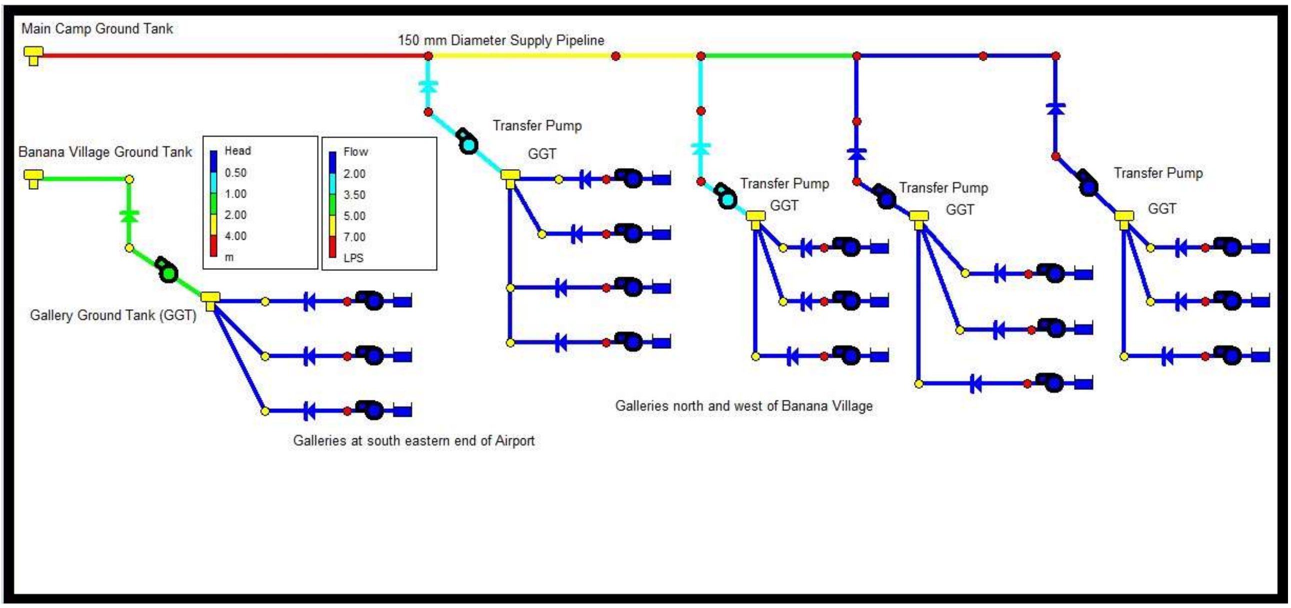

Figure 10 Banana and Main Camp Gallery Supply System Schematic

Both figures use symbols to depict the various components but they are more obvious on the Figure 10 schematic. The following explanations may help with their interpretation.

- The blue rectangles represent the water in the gallery manholes.
- The blue symbols to their left represent the sump pumps.
- The next symbol represents the reflux valves.
- The green, light blue and dark blue “pump” symbols represent the GGT transfer pumps.

- The 7 T-shaped objects represent the 5 proposed GGTs and the 2 village ground tanks at Main Camp and the existing Banana village.
- The coloured lines represent pipes and their colour represents the magnitude of the flow in the pipe according to the legend shown on the diagram.
- All the lines are terminated by nodes which include the tanks and galleries and their colour represents the head of water at that point according to the legend on the diagram.

Model Inputs

Detailed information about this system is not available at this time so this model is a simple overview of a system that would be suitable in this instance. The model should be refined as more information becomes available.

Model assumptions include:

- Water level in all galleries set to 0.3 m above MSL.
- Floor level for all GGTs is 2.0 m above MSL.
- Floor levels for the Main Camp and Banana Village ground tanks are 2.5 m above MSL.
- Gallery pump characteristics are based on Grundfos CC7-A-1 pump data.
- Transfer pump characteristics are typical for the type of pump that would be installed and are loosely based on Xylem ESH series pumps coupled to a 4 pole 50 Hz motor.
- The pipe friction factors are set to a conservative value of 0.3 for the Darcy-Weisbach pipe head loss calculation to allow for pipe deterioration, sand buildup and some air pocket formation in pipelines.

Model Results

Unlike the Four Wells and Decca gallery collection model previously discussed, this is not an extended period simulation. It simply demonstrates that the Grundfos CC7 model submersible pump is quite suitable to collect water from the various galleries and deliver it to its corresponding GGT. The water collected in the various tanks is then transferred to the village ground tanks located in Main Camp and Banana Village at a rate sufficient to deliver the daily design yield of 510 and 84 kL/day, respectively.

Note that in this simulation, greater use is made of GGTs to reduce the length of gallery collection pipes at the expense of more tanks and transfer pumps. There are also water hammer benefits in having more GGTs which will be further discussed in the next section. The extent of this trade-off may change in the final design when the locations of the galleries is better known.

5.2.6 Water Hammer Implications

Water hammer can be a problem when there is a sudden change in velocity in the water column of long pipelines which can cause large positive and negative pressure surges to occur. In the case of the Main Camp pipeline the water column is over 7 km long while the Banana Village pipeline is about 3 km long.

As would be expected, water hammer is more problematic in the Main Camp pipeline because it is both longer and has a higher flow velocity. The worst-case scenario is when there is a power failure and all pumps stop at once. In that case the momentum of the water column continues to draw water into the pipeline for some minutes after the power failure occurs. This would cause the pressure in the pipeline to be reduced to below atmospheric pressure. The magnitude of the pressure reduction is minus 5 m head which is marginally greater than the pressure reduction that occurred in the Tabwakea pipeline.

The greater pressure reduction is caused by the higher velocity in the pipeline due to the greater number of collection galleries.

However, unlike the Tabwakea situation, the water hammer generated during normal operation would be significantly reduced by using a number of transfer pumps so that the velocity change from a single transfer pump stopping is significantly less.

PVC pipe is subject to fatigue problems when there are a large number of pressure surges over the lifetime of the pipeline. With the increased number of GGTs, the water hammer as a result of pump stops is considerably reduced and the only significant water hammer occurs during a power failure. The frequency of power failures in this instance is not known but considering the PVC pipe design information (e.g. Vinidex, 2022), a power failure would have to occur more than twice a day for there to be a significant derating of the pipe for cyclic pressure changes. This is not expected to occur.

5.2.7 Main Camp and Banana Village Ground Storage and Head Tank Transfer Pumps

Village Ground Tank Volume

As discussed in detail for the Tabwakea village ground tank (section 5.1.7), the volume of the village ground tank is a function of the total daily supply allowance (520 kL/day for Main Camp; 90 kL/d for Banana) and the times of the day when water will be pumped up to the head tank for distribution to consumers.

If it is assumed that the morning water availability period will start on or before 8 AM and the afternoon availability period will occur no earlier than 4 PM, then the Main Camp village ground tank working storage could be reduced to 65% of the daily allowance or 340 kL. Similarly, the volume of the village ground tank at Banana Village should be 75 kL.

Transfer Pump Control System

The following algorithm is recommended for controlling the starting and stopping of the watering periods at both centres:

- The morning period is started and stopped based on the time of day.
- The mid-day period (if it is deemed to be suitable) is started and stopped based on the time of day.
- The afternoon period is started based on the time of day but only stopped when the low water float switch is triggered.
- At any time, a water period of 10 minutes will commence if the water level in the tank triggers a high float switch level.
- Similarly, at any time, a water period will be terminated if the low float switch level is reached.

When the system is operating at design capacity, it is expected that the total daily watering period will be less than 2 hours. Initially, if more galleries are installed than is required for the actual population at that time, this watering period could be expected to be more than 2 hours but it would be expected to fall back to below 2 hours as the population approaches the design population.

A system of three transfer pumps similar to those used in London is recommended to pump water from the village ground tank to the head tank at Main Camp. As for London, up to three of the pumps can operate in parallel based on a multitrode level switch in the head tank. Initially, all pumps will start (staggered slightly to reduce starting current draw on the electricity supply) but they are progressively stopped as the water level in the head tank rises towards full.

Unlike London, however, it is recommended that the lead pump rotates to the next pump each time a new watering period starts.

A similar system on a smaller scale is recommended for Banana Village.

Head Tank

The current head tank at Main Camp is unsuitable. The existing 10 m triple tank stand with two 22.5 kL fibreglass tanks at Banana Village would be suitable for future use at Main Camp if they are still in good condition and if the height of the tank stand can be reduced to 6 m. Both Main Camp head tanks should be fitted with nominal 300 mm outlet pipes which are cross-connected using a 300 mm pipe.

A new head tank similar to the existing tank at Tabwakea will be required at Banana Village (i.e. a 22.5 kL tank on a 6 m high tank stand). The tank should be fitted with a 200 mm outlet pipe at its base.

All tanks should be fitted with anti-vortex vanes or plates to prevent air being drawn into the system when the water level is low and so maximise their useful storage.

5.2.8 Reticulation Network Design for Main Camp and Banana Village

Peak Reticulation Demand

Peak reticulation demand was determined using logged performance data from the London reticulation in May 2018. That analysis determined that when the pressure in the reticulation was first raised, the total demand on the reticulation network was 22 L/s or about 7 times the average day rate.

The estimated London population in May 2018 was 2,000 while the design population for Main Camp is approaching 6,500 in 2053. Assuming that the peak per capita demand in both villages is similar, the design peak demand for Main Camp is 72 L/s.

Similarly, the design population for the existing Banana village and New Banana is 1,060 which suggests that the design peak demand for that area is 12 L/s.

EPANET Model of Main Camp and Bamboo

An EPANET model was developed for the ultimate Main Camp reticulation network.

The design of the reticulation network has been determined using the following assumptions and design principles:

- The 2 m high head tank is half full and placed on a 6 m high tank stand.
- The total water demand of 72 L/s is uniform over the proposed development area with each block allocated an instantaneous peak demand of 0.066 L/s.
- All pipes are rubber ring jointed, Class 9 PVC pipe to allow for excessive water hammer generated by entrained air when the system is first pressurised.
- The minimum pipe diameter is 100 mm.
- Cross-connections between parallel pipelines allow most areas to be supplied from alternative sources, allowing minimal disruption to supply when maintenance on parts of the network is required.
- Larger distribution pipelines include some redundancy so that the loss of a single pipeline does not cause large areas of the network to be without water. The exception to this is the large 375 mm outlet pipeline from the tank.
- The degree of redundancy has been determined on the basis of supplying up to 70% of peak demand with one major distribution pipeline out of service.
- Valves have been located to allow isolation of areas of the network without disrupting the whole network. Generally, areas of isolation can be limited to less than 50 blocks.

The proposed reticulation network for Main Camp is shown in Figure 11. It is shown overlaid on a map of the proposed 2053 Development Masterplan for Main Camp. Figure 11 shows the colour coded calculated residual head at pipe junctions. The pipe network has been designed with a very low unit head loss in order to preserve the low static head from the head tank. The minimum residual head for the network just exceeds 4 m when the head tank is half full.

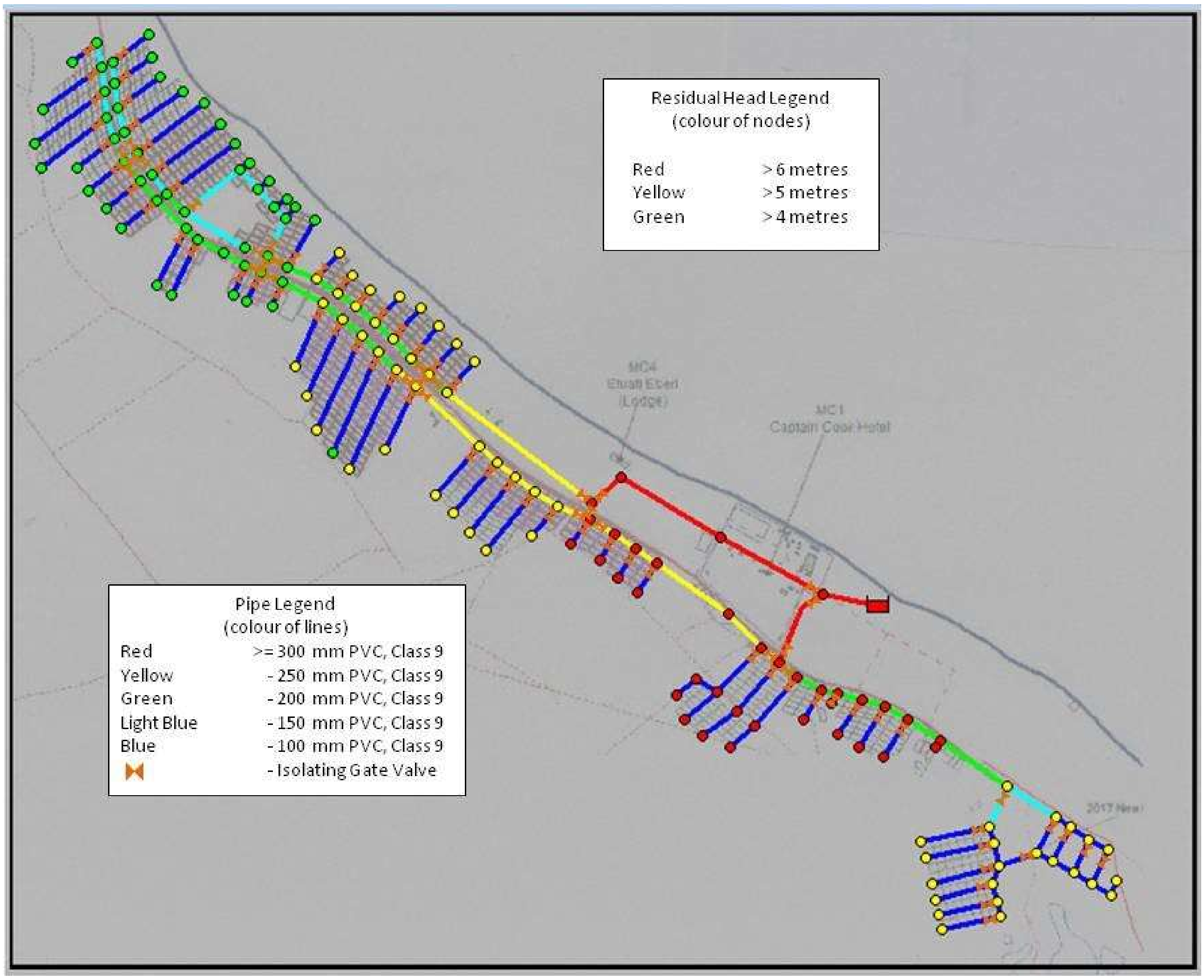

Figure 11 Main Camp and Bamboo Reticulation Network

A minimum of 4 m of head should be sufficient for all areas unless the development includes areas where the ground level is more than a metre higher than the ground level at the head tank site. This means that the residual pressure at those blocks should not drop below 3 m which should be sufficient for most consumers. If a two-storey building is constructed there, it may require a local pump if water is required on an upper floor of the building.

The pipes shown in Figure 11 are also colour coded to reflect their diameter. The minimum pipe diameter for the expanded network is 100 mm. The diameter of the outlet pipe from the head tank is 375 mm which then connects to two 300 mm pipes. There are insufficient colours in the legend to distinguish between the 375 mm and 300 mm pipes in Figure 11.

If there is a preference to use 50 mm PE pipe, it is recommended that its use is limited to the end of dead-end pipelines and that it is limited to serve no more than 6 to 8 blocks. The use of 50 mm pipe will preclude the future extension of the pipeline.

The locations of isolating gate valves have been added to Figure 11 as an aide for developing future sub-division plans. They are generally located on the pipe tee or a flanged extension of the tee so as to anchor the valve against unbalanced pressures when the valve is closed.

Reticulation Networks for the existing Banana Village and New Banana

A reticulation design for the existing Banana Village was produced during the KWASP (71351428 (Banana reticulation plan).dwg) and is shown in Figure 12.

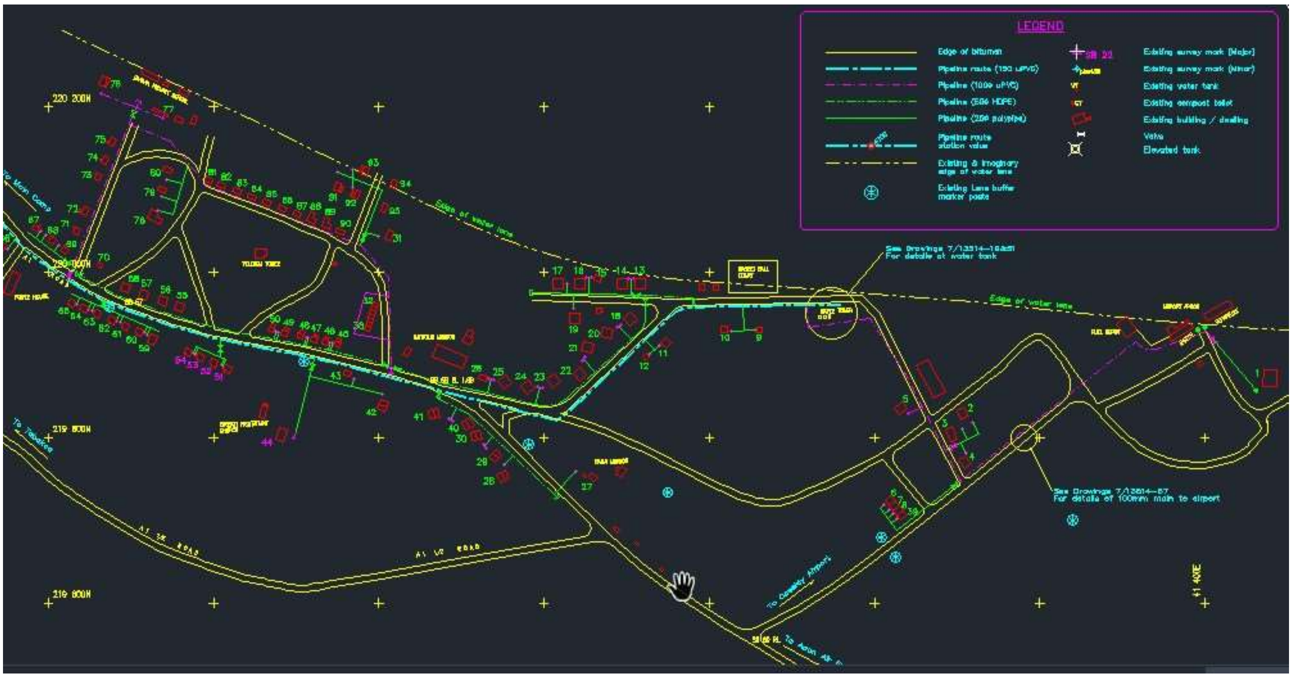

Figure 12 Banana Village Reticulation (KWASP)

However, the WSD Engineer advised that the actual reticulation installed at Banana is as shown by the red lines in Figure 13. The actual condition of the existing reticulation at Banana is unknown although the WSD Engineer indicated that it met the current need of residents and that only some minor replacement of three isolating valves was required at this stage.

If it is found in the future that the reticulation needs to be replaced, the original KWASP drawing as shown in Figure 12 is recommended with a few caveats as follows.

The exact design parameters for the Figure 12 design are unknown but the recommended tank height has been reduced since that time from 10 m to 6 m. Also, the peak instantaneous design flow rate has been significantly increased for this study based on the observed peak consumption flow rates occurring at London.

It is therefore recommended that the minimum pipe diameter be increased from 25 mm to 50 mm. Also, all pipes shown in Figure 12 with a diameter less than 100 mm should be replaced by a 100 mm pipe unless it serves less than 7 houses for a single end feed or 16 houses if it is fed from both ends.

Similarly, all pipes for the new Banana development should be 100 mm diameter unless the pipe supplies fewer than 7 houses and no extension of the serviced area is anticipated.

Both the new and existing Banana developments are supplied from the existing 150 mm pipeline which will now be connected to the new head tank in Banana as discussed in section 5.2.7.

A new isolating valve needs to be installed in the existing 150 mm pipe to isolate the Banana reticulation from the Main Camp reticulation.

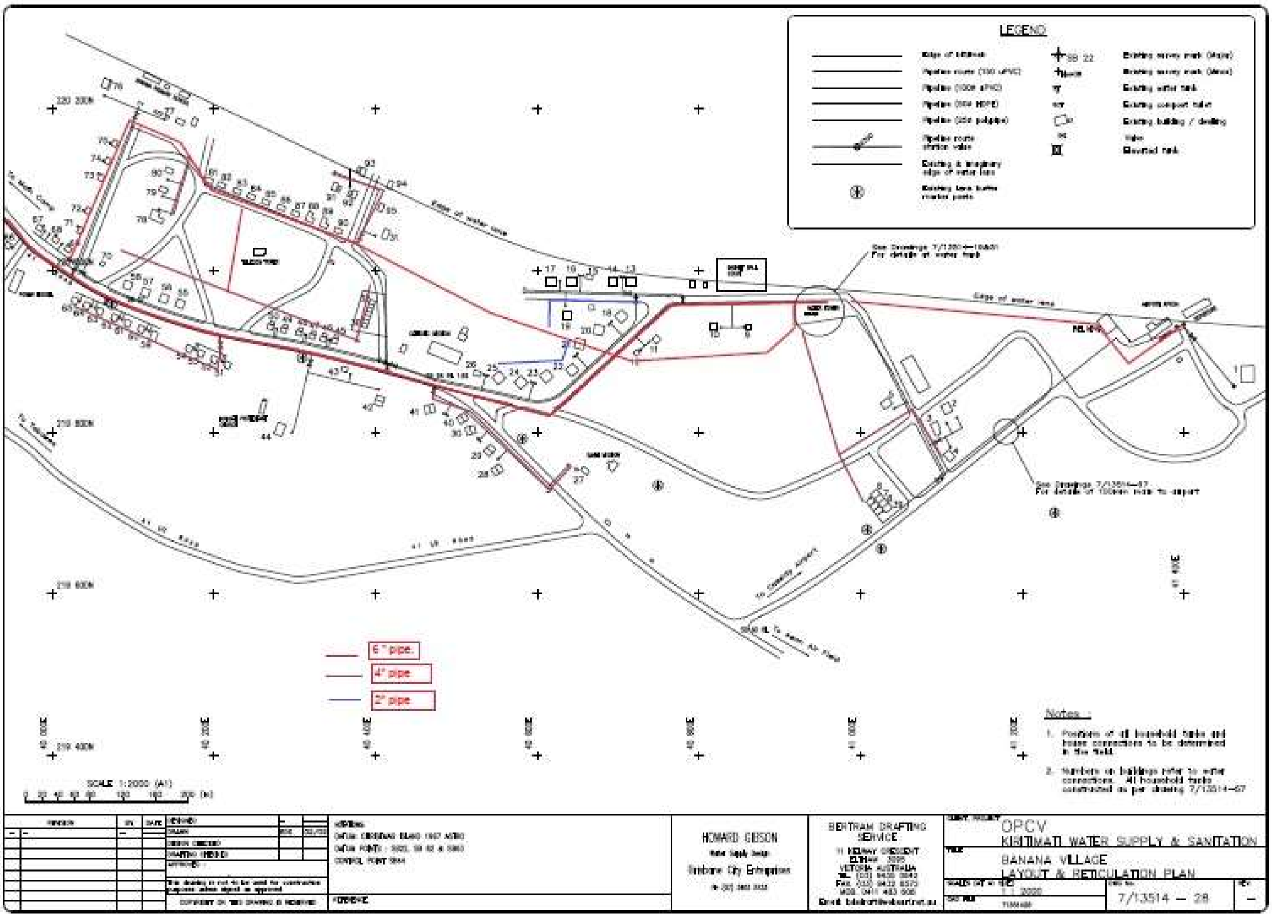

Figure 13 Actual Banana Village Reticulation (revised by WSD)

5.3 New Zealand Airfield Freshwater Lens to Poland Village

5.3.1 Agreed Design Demands

Currently, the small village of Poland with an estimated 2020 population of 403 is partly supplied from the New Zealand Airfield freshwater lens. Figure 14 shows a current Google Earth view of the village which has been overlaid with a portion of the old leases and the new 2017 leases as set out by MLPID and MELAD. The currently serviced houses are outside either the old or new leases and located in the north east portion of Figure 14.

The TOR states that the horizon to be used for design purposes is the year 2045 and the design population is 1,000.

A count of the number of blocks shown on the MELAD development plan for Poland (released after the ToR was published) and their inferred populations are as follows:

- Current Reticulated area – 32 blocks inferring a population of 219.
- Occupied Old Unreticulated Leases – 27 blocks inferring a population of 184.
- New 2017 Leases – 368 blocks inferring a population of 2,208.

The number of new 2017 leases is large relative to the current population and expected growth. For design purposes, it has been assumed that the new leases will have an average occupancy of 6 people per household and that 17.2% of leases will be occupied by migrants from outside Kiritimati, as advised by MELAD.

The design water demand as set out in the TOR is 60 L/p/day combined with a 10% addition for non-residential demand and a leakage rate of 20%.

Using these assumptions and that the yield of a standard 400 m long gallery is 40 kL/day, Table 6 shows the design population based on the number of blocks on the development plan plus the current population of the area.

Figure 14 Existing Poland Village overlaid with MLPID Lease Map

Table 6 Demand Projections based on Poland Development Plan

Location	Blocks	People	Demand (kL/day) @ 60+20%+10%L/p/d	No. of 40 kL/day galleries required
Reticulated Poland Village	32	219	17.3	0.4
Occupied Old Unreticulated Leases	27	184	14.6	0.4
New Leases 2017	368	2,208	174.9	4.4
Total Poland Development	427	2,611	207	5.2

It is noted that the total ultimate population (2,611) to be served is more than two and a half times the 1,000 people set in the TOR.

Based on previous population trends, the projected annual growth rate for the current residents is estimated to be 2.6%. Current planning allows for only 17.2% of the blocks in the development plan to be occupied by migrants from outside Kiritimati. Using these assumptions, full occupation of the 427 blocks indicated on the development plan is not expected to occur before 2085.

5.3.2 Assumed Gallery Supplies

As indicated in Table 6, up to 6 galleries each supplying 40 kL/day will ultimately be required to supply all the currently proposed leases.

Further studies of the New Zealand Airfield freshwater lens are expected to be carried out in the future. In the meantime, the map in Figure 15 identifies the assumed locations of 7 galleries, only 6 of which will be required. The existing gallery is shown in red.

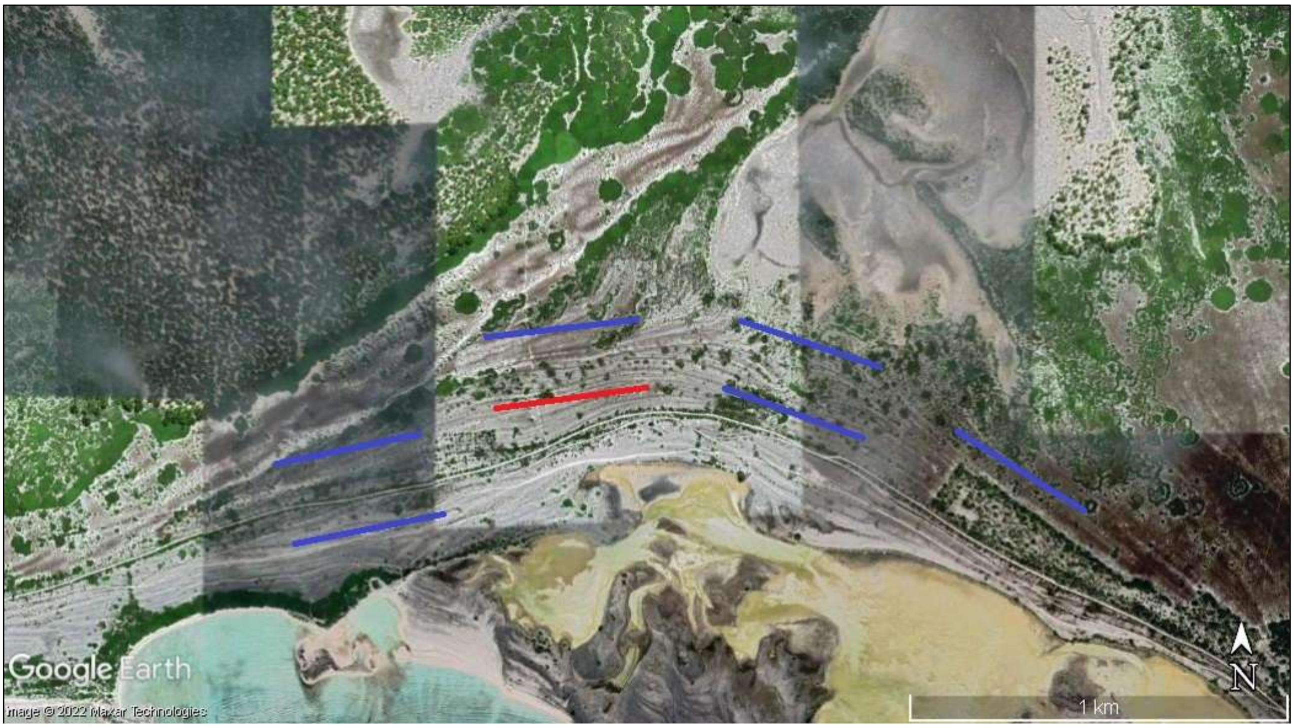

Figure 15 New Zealand Airfield Gallery Locations

Full development of the gallery system to supply Poland is not expected to occur before 2085. It could reasonably be assumed that mains electricity will be available before then to power the gallery pumps. Mains electricity would either be brought from Poland village or from an autonomous solar powered, battery-backed power supply (RAPS).

Submersible pumps in each of the galleries will pump water to a series of GGTs located in close proximity to the galleries. Transfer pumps will then deliver this water to a village ground tank located in Poland.

5.3.3 Need for a New Transmission Pipeline

Currently, there is a DN90mm PN6.3 PE pipeline that transports water 7 km from a single gallery at New Zealand Airfield to Poland. This pipeline has a nominal capacity of about 80 kL/day if it is supplied with solar pumps that can pump at full capacity for 10 hours each day.

At the agreed design demand, a daily supply rate of 80 kL/day would be sufficient to support a population of 1,000. Using the currently projected growth rate of 2.6% and an assumed migrant proportion of 17.2%, this population is not expected to be reached until nearly 2050.

It is expected that it will be possible to provide a 24-hour power supply at the gallery sites sometime before 2050. When 24-hour pumping is available, it will be possible to supply the ultimate population of 2,611 people discussed in section 5.3.1.

Therefore, there seems to be no requirement to replace the existing DN90mm PN6.3 PE supply pipeline in the foreseeable future.

Flow meters should be installed downstream of all pumps. Flow meters are required for performance monitoring of the system as well as assisting in identifying leaks in the transmission pipelines.

5.3.4 Water Storage and Transfer Pumps

It is envisaged that solar pumps will be used at New Zealand Airfield galleries for many years until a reliable electricity supply is available there. Once that is available, it is likely to be more economical to switch to using cheap submersible sump pumps and GGTs as are currently proposed for Four Wells.

GGTs would be required to provide a buffer storage between the higher capacity submersible gallery pumps and the transfer pumps which operate at a lower flow rate over much of the day and night. The flow rate from the gallery pumps is largely determined by the availability of relatively cheap submersible pumps while the transfer pumps need to be matched to the hydraulic requirements of the pipelines into which they discharge.

The GGTs also provide a lower discharge head for the gallery submersible pumps, as discussed in section 4.3.2.

For the ultimate system with 6 galleries in operation, two GGTs are expected to be constructed as shown in Figure 16. This figure shows the modelled pipe network as it appears in the EPANET modelling software overlaying a Google Earth map of the area. It gives a general overview of how the existing gallery (in red) and the 5 new galleries (in light blue) are connected to the two GGTs (green "T") and then transferred to Poland via the two transfer pumps.

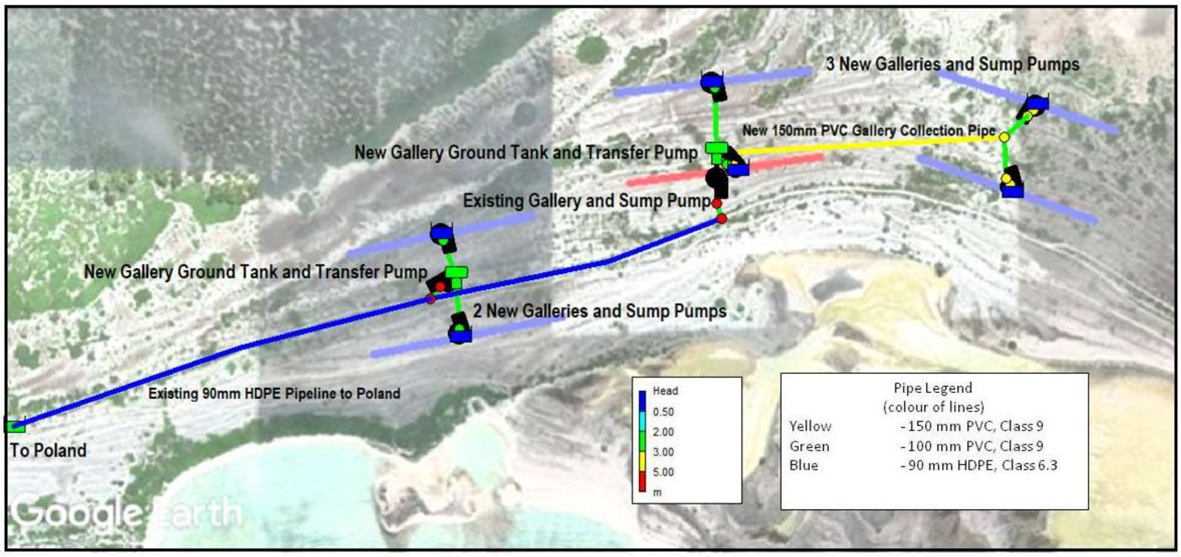

Figure 16 New Zealand Airfield Gallery Pump Configuration

GGTs need to be located at the lowest practical elevation while still being relatively central to the galleries they serve.

The minimum energy required to deliver the water from the GGTs occurs if the flow rate through the transfer pump is such that it operates continuously over a 24-hour period. However, it is not practical to assume a 24-hour period for design purposes as, in reality, pumps and pipelines do not always perform exactly as they are modelled. A model must make assumptions about friction factors for pipes and pipe fittings and these can change with time. Similarly, pump performance can change with time. The exact level of GGTs is also not known at this concept time and the level of water in the galleries changes with time depending on the preceding rainfall.

To allow for variation in these factors but also taking account of the very limited capacity of the existing 90 mm PE pipeline, it has been assumed that the transfer pumps will deliver their design flow in a nominal 22-hour period.

5.3.5 Simulation Model of New Zealand Airfield to Poland System

Model Inputs

Detailed information about this system is not available at this time so this model is a simple overview of a system that would be suitable. The model should be refined as more information becomes available.

Model assumptions include:

- Water level in all galleries set to 0.3 m above MSL.
- Floor level for all GGT is 2.0 m above MSL.
- Floor level of the Poland village ground tank is 2.5 m above MSL.
- Gallery pump characteristics are based on Grundfos CC7-A-1 data.
- Transfer pump characteristics have duty points that are optimised for the number of galleries connected to the GGT. Their duty point flows correspond to 22 hours of pumping.
- The pipe friction factors are set to a conservative value of 0.3 for the Darcy-Weisbach pipe head loss calculation to allow for pipe deterioration, sand buildup and some air pocket formation in pipelines.

Model Results

Unlike the Four Wells and Decca gallery collection model discussed in section 5.1.5, this is not an extended period simulation. It simply demonstrates that the Grundfos CC7 model submersible pump is quite suitable to collect water from the various galleries and deliver it to its corresponding GGT. The water collected in the two GGTs is then transferred to the village ground tank located in Poland at a rate sufficient to deliver the daily gallery yields of 80 and 160 kL/day respectively over a 22-hour period.

Note that in this simulation, greater use is made of GGTs to reduce the length of gallery collection pipes at the expense of more tanks and transfer pumps. There is also a water hammer benefit in having more GGTs which will be further discussed in the next section. The extent of this trade-off may change in the final design when the locations of the galleries is better known.

5.3.6 Water Hammer Implications

Water hammer can be a problem when there is a sudden change in velocity in the water column of long pipelines which can cause large positive and negative pressure surges to occur. In the case of the New Zealand Airfield to Poland pipeline the water column is over 7 km long.

The flow velocity in the Poland supply pipeline when both transfer pumps are operating is marginally less than the velocities in both the Main Camp and Tabwakea supply pipelines resulting in a slightly smaller water hammer impact. As it is the change in flow velocity that causes water hammer, the magnitude of the negative water hammer pressure pulse can be significantly reduced if two transfer pumps are used. The starting and stopping of the transfer pumps is controlled by the water level in their respective tanks so it is very unlikely that both transfer pumps would stop at the same time except during a power failure.

Negative pressures would still be expected following an electricity mains failure when both transfer pumps stop at the same time but the absence of rubber ring joints in this pipeline mean that no adverse impacts are expected from the temporary reduction in pressure to below atmospheric pressure on these rare occasions.

Another advantage of this Poland pipeline being constructed with PE pipe is that it has a slightly lower celerity (at about 240 m/s) than if more rigid PVC pipelines had been used as at the other centres. This again marginally reduces the water hammer impact in this instance although the effect is relatively small.

5.3.7 Poland Ground Storage and Head Tank Transfer Pumps

Village Ground Tank Volume

As discussed in detail for the Tabwakea village ground tank (see section 5.1.7), the volume of the village ground tank is a function of the total daily supply allowance (207 kL/day) and the times of the day when water will be pumped to the head tank for distribution to consumers.

If it is assumed that the morning water availability period will start on or before 8 AM and the afternoon availability period will occur no earlier than 4 PM, then the village ground tank working storage could be reduced to 65% of the daily allowance or 135 kL.

Transfer Pump Control System

The following algorithm is recommended for controlling the starting and stopping of the watering periods at both centres:

- The morning period is started and stopped based on the time of day.
- The mid-day period (if it is deemed to be suitable) is started and stopped based on the time of day.
- The afternoon period is started based on the time of day but only stopped when the low water float switch is triggered.
- At any time, a water period of 10 minutes will commence if the water level in the tank triggers a high float switch level.
- Similarly, at any time, a water period will be terminated if the low float switch level is reached.

When the system is operating at design capacity, it is expected that the total daily watering period will be less than 2 hours. Initially, if more galleries are installed than is required for the actual population at that time, this watering period could be expected to be more than 2 hours but it would be expected to fall back to below 2 hours as the population approaches the design population.

A system of three transfer pumps similar to those used in London is recommended to pump water from the village ground tank to the head tank at Poland. As for London, up to three of the pumps can operate in parallel based on a multitrode level switch in the head tank. Initially, all pumps will start (staggered slightly to reduce starting current draw on the electricity supply) but they are progressively stopped as the water level in the head tank rises towards full.

Unlike London, however, it is recommended that the lead pump of the three duty pumps rotates to the next pump each time a new watering period starts.

Head Tank

The current head tank at Poland has a volume of 22.5 kL and is placed on a 10 m high tank stand. The tank has not been used to date but, assuming that it is still in good order, it should be quite adequate to supply the ultimate design case when the population has increased to approximately 2,600 people. The peak demand or draw from the tank is expected to be up to 29 L/s which is about 30% greater than the current peak demand at London. In order to maximise the useful storage in the head tank, the 250 mm outlet pipe should have anti vortex vanes or plates installed so that air is not drawn down into the outlet pipe when the water level in the tank is low.

The current height of the tank stand at Poland is 10 m. It is recommended that its height be reduced to 6 m as has been done at, or is recommended for, all other centres.

The existing head tank and tankstand at the New Zealand Airfield gallery site is not required and could be dismantled and used elsewhere.

5.3.8 Reticulation Network Design for Poland

Peak Reticulation Demand

Peak reticulation demand was determined using logged performance data from the London reticulation in May 2018. That analysis determined that when the pressure in the reticulation was first raised, the total demand on the reticulation network was 22 L/s or about 7 times the average day rate.

The estimated London population in May 2018 was 2,000 while the ultimate design population for Poland is 2,611 although this population is not expected for many decades at the current growth rate. Assuming that the peak per capita demand in both villages is similar, the design peak demand for Poland is 29 L/s.

EPANET Model of Poland

An EPANET model was developed for the ultimate Poland reticulation network.

The design of the reticulation network has been determined using the following assumptions and design principles:

- The location of the village head tank remains in its current location.
- The 2 m high head tank is half full and placed on a 6 m high tank stand.
- The total water demand of 29 L/s is uniform over the proposed development area with each block allocated an instantaneous peak demand of 0.066 L/s.
- All PVC pipes are rubber ring jointed, Class 9 PVC pipe to allow for excessive water hammer generated by entrained air when the system is first pressurised.
- The minimum pipe diameter is 50 mm PE pipe.
- Cross-connections between parallel pipelines allow most areas to be supplied from alternative sources, allowing minimal disruption to supply when maintenance on parts of the network is required.
- Larger distribution pipelines include some redundancy so that the loss of a single pipeline does not cause large areas of the network to be without water. The exception to this is the large 250 mm outlet pipeline from the tank.
- The degree of redundancy has been determined on the basis of supplying up to 70% of peak demand with one major distribution pipeline out of service.
- Valves have been located to allow isolation of areas of the network without disrupting the whole network. Generally, areas of isolation can be limited to less than 50 blocks.

The proposed reticulation network for Poland is shown in Figure 17. The schematic diagram is shown overlaid on a map of the proposed Development Masterplan for Poland.

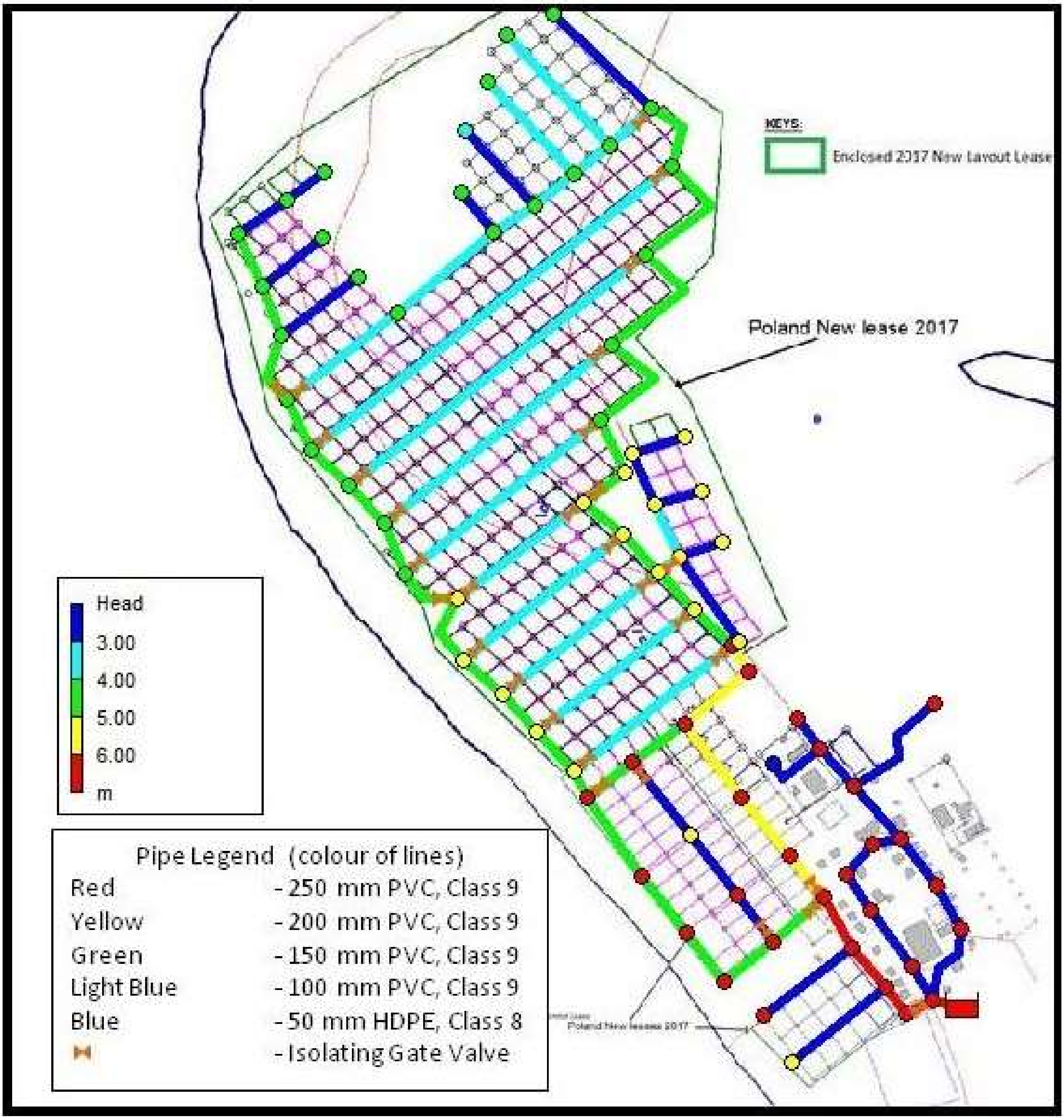

Figure 17 Poland Reticulation Network

Figure 17 shows the colour coded calculated residual head at pipe junctions. The pipe network has been designed with a very low unit head loss in order to preserve the low static head from the head tank. The minimum residual head for the network just exceeds 4 m when the head tank is half full.

A minimum of 4 m of head should be sufficient for all areas unless the development includes areas where the ground level is more than a metre higher than the ground level at the head tank site. This means that the residual pressure at those blocks should not drop below 3 m which should be sufficient for most consumers. If a two-storey building is constructed there, it may require a local pump if water is required on an upper floor of the building.

The pipes shown in Figure 17 are also colour coded to reflect their diameter. The minimum pipe diameter for the expanded network is 50 mm. Generally, 50 mm PE pipe is recommended at the end of dead-end pipelines that are not ever expected to be extended and they serve no more than 6 to 8 blocks. It can also be used when supplied from both ends and in this case could supply up to about 17 blocks.

The locations of isolating gate valves have been added to Figure 17 as an aide for developing future sub-division plans. They are generally located on the pipe tee or a flanged extension of the tee so as to anchor the valve against unbalanced pressures when the valve is closed.

As Poland village develops towards the north-west and the current location of the head tank becomes distant from the centre of the ultimate development, it may prove to be more economic to either move the current head tank to a more central position or split the town into two or more zones each with its own head tank rather than supply the whole area from the current head tank location as shown in Figure 17. These options would involve extending the current supply pipeline from New Zealand Airfield to the new head tank location(s). The advantage of doing this would be a reduction in diameter of some of the larger distribution pipelines that are currently required to move the peak hour flows across the greatly expanded ultimate reticulation network. The savings from reduced pipe sizes, however, need to be traded off against the increased operational complexity and the cost of a new/relocated head tank(s) and their associated village ground tank(s) and pump(s). The shipping cost savings that could come about by increased nesting of pipes should also be considered.

Poland is expected to grow slowly and a very extensive lease development area has been allocated which could take some decades to become sufficiently densely occupied for the residents to require a reticulated water supply. In these circumstances, the timing of a significant movement of the centre of the reticulation towards the north west could be many years into the future. The alternative strategies discussed above should be revisited at the time any expansion of the Poland reticulation is being considered.

6. Costed Ultimate Designs

Table 7 shows the estimated cost of constructing the supply galleries and pipelines and the associated reticulation networks for the ultimate populations discussed in this report. It is noted that these costs are somewhat theoretical as the design populations used are not expected for many decades in the future. This cost estimate assumes that the ultimate system is built now whereas in practice, it is expected that it will be built in a number of stages. It should also be noted that additional costs will need to be added to Tabwakea to supplement the water supply from Four Wells galleries and the two additional galleries at Decca. These 11 galleries are only capable of supplying a Tabwakea population of up to 5,500 people.

The unit rates used in Table 7 are based on rates set out by the Project Coordinator, Jake Ward, in an Excel spreadsheet for costing the first stage of the upgraded water supply system which is mostly focused on improving the water supply to the current residents of Tabwakea (see Annex D).

Table 7 Costed Concept Design Systems for Ultimate Populations

Village		**Tabwakea**		**Main Camp**		**Banana**		**Poand**	
Population		8600		6450		1050		2610	
Bulk Water Supply Rate (kL/day)		440		510		84		207	
Item	**Unit Rate**	**No.**	**Cost**	**No.**	**Cost**	**No.**	**Cost**	**No.**	**Cost**
Contractor Establishment Overheads			$950,000		$800,000		$200,000		$600,000
Supervision (local and external)			$500,000		$600,000		$150,000		$300,000
Gallery Construction including Fencing	$135,000	8	$1,080,000	8	$1,080,000			5	$675,000
Gallery Rehabilitation plus Fencing	$25,000			5	$125,000	3	$75,000	1	$25,000
Gallery Instrumentation & Fittings	$4,000	8	$32,000	13	$52,000	3	$12,000	6	$24,000
Mains Power Connection to Galleries and GGT's			$170,000		$180,000		$50,000		
Sump Pumps	$1,500	8	$12,000	13	$19,500	3	$4,500	6	$9,000
Gallery Ground Tanks, Transfer Pumps & Fittings			$100,000		$160,000		$40,000		$80,000
Mains Power Connection to Village Transfer Pumps			$32,500		$35,000		$20,000		$25,000
Gallery Collection Pipelines - 100mm	$60	1,500	$90,000	4240	$254,400	780	$46,800	580	$34,800
Gallery Collection Pipelines - 150mm	$80	4,400	$352,000	6280	$502,400	3940	$315,200	600	$48,000
Chlorination			$120,000		$135,000		$135,000		$135,000
Village Ground Storage Tank & Pumps			$880,000		$650,000		$100,000		$250,000
Village Head Tank Upgrade			$50,000		$50,000		$50,000		$20,000
Village Reticulation - Pipe 50mm	$50					2003	$100,173	2156	$107,820
Village Reticulation - Pipe 100mm	$60	12,247	$734,820	14,862	$891,718	1384	$83,054	4671	$280,265
Village Reticulation - Pipe 150mm	$80	3,691	$295,280	2,504	$200,341	1082	$86,521	2963	$237,035
Village Reticulation - Pipe 200mm	$115	1,157	$133,055	3,381	$388,846			498	$57,213
Village Reticulation - Pipe 250mm	$150	643	$96,450	2,586	$387,923			298	$44,709
Village Reticulation - Pipe 300mm	$200		$0	1,348	$269,596				
Village Reticulation - Pipe 375mm	$270	57	$15,390	20	$5,400				
Village Reticulation - Valves and Fittings			$210,000		$155,000		$30,000		$65,000
Total Cost			**$5,853,495**		**$6,942,124**		**$1,498,247**		**$3,017,842**

7. References

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Annex A Terms of Reference

ANNEX I

TERMS OF REFERENCE

1. **Project Title**

Safe and sustainable drinking water for Kiritimati Island

2. **Assignment Title**

Consultancy to develop costed concept designs for the Kiritimati Island Water Project

3. Background

Kiritimati (pronounced "Christmas"), one of three inhabited islands in the Line Islands group of Kiribati, is administered by the Ministry of Line and Phoenix Islands Development (MLPID). Kiritimati is the world's largest low-lying coral atoll comprising mostly lagoon and an approximate land area of 388 km² rising to an average 2 to 2.5 meters above mean sea level. The 2020 population was 7,369 according to the 2020 draft national census, spread among four main areas or groups of villages. Kiritimati has had no recorded cases of COVID-19, however the cancellation of the weekly flights to/from Hawaii and Fiji since April 2020 has had a significant impact on the island's typically tourism-dependent economy. Nonetheless, the first batch of COVID-19 vaccines for the Line Islands arrived on Kiritimati on 31 August 2021 with the vaccination program to be rolled-out from September.

The Water and Sanitation Division (WSD), under the Ministry of Line and Phoenix Islands Development (MLPID), manage the island's four main reticulated water supply systems along with water trucking and sanitation services. WSD are challenged with operating and maintaining dated and often dilapidated water infrastructure with little institutional capacity and resources whilst attempting to satisfy growing consumer demand for potable water from the four limited and vulnerable groundwater reserves (Decca, Four Wells, Banana and New Zealand Airfield).

The Government of Kiribati (GoK) has identified Kiritimati Island as a growth centre, and the 2020 population of 7,369 is expected to increase to approximately 17,600 by 2045 with the recent opening of 1,750 new residential land leases in 2017 combined with the construction of a new secondary school and natural population growth. There is, however, only sufficient infrastructure in place (groundwater infiltration galleries, pumps, pipelines, distribution networks, etc.) to meet the demand of 3,080 people (42 percent of the 2020 population; 17.5 percent of the projected 2045 population) at 100 litres per person per day (l/p/d), or 5,140 people (70 percent of the 2020 population; 29 percent of the projected 2045 population) at 60 l/p/d[1]. The effective water supply reach is in fact less due to geographic constraints as the four main freshwater lenses are spread across the island. For example, the Decca water supply which services London, Tennessee and South Tabwakea villages underwent a major upgrade from 2014 to 2018 under the SPC

[1] A range of 60 l/p/d to 100 l/p/d has been used to remain consistent with the Kiritimati Sustainable Water Management Plan (SWMP) and WHO guidance on domestic water quantity levels for low-risk health concern. The population carrying capacity figures also assume 20 percent losses (actual losses are most likely far greater at present) and 10 percent non-residential use.

implemented, EU-funded (10th European Development Fund – EDF-10), *Improved drinking water for Kiritimati Island project*. As a result, the Decca – London system is presently capable of providing up to 94 l/p/d to all residents of these villages. Whilst further optimisation of the Decca – London system may be required, the condition and supply capacity of the other three water systems are far inferior, with:

- Tabwakea residents with access to an average 25 l/p/d reticulated supply from the Four Wells lens
    - The water reticulation network does not extend to many households in Tabwakea
- Banana, Bamboo and Main Camp residents with access to 40 l/p/d from the Banana lens
    - The water reticulation network is not connected to many households in Banana or Main Camp
    - The reticulation does not extend to Bamboo
- Poland residents with access to 71 l/p/d from the New Zealand Airfield lens
    - This average per capita supply is theoretically available to the current Poland population, though the system is in poor condition and likely providing far less water in reality.

If water supply infrastructure (including reticulation) and management capacity were to improve considerably to extract water at the maximum sustainable rate for each lens (as per current estimates), with losses controlled to 20 percent or less and non-residential demand maintained at 10 percent, then there would be at least 60 l/p/d of reticulated water available for all villages as per the 2020 census population, and at least 25 l/p/d in all villages in 2045. The following images display the projected 2045 population for each village or group of villages (yellow) and population carrying capacity for each freshwater lens (blue and bold; i.e. the number of people the freshwater lens can provide water for at a given consumption rate), with the circle size proportional to the magnitude of each.

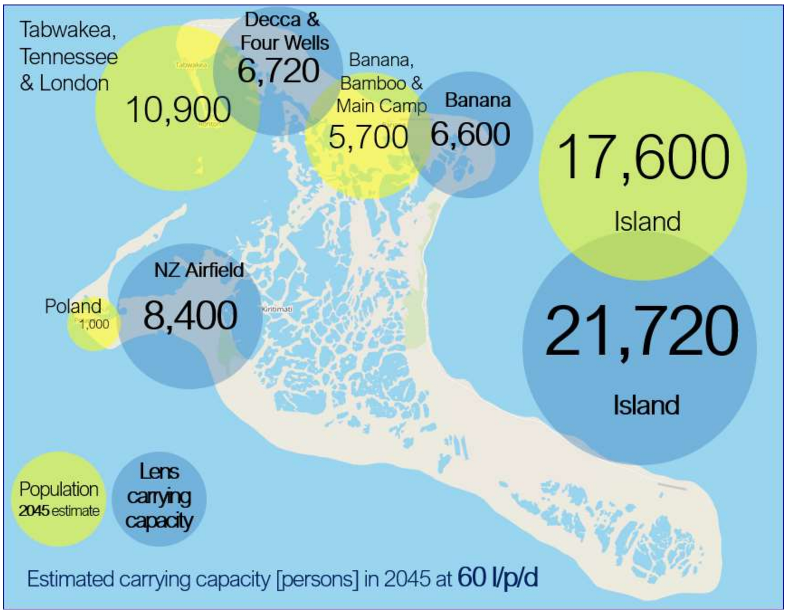

Figure 18. Freshwater lens sustainable population carrying capacity at 60 l/p/d (blue & bold) vs. projected 2045 population (yellow)

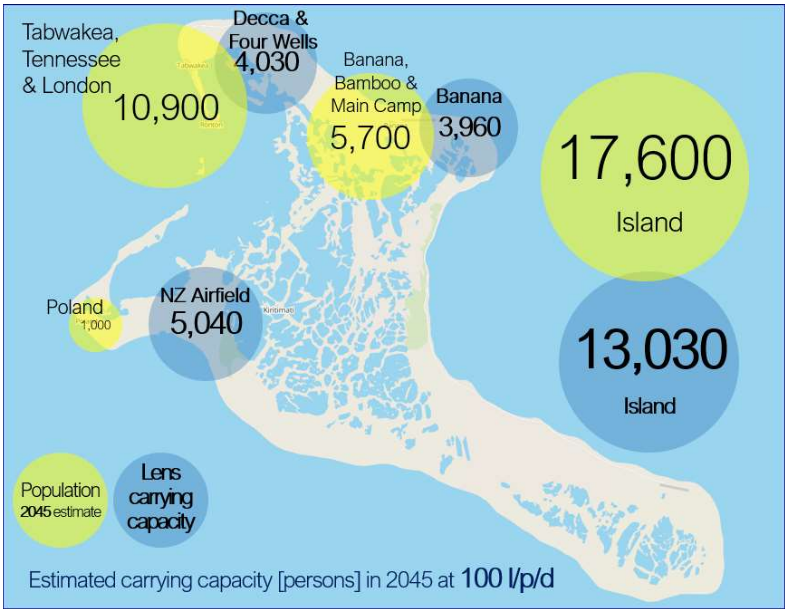

Figure 19. Freshwater lens sustainable population carrying capacity at 100 l/p/d (blue & bold) vs. projected 2045 population (yellow)

As can be seen in the figures above, the total groundwater available is greater than the cumulative island demand for reticulated water at 60 l/p/d (Figure 1). However, the freshwater lens carrying capacity magnitude does not align closely with the population size of adjacent villages. This is further evident when looking at the 100 l/p/d “optimal access” scenario (Figure 2).

Further background and contextual information is included in Table 1 in the Scope of Work section below.

4. Objective of the Assignment

The objective of the assignment is to perform feasibility assessments and develop concept designs, preliminary cost estimates and recommendations for potential water supply infrastructure improvements on Kiritimati Island. After this consultancy, prioritised scope will undergo detailed design, construction and commissioning.

5. Scope of Work

The Consultant will develop a series of concept designs, preliminary cost estimates and recommendations for a range of potential Kiritimati water system upgrades. The proposed works will aim to improve the reliability (security) and quality (safety) of water to households and other establishments throughout Kiritimati. The scale of proposed improvements should not be limited to project resources at this stage. Instead, a range of potential options will be explored, from which prioritised options will be selected in Q1 2022 for delivery under the project, with the other options sidelined (and later incorporated in an updated Sustainable Water Management Plan for Kiritimati, where applicable) until additional funding/capacity/time is available.

The scope of work builds upon the recommendations and lessons learned from the SPC-implemented Improved Drinking Water Supply for Kiritimati Island project from 2014 to 2018. Due to resource constraints, the scope for this previous project was predominantly limited to upgrade the Decca to London and Tennessee water supply. Recommendations and some infrastructure improvements were also implemented for the Four Wells to Tabwakea system (e.g. new solar pumps at galleries, new chlorinator and modifications to the Tabwakea tank stand).

The scope outlined in the table below will be undertaken by the Consultant.

Table 8. Scope of work and estimated timeframes

i. Document review (10 workdays)

Documents to be reviewed include, but are not limited to:
• As constructed and proposed design drawings and plans
• Previous and current water project plans, contracts (for water supply infrastructure upgrades) and reports
• Cost information including unit costs for various infrastructure items which were implemented in the Improved Drinking Water Supply for Kiritimati Island Project (IDWSKP), 2014-2018
• Kiritimati Sustainable Water Management Plan
• WSD Asset Register
• Water supply system performance data (Decca to London and Four Wells to Tabwakea systems only)
    o Gallery pump performance history
    o Flow rates at infiltration galleries and through main (bulk supply) meters
• Summary weather (wind and solar) data, 2015-2021
• Land lease information and maps for existing settlements and new leases
• Population/demographic data and projections.
 	
These documents and information will be provided by MLPID and SPC's PMU. Virtual meetings (convened by SPC and MLPID) between the Consultant, MLPID, SPC and other key stakeholders may be required to share information and discuss scope.

ii. Feasibility assessments (10 workdays)
Investigate the feasibility for water system infrastructure and performance upgrades including, but not limited to: (a) **Continuous pressurised water supply** o Assess the potential use of mains electricity (available to all locations between London and Banana) as the primary or secondary energy source for future pumping from existing and new galleries at the Decca, Four Wells and Banana freshwater lenses. o Provide recommendations for any "upstream" (bulk supply) and "downstream" (reticulation) modifications to infrastructure or operations as a result of continuous pumping at lower flow rates using mains electricity e.g. (a) possible retaining of some solar and/or wind pumps as backups in case of mains electricity outages, and (b) possible disconnection of household header tanks, which are currently used at some households to deal with intermittent water supply, to reduce losses. (b) **Reassessment of gallery pump types and control systems** o Review existing pumping infrastructure at Decca and Four Wells based on available information especially regarding the current solar pumping systems which have suffered from a number of problems since implementation. o Provide recommendations regarding improvements to pump types and control systems especially if mains electricity is considered as the energy source for pumping from existing and proposed new galleries at the Decca, Four Wells and Banana galleries. o Provide recommendations for the type of pumping systems to be used for the existing and proposed new galleries at New Zealand Airfield. o Estimate the costs of converting current pumping systems to alternative pumping systems if changes are recommended. o Estimate the energy requirements and costs of operating the chosen gallery pumps using mains electricity. o If mains electricity is recommended as the energy source for existing and proposed new gallery pumps at Decca, Four Wells and Banana, estimate the size of a solar farm required to offset the mains electricity costs for operating these pumps.
iii. Costed concept design development (30 workdays)
Provide concept designs and preliminary cost estimates for the following three water supply systems using available information (including unit cost estimates for infrastructure components[2]) and further as-needed onsite SPC/MLPID team investigation results.

[2] SPC and MLPID will supply the Consultant with unit cost estimates. These estimates will be provided for installation of galleries, pipes from galleries to connect with transmission pipelines, transmission pipelines, ground-level storages, head tanks and tank stands, transfer pumps and reticulation systems

It is noted that no reticulation design work is required for the villages of London and Tennessee as it is assumed that the current reticulation systems are adequate but that later investigations, including pressure testing, will be required to assess the condition of these systems. These investigations are beyond the scope of this concept design study.

(a) Water supply system No 1: Four Wells and Decca freshwater lenses to Tabwakea village

Background:

At present, there are three infiltration galleries in the Four Wells freshwater lens which supply water to Tabwakea. Each gallery has two pump wells which are equipped with solar pumping systems. The galleries were constructed during the AusAID funded Kiritimati Water and Sanitation Project (KWASP) in the late 1990s and early 2000s and the current solar pumping systems were installed during the IDWSKP.

During the current project, four similar galleries will be constructed at sites within the Four Wells freshwater lens as determined during the previous SPC-implemented water project. There is also potential to increase the water supply to Tabwakea from two additional Four Wells galleries to the south of the main (A1) road and two additional Decca galleries to the north of the A1 Road. Each existing and new gallery will have a design flow of 40 kL/day. If all the potential galleries are constructed, the additional design flow would be 8 x 40 = 320 kL/day. When added to the design flow from the existing three Four Wells galleries of 120 kL/day, the total potential design flow from Four Wells and Decca to Tabwakea would be 440 kL/day.

Further advice regarding the number and location of potential additional galleries at Four Wells and Decca will be provided by the Hydrology Technical Advisor during the concept design process, noting that final decisions will need to be made following further investigations planned for mid-2022.

The three current Four Wells galleries are equipped with six solar pumps which supply water to a 22.5 kL fibreglass head tank on a tank stand at Tabwakea. The water then supplies consumers in the southern part of Tabwakea using a PVC pipe reticulation system. The head tank, 10 m high tank stand and reticulation system were installed during the KWASP. The tank stand was lowered to 6 m during the IDWSKP to decrease water pressure in the reticulation system.

Tasks required:

Transmission pipelines

- Assess the hydraulic capacity of the planned 4.5 km (approximate), 150 mm diameter PVC transmission pipeline from Four Wells to Decca to supply water from up to six new Four Wells galleries (design flow of up to 240 kL/day), noting that this will supplement the design flow of 120 kL/day from the existing three Four Wells galleries via the current 100 mm PVC pipeline from Four Wells to Decca.
- Assess the hydraulic capacity of the current 5 km (approximate), 150 mm diameter PVC transmission pipeline from Decca to Tabwakea to include the design flow of up to 440 kL/day from existing three Four Wells galleries, the currently planned four new Four Wells galleries and the potential four new galleries at Four Wells and Decca.
- If the hydraulic capacities of the above transmission pipelines are insufficient,

assess and make recommendations about the diameter and class of additional PVC transmission pipelines between Four Wells and Decca and between Decca and Tabwakea.
- If mains electricity is to be used as the energy source for the gallery pumps, assess the implications of any water hammer that may occur in the transmission pipelines.
- Provide recommendations about bulk flow meters and valves on any new transmission pipelines.

Water storage and transfer pumps

- Assess the need for and make recommendations about ground-level water storage and transfer pump requirements for Tabwakea. Take account of similar infrastructure improvements that were made at London during the IDWSKP.
- Incorporate water hammer findings when investigating transfer pumps and pipework.

Reticulation system extension

- Calculate the total flow required for the whole of Tabwakea village including new leases based on a design population of 8,600 in the year 2045, a domestic per capita flow rate of 60 litres per person per day (l/p/d), a non-domestic allowance of 10% of the total domestic allowance and a 20% loss rate.
- Using available information and maps for existing settlements and new leases in Tabwakea, analyse and design an extension to the current reticulation system in the southern part of Tabwakea to supply the currently un-serviced houses, buildings and new leases in the northern part of Tabwakea. This design should include a diagram/map showing pipe locations and diameters, valves and possibly "district" flow meters at selected locations within the reticulation system. This reticulation system should supply all leases regardless of the total available water supply from the galleries. Decisions about the extent of the reticulation system within the project scope will be made by SPC and Government of Kiribati personnel after the draft concept design is submitted. It is noted that additional water may later be made available via desalination (beyond the scope of this concept design project).

Water treatment

Consideration of water treatment for the water supply from the Four Wells freshwater lens to Tabwakea is beyond the scope of this concept design. It is most likely that the current chlorinator (located near the Decca head tank) will continue to be used after repairs and possible modifications including changing the energy source from solar to mains electricity.

Preliminary cost estimates

- Provide preliminary cost estimates for the above transmission pipelines, ground-level storages, head tanks and tank stands, transfer pumps and reticulation systems.

(b) Water supply system No 2: Banana freshwater lenses to Banana and Bamboo villages, Main Camp and new leases near Main Camp

<u>Background</u>:

At present, there are eight infiltration galleries in the Banana freshwater lens of similar design to the three current galleries at Four Wells and three of the six current galleries at Decca. The Banana galleries were also installed during the KWASP. Only four of these galleries, all of which are to the north and northwest of Banana village, were equipped with pumps. At present, the number of operating pumps is three (one solar pump, one wind pump and a diesel pump). Most of the pumping is provided by the diesel pump.

Of the four galleries which were never equipped with pumps during the KWASP, all of which are on both sides of and near the eastern end of the airfield, one has been partially destroyed some years ago during construction work at the airfield. The other three will need some remedial work to make them operational. It is expected that seven current galleries will be available for pumping groundwater. There is also potential for two or three additional galleries to be constructed to the north of Banana village. Hence, there is potential for up to ten galleries to supply Banana village, Bamboo, Main Camp and the new leases near Main Camp. Ten galleries each equipped with two pumps would be capable of supplying a design flow of 400 kL/day.

Further advice regarding the number and location of potential additional galleries at the Banana freshwater lens will be provided by the Hydrology Technical Advisor during the concept design process, noting that final decisions will need to be made following further investigations planned for mid-2022.

Water is currently pumped using the few operating pumps to consumers in part of Banana village, where there is only a partial and dilapidated reticulation system. and to consumers in Main Camp. There is currently no piped water supplied to residents of Bamboo (between Banana and Main Camp) or the new leases near Main Camp.

There are two 22.5 kL fibreglass head tanks on a 10 m high triple tank stand near Banana village which are not used (bypassed). The head tanks and tank stand were installed during the KWASP and apparently never used. At the Captain Cook Hotel in Main Camp, there is a small head tank on a tank stand which receives water from Banana and provides water to the hotel and nearby consumers.

There are no flow meters on the gallery pumps as was the case with the Decca and Four Wells gallery pumps before they were installed during the IDWSKP. There is one main meter on the outlet of the Banana head tanks but this is not used as water bypasses these tanks. Its current condition is not known.

<u>Tasks required</u>:

<u>All areas</u>

- Calculate the total flow required for each of Banana village, Bamboo village, Main Camp village (including the Captain Cook Hotel) and new leases near Main Camp based on a combined design population of 5,700[3] in the year 2045 (individual village population projections will be provided to the Consultant), domestic per capita flow rate of 60 l/p/d, a non-domestic allowance of 10% of the total domestic allowance and a 20% loss rate.

<u>Banana village</u>

[3] The forecast population for the new leases near Main Camp may increase with the current construction of the new Padua Senior Secondary School to the east of Main Camp.

- Assess the need for and make recommendations about ground-level water storage and transfer pump requirements to the existing head tanks for Banana village. Take account of similar infrastructure improvements that were made at London during the IDWSKP.
- Incorporate water hammer findings when investigating transfer pumps and pipework. Note: this same task applies to the possible transfer pumps at Bamboo village, Main Camp and the new leases near Main Camp which are considered below.
- Using available information and maps, analyse and design a new reticulation system to supply all houses and buildings in Banana village. This design should include a diagram/map showing pipe locations and diameters, valves and possibly "district" flow meters at selected locations within the reticulation system.

Transmission pipelines

- Assess the hydraulic capacity of the current 6 km (approximate), 150 mm diameter PVC transmission pipeline from Banana to Main Camp to supply water from up to ten Banana galleries (design flow of up to 400 kL/day) with appropriate flow deductions for the total flows to Banana and Bamboo villages.
- If the hydraulic capacity of the above transmission pipeline is insufficient, assess and make recommendations about the diameter and class of an additional PVC transmission pipeline between Banana and Main Camp.
- Analyse and design a new transmission pipeline to the new leases near Main Camp starting from the end cap on the current Banana to Main Camp transmission pipeline. The end cap is located at the western side of Main Camp.
- If mains electricity is to be used as the energy source for the gallery pumps, assess the implications of any water hammer that may occur in the transmission pipelines.
- Provide recommendations about bulk flow meters and valves on existing and any new transmission pipelines.

Bamboo village

- Assess and design the location and diameter of an offtake pipeline to Bamboo village from the Banana to Main Camp transmission pipeline.
- Assess the need for and make recommendations about ground-level water storage, head tank and transfer pump requirements for Bamboo village.
- Using available information and maps, analyse and design a reticulation system to supply all houses and buildings and any new leases in Bamboo village. This design should include a diagram/map showing pipe locations and diameters, valves and possibly "district" flow meters at selected locations within the reticulation system.

Main Camp

- Review available map of the Main Camp reticulation and assess whether any specific modifications are required. It is assumed that the current system is generally adequate but that later investigations, including pressure testing, will be required to assess the condition of these systems. These investigations are beyond the scope of this concept design study.
- Assess the need for and make recommendations about ground-level water storage and transfer pump requirements to the existing head tank at Main Camp. Note that the existing head tank and tank stand could be replaced during the

construction phase of the project using one of the tank stands and possibly one of the head tanks at Banana.

New leases near Main Camp

- Assess the need for and make recommendations about ground-level water storage, head tank and transfer pump requirements for these new leases, including the new Padua Senior Secondary School (SSS) to the east of Main Camp.
- Using available land lease information and maps for all new leases near Main Camp, analyse and design a reticulation system to supply any existing houses and buildings and all new leases, including Padua SSS. This design should include a diagram/map showing pipe locations and diameters, valves and possibly "district" flow meters at selected locations within the reticulation system. Decisions about the extent of the reticulation system within the project scope will be made by SPC and Government of Kiribati personnel after the draft concept design is submitted. It is noted that additional water may be made available via desalination (beyond the scope of this concept design project).

Water treatment

Consideration of water treatment for the water supply from the Banana freshwater lens to the various reticulation systems is beyond the scope of this concept design. It is most likely that the current, non-operational chlorinator (located at the Banana freshwater lens) will be replaced with a new unit using solar energy.

It is understood that there have been some comments made by consumers to WSD about hydrogen sulphide odours in the current Banana water supply. This issue needs further investigation and may become available during the course of the concept design process. At this stage, it is possible that an aeration system will be required in addition to chlorination. While the design of the aeration system is beyond the scope of this concept design, the implications for the hydraulic system of a potential aeration system need to be taken into account when designing pumps and storage.

Preliminary cost estimates

- Provide preliminary cost estimates for the above transmission pipelines, ground-level storages, head tanks and tank stands, transfer pumps and reticulation systems.

(c) Water supply system No 3: New Zealand Airfield freshwater lenses to Poland village and new leases near the village

Background:

At present, there is one infiltration gallery in the New Zealand Airfield freshwater lens which was installed during the KWASP. It is of similar design to the current three galleries at Four wells and eight galleries at Banana freshwater lens. It is equipped with a wind pump at one pump well and a solar pump and diesel pump at the second pump well. The design pumping rate for the gallery is 40 kL/day.

There is potential for many new galleries in the New Zealand Airfield lens. The number of new galleries to be constructed will depend on the total flow requirements to meet the future needs of the existing Poland village and the nearby new leases and also on the available project budget.

Further advice regarding the location of potential additional galleries at the New Zealand Airfield freshwater lens will be provided by the Hydrology Technical Advisor during the concept design process, noting that final decisions will need to be made following further investigations planned for mid-2022.

Water is currently pumped to Poland village through a 7 km pipeline and reticulated in the village. There is currently no piped water supplied to residents of houses to the west of the village and the new leases near the village.

There are two unused (bypassed) 22.5 kL fibreglass head tanks on (a) a 14 m high tank stand at New Zealand Airfield and (b) a 10 m high tank stand near Poland village. The head tanks and tank stands were installed during the KWASP and apparently never used.

There are no flow meters on the gallery pumps as was the case with the Decca and Four Wells gallery pumps before they were installed during the IDWSKP. There is one main meter on the main transmission pipeline from the gallery to Poland. This meter is still working but is rarely read.

Tasks required:

All areas

- Calculate the total flow required for Poland village and the nearby new leases to the west of Poland based on a design population of 1,000 in the year 2045, domestic per capita flow rate of 60 l/p/d, a non-domestic allowance of 10% of the total domestic allowance and a 20% loss rate.[4]

Transmission pipeline

- Assess the hydraulic capacity of the current 7 km (approximate), 90 mm diameter polyethylene (HDPE) transmission pipeline from New Zealand Airfield to Poland village to supply water to meet the water supply requirements of both Poland village and the nearby new leases.
- If the hydraulic capacity of the above transmission pipeline is insufficient, assess and make recommendations about the diameter, type and class of an additional transmission pipeline between New Zealand Airfield and Poland.

Water storage and transfer pumps

- Assess the need for and make recommendations about ground-level water storage and transfer pump requirements for Poland village and the nearby new leases.
- Noting that the existing head tank in Poland could be used, assess the required height of the current tank stand to provide adequate pressure to all consumers.

Water treatment

Consideration of water treatment for the water supply from the New Zealand Airfield freshwater lens to Poland village and the nearby new leases is beyond the scope of this concept design. It is most likely that the current, non-operational chlorinator (located at New Zealand Airfield) will be replaced with a new unit using solar energy.

Reticulation system

[4] Note that the construction of a multipurpose port is tentatively planned for Kiritimati, however the location, size and other information have yet to be determined. For this reason, the multipurpose port and its implications on the island's water supply will not require consideration at this stage.

- It is assumed that the current system is generally adequate but that later investigations, including pressure testing, will be required to assess the condition of this system. These investigations are beyond the scope of this concept design study.
- Using available information and maps for existing settlements and new leases in and near Poland village, analyse and design an extension to the current reticulation system in Poland village to supply the currently un-serviced houses, buildings and new leases near the village. This design should include a diagram/map showing pipe locations and diameters, valves and possibly "district" flow meters at selected locations within the reticulation system. This reticulation system should include all leases regardless of the total available water supply from the galleries. Decisions about the extent of the reticulation system within the project scope will be made by SPC and Government of Kiribati personnel after the draft concept design is submitted. It is noted that additional water may later be made available via desalination (beyond the scope of this concept design project).

Preliminary cost estimates

- Provide preliminary cost estimates for the above transmission pipelines, ground-level storages, head tanks and tank stands, transfer pumps and reticulation systems.

iv. Review and finalisation of deliverables (10 workdays)

Draft feasibility assessments, concept designs, preliminary cost estimates and recommendations will be presented by the SPC PMU to the Action Coordination Group (ACG)[5] for review in February 2022. Final drafts will then be presented by the ACG to the Project Steering Committee (PSC)[6] in March 2022. The Consultant will be required to join these meetings virtually to support SPC and the ACG in explaining the content and answering any questions. The Consultant may be required to amend the proposed designs and recommendations as per both ACG and PSC feedback.

Additional to the consolidated report with all assessments, proposed concept designs, preliminary cost estimates and recommendations, the Consultant will also prepare a short briefing paper (3 to 4 pages) and a PowerPoint presentation (15 to 20 slides) summarising the key information and recommendations to be presented by the ACG to the PSC.

Timing for submission of deliverables is presented in Table 2 below.

C. Expected results and deliverables

[5] The Action Coordination Group (ACG) comprises key decision-makers on Kiritimati who have a direct affiliation with the project. It comprises predominantly members of the SPC and UNICEF project management units, MLPID focal points (mostly the WSD leadership team) and representatives from other Government ministries. The ACG is chaired by the Secretary of MLPID.

[6] The Project Steering Committee (PSC) is the governing body providing high level strategic guidance to the project. It is chaired by the Minister of MLPID and comprises lead decision makers from relevant GoK ministries, SPC, UNICEF and CSOs.

Outputs from this assignment – the feasibility assessments and costed designs for potential water system upgrade and rehabilitation works – will be presented in March 2022 by the Action Coordination Group (ACG) to the Project Steering Committee (PSC) for Improved WASH in the Line Islands. The PSC will evaluate the proposed concept design options and recommendations to define the scope of water system infrastructure work to be performed under the project. Agreed and prioritised scope will then undergo detailed design in advance of construction work.

The expected deliverables and schedule of payments for this assignment are listed below.

Table 9. Expected outputs

#	Milestone	Deliverables	Payment	Deliverable due date
1	Contract signing	• Signed contract	10%	Start of contract
2	Feasibility assessment report submitted	• Approved (by ACG and PSC) feasibility report comprising investigation and recommendations for: o Continuous pressurised water supply o Reassessment of gallery pump types and control systems	20% upon receipt of approved final	Draft: 18 February 2022 (prior to ACG meeting)[7]
3	Concept designs and preliminary cost estimates submitted	• Approved (by ACG and PSC) concept designs, preliminary cost estimates and recommendations for proposed upgrades and optimisation of three major water supply systems on Kiritimati, as per Table 1	50% upon receipt of approved final	Final draft: 18 March 2022 (prior to PSC meeting)
4	Summary brief and presentations submitted	• 3 – 4-page summary brief for sharing at ACG and PSC meetings • 15 – 20 slides summarising key findings and recommendations	20% upon receipt of approved final	Final: two weeks after the March 2022 PSC meeting
		Total	**100%**	

D. **Responsibilities of the Consultant**

The Consultant will be responsible for:

- Performing the scope activities and delivering the expected outputs outlined in this ToR.
- Where possible, and as second priority to completing the scope of work in a timely and quality manner, build capacity of MLPID and SPC staff in performing feasibility assessments and development of concept designs with preliminary cost estimates via virtual interaction and document/knowledge sharing.
- Openly engaging and sharing information and resources with SPC and the Government of Kiribati, and other contracted resources as appropriate.

E. **Responsibilities of SPC and Government of Kiribati**

SPC and Government of Kiribati will be responsible for:

- Ensuring that the required information is made available in a timely manner given the timeframe expected of the Consultant. It is noted that if delays in provision of the information occur, then the timeframe shown in Table 2 may not be met.

[7] Reports, designs and cost estimates should be made available to SPC one week prior to the ACG meeting (draft only), and one week prior to the PSC meeting (final draft). Dates for these meetings are yet to be confirmed, though there will be some flexibility in deliverable submission deadlines should there be delays in contract signing, the ACG/PSC meetings dates are brought forward, and/or other extenuating circumstances.

F. **Institutional Arrangements**

The Consultant will work under the direct supervision of SPC's Project Coordinator, Safe and Sustainable Drinking Water for Kiritimati Island Project.

The WSD Engineer, SPC Project Coordinator and Hydrology Technical Advisor will be focal points for all information requests and feedback with the Consultant.

G. **Duration of the Work**

The work is expected to be performed over a period of approximately 4 months, commencing immediately upon contract signing (est. late November or early December 2021), or shortly thereafter, and conclude two weeks after the March 2022 PSC meeting (date to be confirmed). A total 60 person-workdays has been estimated to perform the necessary scope and deliver the required outputs. Some flexibility in deliverable deadlines will be made available should there be delays in contracting, information provision or other unexpected interruptions.

F. **Duty Station**

Due to likely continuation of COVID-induced international border restrictions in coming months, the Consultant will be based remotely throughout the course of the assignment. Should travel become possible within the contract duration, SPC and the Consultant will evaluate the viability of a trip to Kiritimati and comply with SPC Travel Policy where applicable.

G. **Qualifications, Skills and Experience**

As per Annex III of this RFQ, the bidder is required to provide a brief proposal highlighting compliance, knowledge and previous experience in the following areas and attributes:

- Tertiary qualification(s) in water engineering
- At least 20 years practical experience in design of water supply systems and hydraulics engineering
- On-island experience with Kiritimati Island water supply[8]
- At least 10 years' experience with atoll water supply evaluation and design
- Experience in working with urban water supply authorities.

H. **Proposal Evaluation Matrix**

Bids will be evaluated based on combined technical (70%) and financial (30%) weighted scores as per the table below.

Table 10. Proposal evaluation matrix

Requirements	Score Weight (%)
Tertiary qualification(s) in water engineering	10%

[8] Due to lack of international mobility and hence inability to get the Contractor on-the-ground to perform site assessments, the Contractor will need to be familiar with Kiritimati Island water supply and have previous water-related work experience on-island.

At least 20 years of practical experience in design of water supply systems and hydraulics engineering	15%
On-island experience with Kiritimati Island water supply	20%
At least 10 years of experience with atoll water resources design and management	15%
Experience working with urban water supply authorities	10%
Remuneration (total Consultancy fee)	30%
Total	**100%**

I. **Details of Fees**

- The rates quoted by the Consultant should be tax exempt and represent for best value for money.
- The rate quoted should be valid and remain fixed for a period of one year from the date of award of contract, and must be inclusive of, insurance, charges, GST, levies and taxes.
- If there is a change in the price for reasons beyond the supplier's control, SPC should be advised promptly and upon approval by SPC, the contract rate shall be amended.

Annex B Four Wells to Tabwakea EPANET Model

This Appendix lists the text file of the data for the EPANET model of the gallery collection system for the Four Wells and Decca well fields, as described in section 5.1.5 of the report.

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[TITLE]

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 3                  0               0                               ;
 4                  0               0                               ;
 6                  0               0                               ;
 7                  0               0                               ;
 9                  0               0                               ;
 11                 0               0                               ;
 12                 0               0                               ;
 13                 0               0                               ;
 14                 0               0                               ;
 15                 0               0                               ;
 16                 0               0                               ;
 17                 0               0                               ;
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 22                 0               0                               ;
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 26                 0               0                               ;
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 33                 0               0                               ;
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 42                 0               0                               ;
 43                 0               0                               ;
 44                 0               0                               ;
 45                 0               0                               ;
 46                 0               0                               ;
 47                 0               0                               ;
 48                 0               0                               ;
 49                 0               0                               ;
 50                 0               0                               ;

[RESERVOIRS]
;ID                 Head            Pattern
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 8                  .3                              ;
 19                 .3                              ;
 20                 .3                              ;
 24                 .3                              ;
 38                 0.3                             ;
 39                 0.3                             ;
 51                 .3                              ;
```

```
 52                     .3                                   ;
 53                     .3                                   ;
 54                     .3                                   ;

[TANKS]
;ID                     Elevation      InitLevel      MinLevel
     MaxLevel           Diameter       MinVol         VolCurve
 1                      1.8            0.3            0.3
     2.2                5              0                             ;
 28                     2.8            .3             0              3
     17                 0                             ;
 30                     2.2            .3             .3
     2.5                3              0                             ;

[PIPES]
;ID                     Node1          Node2          Length
     Diameter           Roughness      MinorLoss      Status
 1                      2              1              2
     146.9              0.3            0              Open       ;
 4                      6              7              3              32
     .3                 1              CV        ;
 7                      4              3              500
     104.6              0.3            0              Open       ;
 8                      9              2              50
     146.9              0.3            0              Open       ;
 5                      7              3              500
     104.6              0.3            0              Open       ;
 9                      3              2              600
     146.9              0.3            0              Open       ;
 10                     12             11             3              32
     0.3                1              CV        ;
 11                     11             4              500
     104.6              0.3            0              Open       ;
 12                     13             2              500
     104.6              0.3            0              Open       ;
 13                     14             2              200
     104.6              0.3            0              Open       ;
 14                     15             13             100
     104.6              0.3            0              Open       ;
 15                     17             15             3              32
     0.3                1              CV        ;
 16                     16             14             300
     104.6              0.3            0              Open       ;
 17                     18             16             3              32
     0.3                1              CV        ;
 18                     21             2              300
     104.6              0.3            0              Open       ;
 19                     22             21             100
     104.6              0.3            0              Open       ;
 20                     23             22             3              32
     0.3                1              CV        ;
 25                     25             26             2
     146.9              0.3            0              CV         ;
 26                     26             27             3300
     107.8              0.3            0              Open       ;
 27                     26             27             3300
     146.9              0.3            0              Open       ;
```

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 28                     27              28              5100
     151.3              0.3             0               Open        ;
 30                     29              27              2
     146.9              0.3             0               CV          ;
 31                     33              32              100
     104.6              0.3             0               Open        ;
 36                     35              34              3               32
     0.3                1               CV         ;
 37                     37              36              3               32
     0.3                1               CV         ;
 38                     34              32              300
     104.6              0.3             0               Open        ;
 39                     36              33              400
     104.6              0.3             0               Open        ;
 44                     47              43              3               32
     0.3                1               CV         ;
 45                     43              9               200
     104.6              0.3             0               Open        ;
 46                     48              44              3               32
     0.3                1               CV         ;
 47                     44              40              200
     104.6              0.3             0               Open        ;
 48                     49              45              3               32
     0.3                1               CV         ;
 49                     45              41              200
     104.6              0.3             0               Open        ;
 50                     50              46              3               32
     0.3                1               CV         ;
 51                     46              42              100
     104.6              0.3             0               Open        ;
 52                     42              41              100
     104.6              0.3             0               Open        ;
 53                     41              40              50
     146.9              0.3             0               Open        ;
 54                     40              9               50
     146.9              0.3             0               Open        ;
 55                     32              30              20
     146.9              0.3             0               Open        ;

[PUMPS]
;ID                     Node1           Node2           Parameters
 3                      5               6               HEAD GRCC7 ;P1
 6                      8               12              HEAD GRCC7 ;P2
 21                     19              17              HEAD GRCC7 ;P3
 22                     20              18              HEAD GRCC7 ;P4
 23                     24              23              HEAD GRCC7 ;P5
 24                     1               25              HEAD esh50-2004P ;
 29                     30              29              HEAD esh32-2504P ;
 34                     38              35              HEAD GRCC7 ;P10
 35                     39              37              HEAD GRCC7 ;P11
 40                     51              47              HEAD GRCC7 ;P6
 41                     52              48              HEAD GRCC7 ;P7
 42                     53              49              HEAD GRCC7 ;P8
 43                     54              50              HEAD GRCC7 ;P9

[VALVES]
;ID                     Node1           Node2           Diameter
     Type  Setting           MinorLoss
```

```
[TAGS]

[DEMANDS]
;Junction              Demand          Pattern         Category

[STATUS]
;ID                    Status/Setting
 3                     Closed
 6                     Closed
 21                    Closed
 22                    Closed
 23                    Closed
 24                    Closed
 29                    Closed
 34                    Closed
 35                    Closed
 40                    Closed
 41                    Closed
 42                    Closed
 43                    Closed

[PATTERNS]
;ID                    Multipliers

[CURVES]
;ID                    X-Value         Y-Value
;PUMP: Grunfos Unilift CC7-A1
 GRCC7                 0               7.4
 GRCC7                 0.4             6.3
 GRCC7                 1.4             3.9
 GRCC7                 2               2.5
 GRCC7                 2.6             .8
;PUMP:
 GRKP250               0               7.4
 GRKP250               0.8             6.7
 GRKP250               1.5             5.4
 GRKP250               1.8             4.7
 GRKP250               2.2             3.7
 GRKP250               2.8             1.6
;PUMP:
 esh25                 5.3             13
;EFFICIENCY:
 GRKP250EFF            0               0
 GRKP250EFF            .65             11
 GRKP250EFF            1               15
 GRKP250EFF            1.5             18
 GRKP250EFF            1.8             17.5
 GRKP250EFF            2.4             14.5
 GRKP250EFF            2.8             8
;PUMP:
 esh50-2004P           0               12.9
 esh50-2004P           2               12.5
 esh50-2004P           4               11.7
 esh50-2004P           6               10.5
 esh50-2004P           8               9
 esh50-2004P           10              6.7
;PUMP:
```

```
 esh50-2004PEFF      3.3              55
 esh50-2004PEFF      4.2              60
 esh50-2004PEFF      4.9              63
 esh50-2004PEFF      5.7              66
 esh50-2004PEFF      6.6              68
 esh50-2004PEFF      7.7              69
 esh50-2004PEFF      8.7              68
 esh50-2004PEFF      9.6              66
 esh50-2004PEFF      10.3             63
 esh50-2004PEFF      11.4             55
;PUMP:
 GRCC7EFF            0.4              9
 GRCC7EFF            0.6              12
 GRCC7EFF            0.8              14
 GRCC7EFF            1.0              15
 GRCC7EFF            1.2              15.7
 GRCC7EFF            1.4              16
 GRCC7EFF            1.6              16
 GRCC7EFF            1.8              15.3
 GRCC7EFF            2.0              14
 GRCC7EFF            2.2              12
 GRCC7EFF            2.4              9
;PUMP:
 esh32-2504P         0                13
 esh32-2504P         1                12.6
 esh32-2504P         1.5              12.2
 esh32-2504P         2                11.5
 esh32-2504P         2.5              10.8
 esh32-2504P         3                10
 esh32-2504P         3.5              9
 esh32-2504P         4                7.6
;EFFICIENCY:
 esh32-2504PEFF      1.3              36
 esh32-2504PEFF      1.7              40
 esh32-2504PEFF      1.9              42
 esh32-2504PEFF      2.1              44
 esh32-2504PEFF      2.4              46
 esh32-2504PEFF      2.7              47
 esh32-2504PEFF      3.2              47.7
 esh32-2504PEFF      3.6              47
 esh32-2504PEFF      3.8              46

[CONTROLS]
LINK 3 OPEN AT CLOCKTIME 0 AM
LINK 3 CLOSED AT CLOCKTIME 1 AM
LINK 3 OPEN AT CLOCKTIME 3 AM
LINK 3 CLOSED AT CLOCKTIME 4 AM
LINK 3 OPEN AT CLOCKTIME 6 AM
LINK 3 CLOSED AT CLOCKTIME 7 AM
LINK 3 OPEN AT CLOCKTIME 9 AM
LINK 3 CLOSED AT CLOCKTIME 10 AM
LINK 3 OPEN AT CLOCKTIME 12 PM
LINK 3 CLOSED AT CLOCKTIME 1 PM
LINK 3 OPEN AT CLOCKTIME 3 PM
LINK 3 CLOSED AT CLOCKTIME 4 PM
LINK 3 OPEN AT CLOCKTIME 6 PM
LINK 3 CLOSED AT CLOCKTIME 7 PM
LINK 3 OPEN AT CLOCKTIME 9 PM
```

```
LINK 3 CLOSED AT CLOCKTIME 10 PM

LINK 6 OPEN AT CLOCKTIME 0 AM
LINK 6 CLOSED AT CLOCKTIME 1 AM
LINK 6 OPEN AT CLOCKTIME 3 AM
LINK 6 CLOSED AT CLOCKTIME 4 AM
LINK 6 OPEN AT CLOCKTIME 6 AM
LINK 6 CLOSED AT CLOCKTIME 7 AM
LINK 6 OPEN AT CLOCKTIME 9 AM
LINK 6 CLOSED AT CLOCKTIME 10 AM
LINK 6 OPEN AT CLOCKTIME 12 PM
LINK 6 CLOSED AT CLOCKTIME 1 PM
LINK 6 OPEN AT CLOCKTIME 3 PM
LINK 6 CLOSED AT CLOCKTIME 4 PM
LINK 6 OPEN AT CLOCKTIME 6 PM
LINK 6 CLOSED AT CLOCKTIME 7 PM
LINK 6 OPEN AT CLOCKTIME 9 PM
LINK 6 CLOSED AT CLOCKTIME 10 PM

LINK 21 OPEN AT CLOCKTIME 0 AM
LINK 21 CLOSED AT CLOCKTIME 1 AM
LINK 21 OPEN AT CLOCKTIME 3 AM
LINK 21 CLOSED AT CLOCKTIME 4 AM
LINK 21 OPEN AT CLOCKTIME 6 AM
LINK 21 CLOSED AT CLOCKTIME 7 AM
LINK 21 OPEN AT CLOCKTIME 9 AM
LINK 21 CLOSED AT CLOCKTIME 10 AM
LINK 21 OPEN AT CLOCKTIME 12 PM
LINK 21 CLOSED AT CLOCKTIME 1 PM
LINK 21 OPEN AT CLOCKTIME 3 PM
LINK 21 CLOSED AT CLOCKTIME 4 PM
LINK 21 OPEN AT CLOCKTIME 6 PM
LINK 21 CLOSED AT CLOCKTIME 7 PM
LINK 21 OPEN AT CLOCKTIME 9 PM
LINK 21 CLOSED AT CLOCKTIME 10 PM

LINK 22 OPEN AT CLOCKTIME 0 AM
LINK 22 CLOSED AT CLOCKTIME 1 AM
LINK 22 OPEN AT CLOCKTIME 3 AM
LINK 22 CLOSED AT CLOCKTIME 4 AM
LINK 22 OPEN AT CLOCKTIME 6 AM
LINK 22 CLOSED AT CLOCKTIME 7 AM
LINK 22 OPEN AT CLOCKTIME 9 AM
LINK 22 CLOSED AT CLOCKTIME 10 AM
LINK 22 OPEN AT CLOCKTIME 12 PM
LINK 22 CLOSED AT CLOCKTIME 1 PM
LINK 22 OPEN AT CLOCKTIME 3 PM
LINK 22 CLOSED AT CLOCKTIME 4 PM
LINK 22 OPEN AT CLOCKTIME 6 PM
LINK 22 CLOSED AT CLOCKTIME 7 PM
LINK 22 OPEN AT CLOCKTIME 9 PM
LINK 22 CLOSED AT CLOCKTIME 10 PM

LINK 23 OPEN AT CLOCKTIME 0 AM
LINK 23 CLOSED AT CLOCKTIME 1 AM
LINK 23 OPEN AT CLOCKTIME 3 AM
LINK 23 CLOSED AT CLOCKTIME 4 AM
LINK 23 OPEN AT CLOCKTIME 6 AM
```

```
LINK 23 CLOSED AT CLOCKTIME 7 AM
LINK 23 OPEN AT CLOCKTIME 9 AM
LINK 23 CLOSED AT CLOCKTIME 10 AM
LINK 23 OPEN AT CLOCKTIME 12 PM
LINK 23 CLOSED AT CLOCKTIME 1 PM
LINK 23 OPEN AT CLOCKTIME 3 PM
LINK 23 CLOSED AT CLOCKTIME 4 PM
LINK 23 OPEN AT CLOCKTIME 6 PM
LINK 23 CLOSED AT CLOCKTIME 7 PM
LINK 23 OPEN AT CLOCKTIME 9 PM
LINK 23 CLOSED AT CLOCKTIME 10 PM

LINK 40 OPEN AT CLOCKTIME 0 AM
LINK 40 CLOSED AT CLOCKTIME 1 AM
LINK 40 OPEN AT CLOCKTIME 3 AM
LINK 40 CLOSED AT CLOCKTIME 4 AM
LINK 40 OPEN AT CLOCKTIME 6 AM
LINK 40 CLOSED AT CLOCKTIME 7 AM
LINK 40 OPEN AT CLOCKTIME 9 AM
LINK 40 CLOSED AT CLOCKTIME 10 AM
LINK 40 OPEN AT CLOCKTIME 12 PM
LINK 40 CLOSED AT CLOCKTIME 1 PM
LINK 40 OPEN AT CLOCKTIME 3 PM
LINK 40 CLOSED AT CLOCKTIME 4 PM
LINK 40 OPEN AT CLOCKTIME 6 PM
LINK 40 CLOSED AT CLOCKTIME 7 PM
LINK 40 OPEN AT CLOCKTIME 9 PM
LINK 40 CLOSED AT CLOCKTIME 10 PM

LINK 41 OPEN AT CLOCKTIME 0 AM
LINK 41 CLOSED AT CLOCKTIME 1 AM
LINK 41 OPEN AT CLOCKTIME 3 AM
LINK 41 CLOSED AT CLOCKTIME 4 AM
LINK 41 OPEN AT CLOCKTIME 6 AM
LINK 41 CLOSED AT CLOCKTIME 7 AM
LINK 41 OPEN AT CLOCKTIME 9 AM
LINK 41 CLOSED AT CLOCKTIME 10 AM
LINK 41 OPEN AT CLOCKTIME 12 PM
LINK 41 CLOSED AT CLOCKTIME 1 PM
LINK 41 OPEN AT CLOCKTIME 3 PM
LINK 41 CLOSED AT CLOCKTIME 4 PM
LINK 41 OPEN AT CLOCKTIME 6 PM
LINK 41 CLOSED AT CLOCKTIME 7 PM
LINK 41 OPEN AT CLOCKTIME 9 PM
LINK 41 CLOSED AT CLOCKTIME 10 PM

LINK 42 OPEN AT CLOCKTIME 0 AM
LINK 42 CLOSED AT CLOCKTIME 1 AM
LINK 42 OPEN AT CLOCKTIME 3 AM
LINK 42 CLOSED AT CLOCKTIME 4 AM
LINK 42 OPEN AT CLOCKTIME 6 AM
LINK 42 CLOSED AT CLOCKTIME 7 AM
LINK 42 OPEN AT CLOCKTIME 9 AM
LINK 42 CLOSED AT CLOCKTIME 10 AM
LINK 42 OPEN AT CLOCKTIME 12 PM
LINK 42 CLOSED AT CLOCKTIME 1 PM
LINK 42 OPEN AT CLOCKTIME 3 PM
LINK 42 CLOSED AT CLOCKTIME 4 PM
```

```
LINK 42 OPEN AT CLOCKTIME 6 PM
LINK 42 CLOSED AT CLOCKTIME 7 PM
LINK 42 OPEN AT CLOCKTIME 9 PM
LINK 42 CLOSED AT CLOCKTIME 10 PM

LINK 43 OPEN AT CLOCKTIME 0 AM
LINK 43 CLOSED AT CLOCKTIME 1 AM
LINK 43 OPEN AT CLOCKTIME 3 AM
LINK 43 CLOSED AT CLOCKTIME 4 AM
LINK 43 OPEN AT CLOCKTIME 6 AM
LINK 43 CLOSED AT CLOCKTIME 7 AM
LINK 43 OPEN AT CLOCKTIME 9 AM
LINK 43 CLOSED AT CLOCKTIME 10 AM
LINK 43 OPEN AT CLOCKTIME 12 PM
LINK 43 CLOSED AT CLOCKTIME 1 PM
LINK 43 OPEN AT CLOCKTIME 3 PM
LINK 43 CLOSED AT CLOCKTIME 4 PM
LINK 43 OPEN AT CLOCKTIME 6 PM
LINK 43 CLOSED AT CLOCKTIME 7 PM
LINK 43 OPEN AT CLOCKTIME 9 PM
LINK 43 CLOSED AT CLOCKTIME 10 PM

LINK 34 OPEN AT CLOCKTIME 0 AM
LINK 34 CLOSED AT CLOCKTIME 1 AM
LINK 34 OPEN AT CLOCKTIME 3 AM
LINK 34 CLOSED AT CLOCKTIME 4 AM
LINK 34 OPEN AT CLOCKTIME 6 AM
LINK 34 CLOSED AT CLOCKTIME 7 AM
LINK 34 OPEN AT CLOCKTIME 9 AM
LINK 34 CLOSED AT CLOCKTIME 10 AM
LINK 34 OPEN AT CLOCKTIME 12 PM
LINK 34 CLOSED AT CLOCKTIME 1 PM
LINK 34 OPEN AT CLOCKTIME 3 PM
LINK 34 CLOSED AT CLOCKTIME 4 PM
LINK 34 OPEN AT CLOCKTIME 6 PM
LINK 34 CLOSED AT CLOCKTIME 7 PM
LINK 34 OPEN AT CLOCKTIME 9 PM
LINK 34 CLOSED AT CLOCKTIME 10 PM

LINK 35 OPEN AT CLOCKTIME 0 AM
LINK 35 CLOSED AT CLOCKTIME 1 AM
LINK 35 OPEN AT CLOCKTIME 3 AM
LINK 35 CLOSED AT CLOCKTIME 4 AM
LINK 35 OPEN AT CLOCKTIME 6 AM
LINK 35 CLOSED AT CLOCKTIME 7 AM
LINK 35 OPEN AT CLOCKTIME 9 AM
LINK 35 CLOSED AT CLOCKTIME 10 AM
LINK 35 OPEN AT CLOCKTIME 12 PM
LINK 35 CLOSED AT CLOCKTIME 1 PM
LINK 35 OPEN AT CLOCKTIME 3 PM
LINK 35 CLOSED AT CLOCKTIME 4 PM
LINK 35 OPEN AT CLOCKTIME 6 PM
LINK 35 CLOSED AT CLOCKTIME 7 PM
LINK 35 OPEN AT CLOCKTIME 9 PM
LINK 35 CLOSED AT CLOCKTIME 10 PM


LINK 24 OPEN IF NODE 1 ABOVE 1
```

```
LINK 24 CLOSED IF NODE 1 BELOW 0.3
LINK 29 OPEN IF NODE 30 ABOVE 1
LINK 29 CLOSED IF NODE 30 BELOW 0.3

[RULES]

[ENERGY]
 Global Efficiency    75
 Global Price         0
 Demand Charge        0
 Pump      3               Efficiency GRCC7EFF
 Pump      3               Price      1
 Pump      6               Efficiency GRCC7EFF
 Pump      6               Price      1
 Pump      21              Efficiency GRCC7EFF
 Pump      21              Price      1
 Pump      22              Efficiency GRCC7EFF
 Pump      22              Price      1
 Pump      23              Efficiency GRCC7EFF
 Pump      23              Price      1
 Pump      24              Efficiency esh50-2004PEFF
 Pump      24              Price      1
 Pump      29              Efficiency esh32-2504PEFF
 Pump      29              Price      1
 Pump      34              Efficiency GRCC7EFF
 Pump      34              Price      1
 Pump      35              Efficiency GRCC7EFF
 Pump      35              Price      1
 Pump      40              Efficiency GRCC7EFF
 Pump      40              Price      1
 Pump      41              Efficiency GRCC7EFF
 Pump      41              Price      1
 Pump      42              Efficiency GRCC7EFF
 Pump      42              Price      1
 Pump      43              Efficiency GRCC7EFF
 Pump      43              Price      1

[EMITTERS]
;Junction             Coefficient

[QUALITY]
;Node                 InitQual

[SOURCES]
;Node                 Type             Quality          Pattern

[REACTIONS]
;Type      Pipe/Tank       Coefficient


[REACTIONS]
 Order Bulk                 1
 Order Tank                 1
 Order Wall                 1
 Global Bulk                0
 Global Wall                0
 Limiting Potential         0
 Roughness Correlation      0
```

```
[MIXING]
;Tank                 Model

[TIMES]
 Duration             24
 Hydraulic Timestep   0:01
 Quality Timestep     0:05
 Pattern Timestep     1:00
 Pattern Start        0:00
 Report Timestep      0:01
 Report Start         0:00
 Start ClockTime      12 am
 Statistic            None

[REPORT]
 Status               No
 Summary              No
 Page                 0

[OPTIONS]
 Units                LPS
 Headloss             D-W
 Specific Gravity     1
 Viscosity            1
 Trials               40
 Accuracy             0.001
 CHECKFREQ            2
 MAXCHECK             10
 DAMPLIMIT            0
 Unbalanced           Continue 10
 Pattern              1
 Demand Multiplier    1.0
 Emitter Exponent     0.5
 Quality              None mg/L
 Diffusivity          1
 Tolerance            0.01

[COORDINATES]
;Node                 X-Coord          Y-Coord
 2                    10259.20         7993.31
 3                    11900.00         8000.00
 4                    11900.00         7500.00
 6                    12800.00         8000.00
 7                    12300.00         8000.00
 9                    11000.00         4900.00
 11                   12300.00         7500.00
 12                   12800.00         7500.00
 13                   11500.00         7000.00
 14                   11500.00         6500.00
 15                   12300.00         7000.00
 16                   12300.00         6500.00
 17                   12800.00         7000.00
 18                   12800.00         6500.00
 21                   11500.00         6000.00
 22                   12300.00         6000.00
 23                   12800.00         6000.00
 25                   8921.40          8000.00
```

```
 26                     8185.62          8000.00
 27                     4000.00          8000.00
 29                     4000.00          7190.64
 32                     4800.00          5400.00
 33                     4800.00          4800.00
 34                     5400.00          5400.00
 35                     5900.00          5400.00
 36                     5400.00          4800.00
 37                     5900.00          4800.00
 40                     11000.00         4300.00
 41                     11000.00         3800.00
 42                     11000.00         3300.00
 43                     11600.00         4900.00
 44                     11600.00         4300.00
 45                     11600.00         3800.00
 46                     11600.00         3300.00
 47                     12100.00         4900.00
 48                     12100.00         4300.00
 49                     12100.00         3800.00
 50                     12100.00         3300.00
 5                      13600.00         8000.00
 8                      13600.00         7500.00
 19                     13600.00         7000.00
 20                     13600.00         6500.00
 24                     13600.00         6000.00
 38                     6700.00          5400.00
 39                     6700.00          4800.00
 51                     12900.00         4900.00
 52                     12900.00         4300.00
 53                     12900.00         3800.00
 54                     12900.00         3300.00
 1                      9824.41          8000.00
 28                     -1647.16         8000.00
 30                     4800.00          6755.85

[VERTICES]
;Link                   X-Coord          Y-Coord
 27                     7984.38          7707.76
 27                     4222.41          7709.03

[LABELS]
;X-Coord          Y-Coord          Label & Anchor Node
 3653.85         8511.71         "Decca"
 10091.97        8578.60         "Four Wells"
 -2165.55        8545.15         "Tabwakea"

[BACKDROP]
 DIMENSIONS      0.00            0.00            10000.00
     10000.00
 UNITS           None
 FILE
 OFFSET          0.00            0.00

[END]
```

Annex C Tabwakea Reticulation Network EPANET Model

This Annex lists the text file of the data for the EPANET model of the Tabwakea reticulation network, as described in section 5.1.8 of the report.

```
[TITLE]


[JUNCTIONS]
;ID              Elev            Demand          Pattern
 4               0               .5                              ;
 5               0               .5                              ;
 6               0               .5                              ;
 7               0               .5                              ;
 8               0               .5                              ;
 9               0               .5                              ;
 11              0               .5                              ;
 12              0               .5                              ;
 14              0               .5                              ;
 15              0               .5                              ;
 16              0               .5                              ;
 17              0               .5                              ;
 18              0               .5                              ;
 20              0               .5                              ;
 21              0               .5                              ;
 24              0               .5                              ;
 25              0               .5                              ;
 27              0               .5                              ;
 28              0               .5                              ;
 29              0               .5                              ;
 30              0               .5                              ;
 32              0               .5                              ;
 33              0               .5                              ;
 34              0               .5                              ;
 35              0               .1                              ;
 36              0               .5                              ;
 37              0               5                               ;
 38              0               .5                              ;
 39              0               .5                              ;
 40              0               .5                              ;
 41              0               .5                              ;
 42              0               .5                              ;
 43              0               .5                              ;
 44              0               .5                              ;
 45              0               .5                              ;
 46              0               .5                              ;
 47              0               .5                              ;
 49              0               .5                              ;
 50              0               .5                              ;
 51              0               .5                              ;
 52              0               .5                              ;
 53              0               .5                              ;
 55              0               .5                              ;
 56              0               .5                              ;
 57              0               .5                              ;
 58              0               .5                              ;
 59              0               0                               ;
 60              0               .5                              ;
```

61	0	.5	;
62	0	.5	;
64	0	.5	;
66	0	.5	;
68	0	.5	;
69	0	.5	;
72	0	.5	;
73	0	.5	;
75	0	.5	;
76	0	.5	;
78	0	.5	;
79	0	.5	;
81	0	.5	;
82	0	.5	;
83	0	.5	;
84	0	.5	;
85	0	.5	;
86	0	.5	;
88	0	.5	;
89	0	.5	;
90	0	.5	;
92	0	.5	;
93	0	.5	;
94	0	.5	;
95	0	.5	;
96	0	.5	;
97	0	.1	;
98	0	.5	;
99	0	.5	;
101	0	.5	;
102	0	.5	;
103	0	.5	;
104	0	.5	;
106	0	.5	;
107	0	.5	;
109	0	.5	;
112	0	.5	;
114	0	.5	;
117	0	.5	;
119	0	.5	;
120	0	.5	;
122	0	.5	;
123	0	0	;
124	0	0	;
125	0	.5	;
126	0	.5	;
127	0	.5	;
129	0	.5	;
130	0	0	;
132	0	.5	;
133	0	.5	;
135	0	.5	;
137	0	.5	;
139	0	.5	;
141	0	.5	;
144	0	.5	;
145	0	.5	;
146	0	.5	;

```
147     0     .5      ;
148     0     0.3     ;
149     0     0.3     ;
151     0     .5      ;
152     0     0       ;
153     0     .5      ;
154     0     .5      ;
155     0     .5      ;
156     0     .5      ;
158     0     .5      ;
159     0     .5      ;
160     0     .5      ;
161     0     .5      ;
163     0     .5      ;
164     0     .5      ;
167     0     .5      ;
168     0     .5      ;
169     0     .5      ;
170     0     .5      ;
173     0     .5      ;
175     0     .5      ;
177     0     .5      ;
178     0     .5      ;
179     0     .5      ;
180     0     .5      ;
181     0     .5      ;
182     0     .5      ;
183     0     .5      ;
184     0     .6      ;
185     0     .5      ;
186     0     .5      ;
187     0     .5      ;
188     0     .5      ;
189     0     .5      ;
190     0     .5      ;
191     0     .5      ;
192     0     0.3     ;
193     0     0.3     ;
194     0     .3      ;
195     0     0.3     ;
197     0     .5      ;
198     0     .5      ;
199     0     .5      ;
200     0     0.5     ;
201     0     .5      ;
202     0     .5      ;
203     0     .5      ;
204     0     .5      ;
205     0     .5      ;
206     0     .5      ;
207     0     .5      ;
208     0     .5      ;
209     0     0.3     ;
210     0     .5      ;
211     0     .5      ;
212     0     .5      ;
213     0     .5      ;
214     0     .5      ;
```

```
 215                     0                 .5                               ;
 216                     0                 .5                               ;
 218                     0                 .5                               ;
 219                     0                 .5                               ;
 220                     0                 .5                               ;
 221                     0                 .5                               ;
 222                     0                 .5                               ;
 223                     0                 .5                               ;
 224                     0                 .5                               ;
 225                     0                 5                                ;
 226                     0                 .5                               ;
 227                     0                 0                                ;
 228                     0                 .5                               ;
 229                     0                 .5                               ;
 230                     0                 .5                               ;
 231                     0                 .5                               ;
 232                     0                 .5                               ;
 237                     0                 0.5                              ;
 238                     0                 .1                               ;
 239                     0                 0                                ;

[RESERVOIRS]
;ID                      Head              Pattern
 1                       7                                ;

[TANKS]
;ID                      Elevation         InitLevel        MinLevel
     MaxLevel            Diameter          MinVol           VolCurve

[PIPES]
;ID                      Node1             Node2            Length
     Diameter            Roughness         MinorLoss        Status
 1                       1                 4                57.08
     370.7               0.3               0                Open        ;
 2                       4                 5                38.01
     208.5               0.3               0                Open        ;
 3                       5                 6                125.68
     146.9               0.3               0                Open        ;
 4                       6                 7                98.44
     104.6               0.3               0                Open        ;
 5                       7                 16               50.53
     104.6               0.3               0                Open        ;
 6                       16                12               41.34
     104.6               0.3               0                Open        ;
 7                       6                 14               88.87
     104.6               0.3               0                Open        ;
 11                      5                 24               135.07
     146.9               0.3               0                Open        ;
 13                      24                25               53.93
     104.6               0.3               0                Open        ;
 14                      25                27               72.28
     104.6               0.3               0                Open        ;
 15                      27                28               55.43
     104.6               0.3               0                Open        ;
 16                      28                30               63.04             50
     0.3                 0                 Open        ;
 19                      25                21               159.24
     104.6               0.3               0                Open        ;
```

```
 22                   15               18               75.33              50
     0.3              0                Open        ;
 23                   15               17               58.96
     104.6            0.3              0                Open        ;
 25                   14               21               68.00
     104.6            0.3              0                Open        ;
 26                   21               17               94.96
     104.6            0.3              0                Open        ;
 28                   17               20               115.40             50
     0.3              0                Open        ;
 29                   28               29               111.09
     104.6            0.3              0                Open        ;
 30                   29               20               77.78
     104.6            0.3              0                Open        ;
 31                   20               34               76.52
     104.6            0.3              0                Open        ;
 34                   20               32               121.47
     104.6            0.3              0                Open        ;
 35                   32               33               70.87
     104.6            0.3              0                Open        ;
 36                   32               35               123.04             50
     0.3              0                Open        ;
 37                   36               37               142.63
     146.9            0.3              0                Open        ;
 38                   4                44               37.82
     259.4            0.3              0                Open        ;
 39                   44               45               115.03
     146.9            0.3              0                Open        ;
 40                   227              46               139.97
     104.6            0.3              0                Open        ;
 41                   46               47               73.78
     104.6            0.3              0                Open        ;
 42                   46               42               81.83
     104.6            0.3              0                Open        ;
 43                   42               43               121.33
     104.6            0.3              0                Open        ;
 44                   42               41               83.20
     104.6            0.3              0                Open        ;
 45                   41               40               107.80
     104.6            0.3              0                Open        ;
 46                   40               39               125.71
     104.6            0.3              0                Open        ;
 47                   39               38               101.01
     104.6            0.3              0                Open        ;
 50                   6                186              79.05              50
     0.3              0                Open        ;
 51                   7                185              74.48
     104.6            0.3              0                Open        ;
 52                   9                8                93.39              50
     0.3              0                Open        ;
 53                   8                11               97.11
     104.6            0.3              0                Open        ;
 56                   9                180              65.24              50
     0.3              0                Open        ;
 58                   45               81               80.01
     146.9            0.3              0                Open        ;
 62                   97               98               100.10
     104.6            0.3              0                Open        ;
```

63		96	95	110.43	
	104.6	0.3	0	Open	;
64		81	82	102.49	
	146.9	0.3	0	Open	;
65		82	84	85.80	
	146.9	0.3	0	Open	;
66		84	85	85.21	
	146.9	0.3	0	Open	;
67		85	86	80.13	
	146.9	0.3	0	Open	;
70		88	89	57.51	
	104.6	0.3	0	Open	;
71		82	95	89.78	
	104.6	0.3	0	Open	;
74		94	99	91.13	
	104.6	0.3	0	Open	;
75		98	99	84.85	
	104.6	0.3	0	Open	;
76		95	94	78.05	
	104.6	0.3	0	Open	;
77		94	93	82.48	
	104.6	0.3	0	Open	;
78		93	92	80.93	
	104.6	0.3	0	Open	;
82		86	92	89.19	
	104.6	0.3	0	Open	;
85		45	49	85.33	
	104.6	0.3	0	Open	;
86		49	50	100.23	
	208.5	0.3	0	Open	;
87		49	58	83.72	
	104.6	0.3	0	Open	;
88		81	58	92.44	
	104.6	0.3	0	Open	;
89		58	83	104.95	
	104.6	0.3	0	Open	;
90		82	83	90.94	
	104.6	0.3	0	Open	;
91		83	59	36.36	
	104.6	0.3	0	Open	;
92		59	60	53.28	
	104.6	0.3	0	Open	;
93		60	61	87.69	
	104.6	0.3	0	Open	;
94		61	62	73.84	
	104.6	0.3	0	Open	;
100		86	62	92.46	
	146.9	0.3	0	Open	;
103		59	66	90.84	
	104.6	0.3	0	Open	;
106		68	69	78.97	
	104.6	0.3	0	Open	;
112		62	69	96.55	
	146.9	0.3	0	Open	;
115		66	73	89.94	
	104.6	0.3	0	Open	;
118		75	76	79.77	
	104.6	0.3	0	Open	;

```
122             69          76          91.61
     146.9      0.3         0           Open        ;
124             49          51          142.37
     208.5      0.3         0           Open        ;
125             51          52          84.09
     104.6      0.3         0           Open        ;
126             51          57          86.38
     104.6      0.3         0           Open        ;
127             58          57          138.78
     104.6      0.3         0           Open        ;
128             57          56          138.44
     104.6      0.3         0           Open        ;
129             51          101         142.70
     208.5      0.3         0           Open        ;
130             101         102         86.00
     104.6      0.3         0           Open        ;
131             101         56          85.32
     104.6      0.3         0           Open        ;
132             56          78          113.55
     104.6      0.3         0           Open        ;
133             78          79          77.00
     104.6      0.3         0           Open        ;
134             73          78          94.96
     104.6      0.3         0           Open        ;
137             79          124         113.28
     104.6      0.3         0           Open        ;
138             56          55          82.18
     104.6      0.3         0           Open        ;
141             101         53          113.39
     208.5      0.3         0           Open        ;
143             124         119         51.40
     104.6      0.3         0           Open        ;
155             76          119         92.25
     146.9      0.3         0           Open        ;
163             119         122         91.09
     146.9      0.3         0           Open        ;
164             124         123         86.33
     104.6      0.3         0           Open        ;
166             78          126         87.19
     104.6      0.3         0           Open        ;
167             55          126         102.13
     146.9      0.3         0           Open        ;
168             126         125         87.84
     146.9      0.3         0           Open        ;
169             125         123         107.17
     146.9      0.3         0           Open        ;
170             123         122         52.57
     146.9      0.3         0           Open        ;
176             145         146         116.58
     104.6      0.3         0           Open        ;
179             130         144         52.59
     104.6      0.3         0           Open        ;
180             123         130         81.01
     104.6      0.3         0           Open        ;
183             55          139         88.26
     146.9      0.3         0           Open        ;
184             139         141         106.00
     146.9      0.3         0           Open        ;
```

```
 186                  141             226             96.28
     208.5            0.3             0               Open        ;
 187                  139             127             104.36
     104.6            0.3             0               Open        ;
 189                  127             129             90.76
     104.6            0.3             0               Open        ;
 191                  129             130             109.11
     104.6            0.3             0               Open        ;
 196                  139             135             88.81
     146.9            0.3             0               Open        ;
 207                  135             151             100.10
     146.9            0.3             0               Open        ;
 210                  137             147             44.23
     104.6            0.3             0               Open        ;
 211                  149             148             52.43
     104.6            0.3             0               Open        ;
 214                  151             152             58.65
     104.6            0.3             0               Open        ;
 215                  152             153             50.81
     104.6            0.3             0               Open        ;
 216                  153             154             72.13
     104.6            0.3             0               Open        ;
 218                  151             156             95.02
     146.9            0.3             0               Open        ;
 222                  159             158             51.07
     104.6            0.3             0               Open        ;
 225                  156             155             105.52
     104.6            0.3             0               Open        ;
 229                  156             163             89.93
     146.9            0.3             0               Open        ;
 230                  163             164             82.11
     104.6            0.3             0               Open        ;
 233                  160             167             91.61
     104.6            0.3             0               Open        ;
 235                  161             160             51.61
     146.9            0.3             0               Open        ;
 238                  168             167             48.10
     104.6            0.3             0               Open        ;
 243                  167             170             94.52
     104.6            0.3             0               Open        ;
 244                  170             169             58.26
     104.6            0.3             0               Open        ;
 249                  170             175             91.39
     104.6            0.3             0               Open        ;
 250                  175             224             92.33
     146.9            0.3             0               Open        ;
 253                  186             189             101.63          50
     0.3              0               Open        ;
 254                  185             190             99.67
     104.6            0.3             0               Open        ;
 255                  8               179             68.73
     104.6            0.3             0               Open        ;
 256                  179             188             95.77
     104.6            0.3             0               Open        ;
 257                  180             187             96.55           50
     0.3              0               Open        ;
 260                  103             182             126.41
     146.9            0.3             0               Open        ;
```

```
 261                 177             181             135.66
     104.6           0.3             0               Open          ;
 262                 183             182             95.19
     146.9           0.3             0               Open          ;
 263                 182             181             100.30
     104.6           0.3             0               Open          ;
 264                 181             184             93.70
     104.6           0.3             0               Open          ;
 265                 189             9               75.87              50
     0.3             0               Open          ;
 266                 190             8               76.03
     104.6           0.3             0               Open          ;
 267                 188             177             80.24
     104.6           0.3             0               Open          ;
 268                 187             103             82.09              50
     0.3             0               Open          ;
 270                 182             195             132.21
     146.9           0.3             0               Open          ;
 272                 195             194             34.81
     104.6           0.3             0               Open          ;
 273                 181             193             122.36
     104.6           0.3             0               Open          ;
 274                 194             193             66.25
     104.6           0.3             0               Open          ;
 275                 193             192             26.33
     104.6           0.3             0               Open          ;
 276                 192             191             64.18
     104.6           0.3             0               Open          ;
 277                 192             198             108.30
     104.6           0.3             0               Open          ;
 278                 194             197             103.58
     104.6           0.3             0               Open          ;
 279                 197             199             85.13
     104.6           0.3             0               Open          ;
 280                 197             198             95.38
     104.6           0.3             0               Open          ;
 281                 198             200             104.42
     104.6           0.3             0               Open          ;
 282                 197             201             108.31
     104.6           0.3             0               Open          ;
 285                 200             203             104.04
     104.6           0.3             0               Open          ;
 286                 201             204             102.76
     104.6           0.3             0               Open          ;
 287                 204             205             90.06
     104.6           0.3             0               Open          ;
 288                 204             203             93.20
     104.6           0.3             0               Open          ;
 289                 203             206             102.34
     104.6           0.3             0               Open          ;
 290                 204             207             105.48
     104.6           0.3             0               Open          ;
 293                 183             209             133.71
     208.5           0.3             0               Open          ;
 294                 209             210             192.31
     208.5           0.3             0               Open          ;
 295                 210             211             37.29
     208.5           0.3             0               Open          ;
```

296		207	218	100.72	
	104.6	0.3	0	Open	;
298		206	220	103.41	
	104.6	0.3	0	Open	;
301		218	221	110.34	
	104.6	0.3	0	Open	;
302		220	223	115.01	
	104.6	0.3	0	Open	;
303		221	223	93.65	
	104.6	0.3	0	Open	;
304		221	225	125.14	
	104.6	0.3	0	Open	;
305		175	212	94.93	
	104.6	0.3	0	Open	;
307		213	214	51.61	
	104.6	0.3	0	Open	;
309		212	216	51.30	
	104.6	0.3	0	Open	;
310		212	215	55.54	
	104.6	0.3	0	Open	;
311		212	213	53.05	
	104.6	0.3	0	Open	;
313		211	224	236.84	
	208.5	0.3	0	Open	;
315		224	225	160.50	
	146.9	0.3	0	Open	;
316		175	173	121.26	
	104.6	0.3	0	Open	;
317		170	231	137.02	
	104.6	0.3	0	Open	;
318		167	232	128.45	
	104.6	0.3	0	Open	;
319		160	163	98.95	
	146.9	0.3	0	Open	;
320		158	156	104.57	
	104.6	0.3	0	Open	;
321		149	151	104.03	
	104.6	0.3	0	Open	;
322		137	135	104.87	
	104.6	0.3	0	Open	;
323		135	133	106.31	
	104.6	0.3	0	Open	;
324		133	132	151.44	
	104.6	0.3	0	Open	;
326		120	114	115.70	
	104.6	0.3	0	Open	;
328		122	120	129.78	
	104.6	0.3	0	Open	;
329		119	117	107.67	
	104.6	0.3	0	Open	;
330		76	107	114.19	
	104.6	0.3	0	Open	;
331		107	109	102.80	
	104.6	0.3	0	Open	;
332		117	112	137.29	
	104.6	0.3	0	Open	;
333		86	88	107.97	
	104.6	0.3	0	Open	;

334	226	183	56.16	259.4	0.3	0	Open	;
336	210	161	39.79	146.9	0.3	0	Open	;
337	211	237	56.33	146.9	0.3	0	Open	;
338	69	72	164.56	104.6	0.3	0	Open	;
339	62	64	166.95	104.6	0.3	0	Open	;
340	53	141	55.47	208.5	0.3	0	Open	;
342	97	47	56.72	104.6	0.3	0	Open	;
343	73	75	137.29	104.6	0.3	0	Open	;
344	66	68	140.32	104.6	0.3	0	Open	;
345	227	45	89.70	104.6	0.3	0	Open	;
346	5	227	128.29	104.6	0.3	0	Open	;
347	227	96	69.70	104.6	0.3	0	Open	;
348	44	50	59.53	208.5	0.3	0	Open	;
349	219	222	71.70	104.6	0.3	0	Open	;
350	208	219	105.31	104.6	0.3	0	Open	;
351	205	208	103.64	104.6	0.3	0	Open	;
352	202	237	59.52	104.6	0.3	0	Open	;
353	199	202	105.62	104.6	0.3	0	Open	;
354	184	191	126.41	104.6	0.3	0	Open	;
355	144	145	122.65	104.6	0.3	0	Open	;
356	178	184	129.78	104.6	0.3	0	Open	;
357	228	178	86.03	104.6	0.3	0	Open	;
358	229	228	98.58	104.6	0.3	0	Open	;
359	11	229	64.45	104.6	0.3	0	Open	;
360	230	11	109.14	104.6	0.3	0	Open	;
361	12	230	145.36	104.6	0.3	0	Open	;
362	92	90	116.98	104.6	0.3	0	Open	;
365	239	104	236.16	259.4	0.3	0	Open	;
366	104	4	231.64	259.4	0.3	0	Open	;

```
 367                  102             52              147.44
     104.6            0.3             0               Open        ;
 368                  52              50              141.66
     104.6            0.3             0               Open        ;
 369                  237             205             46.53
     104.6            0.3             0               Open        ;
 370                  103             177             89.24           50
     0.3              0               Open        ;
 371                  29              238             50.03           50
     0.3              0               Open        ;
 372                  24              36              302.63
     146.9            0.3             0               Open        ;
 373                  102             106             115.86
     104.6            0.3             0               Open        ;
 374                  239             226             81.46
     259.4            0.3             0               Open        ;
 375                  239             103             105.24
     146.9            0.3             0               Open        ;

[PUMPS]
;ID                   Node1           Node2           Parameters

[VALVES]
;ID                   Node1           Node2           Diameter
     Type  Setting         MinorLoss

[TAGS]
 NODE      4               1
 NODE      5               1
 NODE      6               1
 NODE      7               1
 NODE      8               1
 NODE      9               1
 NODE      11              1
 NODE      12              1
 NODE      14              1
 NODE      15              1
 NODE      16              1
 NODE      17              1
 NODE      18              1
 NODE      20              1
 NODE      21              1
 NODE      24              1
 NODE      25              1
 NODE      27              1
 NODE      28              1
 NODE      29              1
 NODE      30              1
 NODE      32              1
 NODE      33              1
 NODE      34              1
 NODE      35              1
 NODE      36              1
 NODE      37              1
 NODE      38              1
 NODE      39              1
 NODE      40              1
 NODE      41              1
```

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NODE      42              1
NODE      43              1
NODE      44              1
NODE      45              1
NODE      46              1
NODE      47              1
NODE      49              1
NODE      50              1
NODE      51              1
NODE      52              1
NODE      53              1
NODE      55              1
NODE      56              1
NODE      57              1
NODE      58              1
NODE      59              1
NODE      60              1
NODE      61              1
NODE      62              1
NODE      64              1
NODE      66              1
NODE      68              1
NODE      69              1
NODE      72              1
NODE      73              1
NODE      75              1
NODE      76              1
NODE      78              1
NODE      79              1
NODE      81              1
NODE      82              1
NODE      83              1
NODE      84              1
NODE      85              1
NODE      86              1
NODE      88              1
NODE      89              1
NODE      90              1
NODE      92              1
NODE      93              1
NODE      94              1
NODE      95              1
NODE      96              1
NODE      97              1
NODE      98              1
NODE      99              1
NODE      101             1
NODE      102             1
NODE      103             1
NODE      104             1
NODE      106             1
NODE      107             1
NODE      109             1
NODE      112             1
NODE      114             1
NODE      117             1
NODE      119             1
NODE      120             1
```

```
NODE      122          1
NODE      123          1
NODE      124          1
NODE      125          1
NODE      126          1
NODE      127          1
NODE      129          1
NODE      130          1
NODE      132          1
NODE      133          1
NODE      135          1
NODE      137          1
NODE      139          1
NODE      141          1
NODE      144          1
NODE      145          1
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NODE      178          1
NODE      179          1
NODE      180          1
NODE      181          1
NODE      182          1
NODE      183          1
NODE      184          1
NODE      185          1
NODE      186          1
NODE      187          1
NODE      188          1
NODE      189          1
NODE      190          1
NODE      191          1
NODE      192          1
NODE      193          1
NODE      194          1
NODE      195          1
NODE      197          1
```

```
 NODE      198              1
 NODE      199              1
 NODE      200              1
 NODE      201              1
 NODE      202              1
 NODE      203              1
 NODE      204              1
 NODE      205              1
 NODE      206              1
 NODE      207              1
 NODE      208              1
 NODE      209              1
 NODE      210              1
 NODE      211              1
 NODE      212              1
 NODE      213              1
 NODE      214              1
 NODE      215              1
 NODE      216              1
 NODE      218              1
 NODE      219              1
 NODE      220              1
 NODE      221              1
 NODE      222              1
 NODE      223              1
 NODE      224              1
 NODE      225              1

[DEMANDS]
;Junction              Demand          Pattern         Category

[STATUS]
;ID                    Status/Setting

[PATTERNS]
;ID                    Multipliers

[CURVES]
;ID                    X-Value         Y-Value

[CONTROLS]

[RULES]

[ENERGY]
 Global Efficiency     75
 Global Price          0
 Demand Charge         0

[EMITTERS]
;Junction              Coefficient

[QUALITY]
;Node                  InitQual

[SOURCES]
;Node                  Type            Quality         Pattern
```

```
[REACTIONS]
;Type      Pipe/Tank       Coefficient


[REACTIONS]
 Order Bulk               1
 Order Tank               1
 Order Wall               1
 Global Bulk              0
 Global Wall              0
 Limiting Potential       0
 Roughness Correlation    0

[MIXING]
;Tank                 Model

[TIMES]
 Duration             0
 Hydraulic Timestep   1:00
 Quality Timestep     0:05
 Pattern Timestep     1:00
 Pattern Start        0:00
 Report Timestep      1:00
 Report Start         0:00
 Start ClockTime      12 am
 Statistic            None

[REPORT]
 Status               No
 Summary              No
 Page                 0

[OPTIONS]
 Units                LPS
 Headloss             D-W
 Specific Gravity     1
 Viscosity            1
 Trials               40
 Accuracy             0.001
 CHECKFREQ            2
 MAXCHECK             10
 DAMPLIMIT            0
 Unbalanced           Continue 10
 Pattern              1
 Demand Multiplier    1
 Emitter Exponent     0.5
 Quality              None mg/L
 Diffusivity          1
 Tolerance            0.01

[COORDINATES]
;Node                 X-Coord          Y-Coord
 4                    1047.94          628.69
 5                    1067.37          596.03
 6                    951.06           548.39
 7                    858.01           516.27
 8                    722.87           726.74
 9                    809.27           762.18
```

11	632.04	692.40
12	773.45	480.82
14	966.57	460.88
15	864.66	419.90
16	812.60	494.12
17	890.14	366.73
18	793.77	394.42
20	932.23	259.28
21	980.97	394.42
24	1135.41	479.34
25	1137.16	425.44
27	1118.33	355.65
28	1116.11	300.27
29	1006.45	282.54
30	1133.99	239.81
32	958.81	140.76
33	894.57	110.85
34	861.34	230.48
35	1002.02	25.55
36	1219.13	222.73
37	1234.63	80.94
38	1277.61	64.79
39	1262.95	164.73
40	1273.61	289.99
41	1289.60	396.59
42	1333.58	467.22
43	1409.53	561.83
44	1026.75	660.02
45	1133.53	702.79
46	1269.15	517.68
47	1333.98	552.91
49	1077.49	767.13
50	994.91	710.32
51	994.34	882.69
52	927.01	832.31
53	852.00	1095.50
55	943.60	1113.82
56	985.88	1043.35
57	1066.21	930.61
58	1145.14	816.45
59	1255.63	902.76
60	1300.16	932.02
61	1375.30	977.22
62	1436.86	1017.99
64	1573.57	1113.82
66	1201.51	975.71
68	1318.48	1053.22
69	1383.31	1098.32
72	1520.01	1189.92
73	1149.36	1048.99
75	1260.70	1129.32
76	1328.35	1171.60
78	1077.25	1110.77
79	1139.50	1156.10
81	1202.25	743.76
82	1286.67	801.88
83	1232.35	874.82
84	1356.53	851.69

85	1427.00	899.60
86	1493.24	944.70
88	1580.61	1008.12
89	1627.12	1041.95
90	1634.17	937.66
92	1539.74	868.60
93	1473.51	822.09
94	1404.45	776.99
95	1341.52	730.82
96	1249.42	669.89
97	1308.62	603.65
98	1390.36	661.43
99	1462.23	706.53
101	912.60	999.67
102	840.98	952.05
103	673.01	964.43
104	911.90	810.22
106	773.21	1045.90
107	1421.36	1237.84
109	1507.33	1294.21
112	1473.51	1392.86
114	1427.00	1460.51
117	1362.17	1312.53
119	1276.20	1247.71
120	1331.16	1395.68
122	1224.06	1322.40
123	1181.49	1291.55
124	1231.98	1221.52
125	1095.17	1228.04
126	1022.52	1178.65
127	973.51	1243.61
129	1047.89	1295.62
130	1136.68	1359.04
132	1048.39	1404.37
133	923.87	1318.17
135	837.84	1255.72
137	751.94	1195.56
139	888.64	1182.88
141	802.67	1120.87
144	1180.41	1388.26
145	1279.21	1460.93
146	1373.44	1529.57
147	713.88	1173.01
148	651.87	1244.89
149	694.15	1275.89
151	778.71	1336.49
152	826.63	1370.32
153	868.91	1398.50
154	928.39	1439.31
155	811.42	1472.72
156	723.75	1414.00
158	640.60	1350.59
159	601.14	1318.17
160	595.50	1432.33
161	553.22	1402.73
163	675.83	1490.11
164	744.59	1535.00
167	548.99	1511.25

168	508.12	1485.88
169	467.25	1569.03
170	516.58	1600.03
173	582.21	1759.25
175	485.58	1686.00
177	589.86	932.02
178	498.26	902.42
179	682.88	782.63
180	773.08	816.45
181	512.35	1043.35
182	608.19	1072.95
183	694.15	1113.82
184	424.97	1009.53
185	816.76	578.28
186	908.37	614.92
187	719.52	896.79
188	630.73	862.96
189	852.00	699.48
190	761.80	661.43
191	360.15	1118.05
192	420.75	1139.19
193	446.11	1146.23
194	506.71	1173.01
195	539.13	1185.70
197	448.93	1258.98
198	358.74	1227.97
199	529.26	1287.17
200	303.77	1316.76
201	391.15	1350.59
202	474.30	1377.36
203	260.08	1411.19
204	347.46	1443.60
205	432.02	1474.61
206	220.62	1505.61
207	306.59	1540.84
208	392.56	1570.44
209	622.28	1226.57
210	516.58	1387.23
211	505.37	1422.79
212	455.98	1776.20
213	496.85	1810.02
214	539.13	1839.62
215	410.88	1743.78
216	437.66	1824.12
218	275.59	1636.68
219	364.37	1671.91
220	189.62	1604.26
221	245.00	1742.69
222	336.27	1737.87
223	155.80	1714.19
224	406.65	1638.09
225	360.15	1791.70
226	723.56	1065.98
227	1190.15	633.22
228	542.56	828.67
229	597.25	746.65
230	691.42	600.82
231	629.27	1677.99

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 232                    654.93          1583.88
 237                    449.73          1431.58
 238                    994.26          331.06
 239                    771.91          1000.42
 1                      1102.55         645.26

[VERTICES]
;Link                   X-Coord         Y-Coord
 366                    1021.18         639.32
 368                    982.89          755.01
 372                    1215.26         406.63
 372                    1209.55         355.30
 372                    1240.92         268.33
 373                    795.45          1018.93

[LABELS]
;X-Coord             Y-Coord          Label & Anchor Node

[BACKDROP]
 DIMENSIONS     0.00            0.00            1746.00         1961.00
 UNITS          Meters
 FILE           C:\Users\Owner\Dropbox\Kirimati 2021\Epanet\Tabwakea
Light Background.bmp
 OFFSET         0.00            0.00

[END]
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Annex D Project Design Cost Estimate

Cost estimates for Kiritimati Island Water Project Concept Design

Item	Power supply	Description	Unit	Unit cost [AUD]*	Mob/demob & supervision	1a. FW - Tabwakea stage 1 (solar-1)		1b. FW - Tabwakea stage 1 (solar-2)		1c. FW - Tabwakea stage 1 (grid)		2a. Decca - London stage 1 (solar)		2b. Decca - London stage 1 (grid)		3a. Banana - Main Camp stage 1 (solar 1)		3b. Banana - Main Camp stage 1 (solar 2)		3c. Banana - Main Camp stage 1 (grid)		4. NZ Airfield - Poland stage 1		5.Tabwakea full retic extension		TOTAL STAGE 1 (grid)	
					$ 1,200,000		$ 2,957,500		$ 3,221,500		$ 2,425,000		$ 256,000		$ 203,000		$ 476,500		$ 556,500		$ 398,500		$ 310,000		$ 1,750,995		$ 6,437,195
Contractor mob/demob	n/a	Contractor mobilisation, establishment and demobilisation (shipping, etc.)	lump	$ 950,000	$ 950,000		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ 950,000
Supervision	n/a	Supervision of all major construction work (local & external)	lump	$ 250,000	$ 250,000		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ 250,000
Gallery - 2 pump wells	n/a	400m gallery with 2 pump wells (no pumps)	gallery	$ 150,000			$ -	6	$ 900,000		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Gallery - 1 pump well	n/a	400m gallery with 1 central pump well (no pump)	gallery	$ 130,000		6	$ 780,000		$ -	6	$ 780,000		$ -		$ -		$ -		$ -		$ -		$ -		$ -	6	$ 780,000
Gallery rehab - used	n/a	Rehabilitation & cleaning of existing used galleries	gallery	$ 10,000			$ -		$ -		$ -		$ -		$ -	4	$ 40,000	4	$ 40,000	4	$ 40,000		$ -		$ -	4	$ 40,000
Gallery rehab - unused (N)	n/a	Rehabilitation & cleaning of existing unused galleries (N of runway)	gallery	$ 30,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Gallery rehab - unused (S)	n/a	Rehabilitation & cleaning of existing unused galleries (S of runway)	gallery	$ 15,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Gallery reconfiguration	n/a	Reconfiguration of existing galleries from 2 to 1 pump well	gallery	$ 20,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Solar pump - 40kl/d	solar	Solar panels, frame, controller, pump for 40 kl/d gallery pump well	set	$ 35,000		6	$ 210,000		$ -		$ -		$ -		$ -	4	$ 140,000		$ -		$ -		$ -		$ -	-	$ -
Solar pump - 20kl/d	solar	Solar panels, frame, controller, pump for 20 kl/d gallery pump well	set	$ 24,000			$ -	12	$ 288,000		$ -	1	$ 24,000		$ -		$ -	8	$ 192,000		$ -	2	$ 48,000		$ -	2	$ 48,000
Submersible pump	grid	Submersible pump - grid connected; similar capacity to Lorentz solar pumps	ea	$ 3,000			$ -		$ -		$ -		$ -	1	$ 3,000		$ -		$ -		$ -		$ -		$ -	1	$ 3,000
Sump pump	grid	Sump pump for gallery pump well	pump	$ 1,500			$ -		$ -	6	$ 9,000		$ -		$ -		$ -		$ -	4	$ 6,000		$ -		$ -	10	$ 15,000
Diesel pump	fuel	Diesel pump backup for gallery pump well	pump	$ 10,000			$ -		$ -				$ -		$ -	1	$ 10,000	1	$ 10,000	1	$ 10,000	1	$ 10,000		$ -	2	$ 20,000
Diesel pump shed	n/a	Diesel pump shed replacement	shed	$ 5,000			$ -		$ -				$ -		$ -	1	$ 5,000	1	$ 5,000	1	$ 5,000		$ -		$ -	1	$ 5,000
Solar pump repair	solar	Repair/rehab existing solar pump/controller/panels	ea	$ 5,000		2	$ 10,000	2	$ 10,000	2	$ 10,000	2	$ 10,000	2	$ 10,000		$ -		$ -		$ -		$ -		$ -	4	$ 20,000
Wind pump repair	wind	Repair/rehab existing wind pump (e.g. bucket replacement)	ea	$ 2,000		2	$ 4,000	2	$ 4,000	2	$ 4,000	2	$ 4,000	2	$ 4,000		$ -		$ -		$ -	1	$ 2,000		$ -	5	$ 10,000
Valves, meters, gauges for pu	n/a	Valves, meters, gauges, piping and fittings for gallery pump wells	set	$ 2,000		6	$ 12,000	12	$ 24,000	6	$ 12,000	1	$ 2,000	1	$ 2,000	4	$ 8,000	8	$ 16,000	4	$ 8,000	2	$ 4,000		$ -	13	$ 26,000
GGT - 2 gallery	grid	Gallery ground tank and pump station (2 galleries connected)	station	$ 25,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
GGT - 4 gallery	grid	Gallery ground tank and pump station (4 galleries connected)	station	$ 38,000			$ -		$ -	2	$ 76,000		$ -		$ -		$ -		$ -	-	$ -		$ -		$ -	2	$ 76,000
GGT - 6 gallery	grid	Gallery ground tank and pump station (6 galleries connected)	station	$ 50,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Lowering header tank	n/a	Lower head tank from 10m to 6m with new timber platform & painting	ea	$ 20,000			$ -		$ -		$ -		$ -		$ -	1	$ 20,000	1	$ 20,000	1	$ 20,000	1	$ 20,000		$ -	2	$ 40,000
Pipeline PVC 80mm	n/a	Pipeline PVC PN9 DN80	m	$ 55			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Pipeline PVC 100mm	n/a	Pipeline PVC PN9 DN100 rubber ring jointed	m	$ 60		1,500	$ 90,000	1,900	$ 114,000	1,500	$ 90,000		$ -		$ -		$ -		$ -		$ -		$ -	12,247	$ 734,820	13,747	$ 824,820
Pipeline PVC 150mm	n/a	Pipeline PVC PN9 DN150 rubber ring jointed	m	$ 80		8,700	$ 696,000	8,700	$ 696,000	3,600	$ 288,000		$ -		$ -		$ -		$ -		$ -		$ -	3,691	$ 295,280	7,291	$ 583,280
Pipeline PVC 200mm	n/a	Pipeline PVC PN9 DN200 rubber ring jointed	m	$ 115			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	1,157	$ 133,055	1,157	$ 133,055
Pipeline PVC 250mm	n/a	Pipeline PVC PN9 DN250 rubber ring jointed	m	$ 150			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	643	$ 96,450	643	$ 96,450
Pipeline PVC 292mm	n/a	Pipeline PVC PN9 DN292 rubber ring jointed	m	$ 200			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Pipeline PVC 375mm	n/a	Pipeline PVC PN9 DN375 rubber ring jointed	m	$ 270			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	57	$ 15,390	57	$ 15,390
Pipeline PE 50mm	n/a	Pipeline PE DN50 - gallery pipeline	m	$ 50			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Pipeline PE 180mm	n/a	Pipeline PE DN180 - not anchored	m	$ 90			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Air valve 50mm	n/a	DN50 air valve connected to main line	ea	$ 2,000		6	$ 12,000	6	$ 12,000	4	$ 8,000		$ -		$ -	2	$ 4,000	2	$ 4,000	2	$ 4,000	4	$ 8,000		$ -	10	$ 20,000
Stop/gate valve 50mm	n/a	DN50 stop or gate valve connected to main line	ea	$ 250			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	4	$ 1,000
Stop/gate valve 80mm	n/a	DN80 stop or gate valve connected to main line	ea	$ 350			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	4	$ 1,400
Stop/gate valve 100mm	n/a	DN80 stop or gate valve connected to main line	ea	$ 450			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	4	$ 1,800
Reticulation valves & fittings	n/a	Approx. cost of unaccounted retic valves, gauges and fittings (~10% of total)	lump	n/a		-	$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	1	$ 200,000	4	$ 213,500
Pressure gauge	n/a	Pressure gauge connected to pipeline	ea	$ 1,000		4	$ 4,000	4	$ 4,000	2	$ 2,000	-	$ -	-	$ -	2	$ 2,000	2	$ 2,000	2	$ 2,000	2	$ 2,000	6	$ 6,000	24	$ 24,000
Flow meter 80mm	n/a	DN80 flow meter connected to main line	ea	$ 3,000		4	$ 12,000	4	$ 12,000	2	$ 6,000	2	$ 6,000	2	$ 6,000	2	$ 6,000	2	$ 6,000	2	$ 6,000	2	$ 6,000		$ -	8	$ 24,000
Fence & gate for gallery infra	n/a	Fencing, gate & locks for above-ground gallery infrastructure	set	$ 5,000		7	$ 35,000	13	$ 65,000	3	$ 15,000	1	$ 5,000		$ -	5	$ 25,000	9	$ 45,000	1	$ 5,000	3	$ 15,000		$ -	7	$ 35,000
Solar chlorinator	solar	Solar-battery powered chlorination unit	set	$ 180,000		1	$ 180,000	1	$ 180,000		$ -	1	$ 180,000		$ -	1	$ 180,000	1	$ 180,000		$ -	1	$ 180,000		$ -	1	$ 180,000
Chlorinator	grid	Grid-powered chlorination unit	set	$ 120,000			$ -		$ -	1	$ 120,000		$ -	1	$ 120,000		$ -		$ -	1	$ 120,000		$ -		$ -	3	$ 360,000
Chlorination shed	n/a	Shed for chlorination unit (solar or grid)	shed	$ 15,000			$ -		$ -		$ -		$ -		$ -	1	$ 15,000	1	$ 15,000	1	$ 15,000	1	$ 15,000		$ -	2	$ 30,000
Village tank and pump statio	grid	250kL tank, transfer pumps, controls & security for London station	lump	$ 440,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Village tank and pump statio	grid	Ground tank, transfer pumps, controls & security for Tabwakea station	lump	$ 880,000		1	$ 880,000	1	$ 880,000	1	$ 880,000		$ -		$ -		$ -		$ -		$ -		$ -		$ -	1	$ 880,000
Village tank and pump statio	grid	Ground tank, transfer pumps, controls & security for Main Camp station	lump	$ 660,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Village tank and pump statio	grid	Ground tank, header tank, transfer pumps, controls & security for Banana sta	lump	$ 264,000			$ -		$ -		$ -		$ -		$ -	-	$ -	-	$ -	-	$ -		$ -		$ -	-	$ -
Village tank and pump statio	grid	Ground tank, transfer pumps, controls & security for Poland station	lump	$ 440,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Village pump station reconfig	grid	Reconfigured controls/automation of London pumps	lump	$ 25,000			$ -		$ -		$ -	1	$ 25,000	1	$ 25,000		$ -		$ -		$ -		$ -		$ -	1	$ 25,000
Retic repair lump sum	n/a	Lump sum for whole of village retic repairs	lump	$ 20,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	1	$ 20,000	4	$ 80,000
Household connection	n/a	Metered household or commercial water connection with 25mm branch line	household	$ 500			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	500	$ 250,000	620	$ 310,000
Household head tank	n/a	500L head tank on raised slab with float valve and in/outlet pipwork	tank	$ 1,500			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -	-	$ -
3-phase connection fee	grid	3-phase 415V commercial/gov connection fee - gallery infrastructure	ea	$ 150			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
1-phase connection fee	grid	Single-phase 230V commercial/gov connection fee - gallery infrastructure	ea	$ 50			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Grid extension	grid	Cable cost per meter xlpe 6mm - gallery infrastructure	m	$ 10			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Trenching for cable laying	grid	Trenching for electrical cable laying	m	$ 10			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Transformer	grid	Step-down transformer for grid extension at galleries	ea	$ 15,000			$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -		$ -	-	$ -
Grid connection at village tan	grid	Grid connection at villlage tank & pump station (site specific)	lump	n/a		1	$ 32,500	1	$ 32,500	1	$ 32,500				$ -	1	$ 21,500	1	$ 21,500	1	$ 21,500		$ -		$ -	2	$ 54,000
Grid connection at lens	grid	Grid connection at lens (site specific)	lump	n/a			$ -		$ -	1	$ 92,500			1	$ 33,000		$ -		$ -	1	$ 136,000		$ -		$ -	3	$ 261,500