Climate and Abstraction Impacts in Atoll Environments (CAIA)

Flow meter testing, Buota and Bonriki Water Reserves, Tarawa, Kiribati

Aminisitai Loco

EUROPEAN UNION

Pacific Community
Communauté du Pacifique

Climate and Abstraction Impacts in Atoll Environments (CAIA)

Flow meter testing, Buota and Bonriki Water Reserves, Tarawa, Kiribati

Geoscience Division of the Pacific Community

Aminisitai Loco

Pacific Community
Communauté du Pacifique

Suva, Fiji
2017

Original text: English

Pacific Community Cataloguing-in-publication data

Loco, Aminisitai

Flow meter testing, Buota and Bonriki Water Reserves, Tarawa, Kiribati / by Aminisitai Loco

(SPC Technical Report SPC00050)

1. Sea level — Climatic factors — Kiribati.
2. Floods — Kiribati.
3. Climatic changes — Social aspects — Kiribati.
4. Climatic changes — Management — Kiribati.
5. Climatic changes — Environmental aspects — Kiribati.
6. Climate change mitigation — Kiribati.

I. Loco, Aminisitai II. Title III. Pacific Community IV. Series

577.220 99593 AACR2

ISBN: 978-982-00-1057-4

Contents

Acknowledgements vii
1 Introduction 2
2 Background 2
3 Objectives 4
4 Previous work 4
5 Test methodology, instrumentation and survey team 7
5.1 Current flow meter 7
5.2 Test instrumentation and procedure 9
5.3 Survey team and schedule 11
6 Results and data analysis 13
7 Major observations 19
8 Recommendations 20
9 Summary and Conclusion 21
10 References 22

Annexes
Annex 1 – Flow meter testing schedule
Annex 2 – Field test results for transmission main meters and gallery meter
Annex 3 – Gallery pump house piping layout
Annex 4 – Field photos

List of Tables

Table 1: Proposed design yield for the Bonriki and Buota galleries (Falkland, 2003b). 4
Table 2: Result from the above test at Bonriki WTP (Schwalger & Skerjanz, 2014). 5
Table 3: Results from the meter testing run in December 2014 by PUB and KAP III leak detection team. 6
Table 4: Agreed work schedule between PUB and SPC. 11
Table 5: Summary of flow rates and variability recorded by FFM and UFM at the Buota and Bonriki main meters and Bonriki galleries. 14
Table 6: Tested gallery design yield (Falkland, 2003b) and estimated flow data and variability from June 2015. 17

List of Figures

Figure 1: Location map of the tested main transmission lines in Bonriki and Buota water reserves; and the pumping galleries in the Bonriki water reserve. Please note the spatial coverage of the new solar infrastructure (shown by the hashed lines around the Bonriki Water Treatment Plant (WTP), extending towards galleries 8, 9 and 10. 3
Figure 2: Water meter accuracy test at the Bonriki WTP main meter (Schwalger & Skerjanz, 2014)... 5
Figure 3: FFM at the WTP outlet in Bonriki reading 8311631.77 m^3. 7
Figure 4: FFM at gallery 13 pump house reading 27887.096 m^3. 7
Figure 5: Location of new FFM installed by SPC during the BIVA Project, between September 2013 and January 2014. 8
Figure 6: Typical layout in a gallery pump house, comprising the pump motor, FFM, non-return valve and a gate valve. The numerous pipe bending and connections are likely to cause turbulent flow and generate erroneous flow readings. 10
Figure 7: Team digging the test hole outside the Bonriki WTP approximately 10 m away from the FFM. 10
Figure 8: PUB technician setting up UFM unit 2 to test the Bonriki WTP main transmission line. 10
Figure 9: Gallery 2 showing no pump due to previous electrical failure. 10
Figure 10: Excavation team digging down to the drainage line for gallery 16. 10
Figure 11: PUB personnel setting up UFM at gallery 12. Note that access into the pump house was prevented by the two concrete slabs. 10
Figure 13: UFM device attached onto the PVC drainage pipe outside gallery 21. 11
Figure 12: UFM device attached onto the polyethylene 11
Figure 14: Water flow discharge and cumulative volumetric flow measured at the Bonriki WTP main, commencing at 2.54 pm on Friday, June 12th, 2015. 15
Figure 15: FFM at gallery 19 reading 319656.862 m^3 at the beginning of the test. 15
Figure 16: UFM #1 gallery 19 reading 0.056 m^3 and 3.84 m^3/h, equivalent to 1.07 L/s. 15
Figure 17: FFM at gallery 5 reading 140276.342 m^3 at the end of the meter test at 10.25 pm (18th June 2015). 16
Figure 18: UFM at gallery 5 reading 21.856 m^3 and 4.31 m^3/h, equivalent to 1.20 L/s, at the end of the meter test at 10.25 pm (18th June 2015). 16
Figure 19: FFM at gallery 12 showing 7789.994 m^3 at the start of the test. 16

Figure 20: FFM at gallery 12 showing 7789.994 m^3 several minutes after photo at Figure 17 was taken, indicating that there was no water flow and suggesting that the pump may not be working, even though the motor was on. 16
Figure 21: UFM displaying 0 volumetric flow and 0 discharge rate at gallery 12 suggesting that the pump may not be working even though the motor was observed to be on. 16
Figure 22: Design yield versus actual flow rate at the tested galleries showing increased abstraction at 9 galleries based on UFM readings. 17
Figure 23: Statistical analysis of tested galleries in Bonriki showing more than 85% of the tested gallery meters showing flow discrepancy of more than 10%. 18

Abbreviations Used

AusAID - Australian Agency for International Development

CAIA - Climate and abstraction impacts on Atoll Environments

BIVA - Bonriki Inundation Vulnerability Assessment

EU - European Union

GoK - Government of Kiribati

GSD - GeoScience Division within SPC

FFM - Fixed flow meter

KAP III - Kiribati Adaptation Phase III

MELAD - Ministry of Environment, Land and Agricultural Development

MPWU - Ministry of Public Works and Utilities

PUB - Public Utilities Board

SPC - Secretariat of the Pacific Community

UFM - Ultrasonic flow meters

WSP - Water and Sanitation Program with the GSD

WTP - Water treatment plant

Measurements Units

KL/day - kilo litres per day

L/s - litres per seconds

m^3 - cubic meters

m^3/d - cubic meters per day

Acknowledgements

The preparation of this field mission, the data collection and document review, involved the support and assistance of a large number of people. The author particularly acknowledges with gratitude the following contributions of the Government and people of Kiribati:

- the KAP III Project Manager for granting the use of the Project's ultrasonic meter and their field technicians for this flow exercise;
- the Public Utilities Board for granting access into the infiltration gallery pump chambers to permit the measurement of flow from existing flow meters; and
- the Bonriki community for providing assistance during the excavation of test holes around all the operational galleries and trunk main.

Executive summary

Flow meter testing within the Bonriki and Buota water reserves, in Tarawa, was conducted as part of the European Union-funded Climate and Abstraction Impacts on Atoll Environments Project. Existing fixed flow meters installed near the main transmission lines and galleries were tested against portable ultrasonic flow meters to determine the:

- actual flow or abstraction data from the main transmission lines in Buota and Bonriki and individual galleries in Bonriki; and
- the accuracy and variability of abstraction data given by the fixed flow meters.

The Public Utilities Board and the GeoScience Division of the Secretariat of the Pacific Community conducted the field investigation from 12th to 20th June 2015.

An over-estimated flow of 18 % and 9 % were measured at the Bonriki and Buota main transmission lines flow meters, respectively. Fifteen (15) of the twenty-two (22) gallery flow meters at Bonriki registered a significant flow over-reading in the range 6 – 43%, with more than 85% of the tested galleries recording flow over-registration of more than 10%. Incorrect flow meter installation and turbulence-induced errors associated with the gallery pump-house pipe works are possible causes of the variability margin.

Replacement of flow meters, replacement of pumps and the establishment and implementation of accurate flow meters procedure are amongst the key remedial measures to ensure the accurate estimation of abstraction data for the modelling and sustainable management of the water reserves.

1 Introduction

As part of the European Union (EU)-funded Climate and Abstraction Impacts on Atoll Environments (CAIA) Project, a flow meter testing exercise was undertaken at the Buota and Bonriki water reserves in Tarawa, Republic of Kiribati. The field assessment was conducted by a partnership of the Government of Kiribati (GoK) as the utility provider, the Public Utilities Board (PUB), and the Secretariat of the Pacific Community (SPC), (GeoScience Division's (GSD) Water & Sanitation Program (WSP)) from the 10th to 20th June 2015. This summary report presents the background and the objectives of this flow meter testing work before the results and recommendations attained during the investigation are provided.

2 Background

Over-abstraction of groundwater around the Buota and Bonriki water reserves with respect to the estimated sustainable yields, coupled with the frequent climatic and tidal variability can threaten the availability and usability of fresh groundwater in atoll environments, such as in South Tarawa. The EU has funded the CAIA Project to explore the impacts of abstraction and climatic variabilities on the Buota and Bonriki water reserves, the main sources of water supply in South Tarawa. The testing of all flow meters within the water reserves was identified as a critical activity for this project. This is closely linked to the AusAID-funded Bonriki Inundation Vulnerability Assessment (BIVA) Project's groundwater modelling component, which tested and predicted the freshwater lens responses under various climatic, tidal and abstraction conditions.

This flow meter exercise was designed to establish actual groundwater abstraction around the water reserves – a critical modelling parameter.

A "Drought Committee" meeting, held in Tarawa in May 2015, identified the urgent need to review all installed flow meters in the water reserves and determine their accuracy and/or variability as per the known safe yield or pumping rates.

Hence, the meter testing exercise was conducted through the synchronous testing of two utrasonic flow meters (UFMs), the fixed flow meters (FFMs) attached to the main transmission lines in Buota and Bonriki, together with all the pumping galleries within the Bonriki water reserve (Figure 1).

Figure 1: Location map of the tested main transmission lines in Bonriki and Buota water reserves; and the pumping galleries in the Bonriki water reserve. Please note the spatial coverage of the new solar infrastructure (shown by the hashed lines around the Bonriki Water Treatment Plant (WTP), extending towards galleries 8, 9 and 10.

3 Objectives

This report is focussed on the flow meter test which was conducted in June 2015 with the following objectives:

1. Determine the actual flow or abstraction data from the main transmission lines in Buota and Bonriki and individual galleries in Bonriki.
2. Determine the accuracy and variability of abstraction data given by the fixed flow meters.

The meter test was conducted using an improved field approach (section 5) that considers the placement of fixed flow meters in relation to existing piping systems in the main transmission lines and galleries, together with the need to accurately install and use ultrasonic flow meters or UFM.

4 Previous work

Numerous studies have been conducted on the evaluation and characterisation of groundwater resources within the Bonriki and Buota water reserves. Alam et. al (2002) and Falkland (2003a) provided the modelling and establishment of the combined sustainable yield of 2,010 KL/day for the water reserves, with Bonriki yielding 1,660 KL/day and Buota 350 KL/day. This was followed by the design yield proposed for all the galleries by Falkland (2003b), shown in Table 1 below:

Table 1: Proposed design yield for the Bonriki and Buota galleries (Falkland, 2003b).

Gallery	Proposed pump rate	
Buota	L/min	m3/day
1	38.2	55
2	38.2	55
3	38.2	55
4	48.6	70
5	38.2	55
6	38.2	55
Total (Buota)	240	345
Bonriki		
1	59.0	85
2	59.0	85
3	59.0	85
4	59.0	85
5	48.6	70
6	38.2	55
7	38.2	55
8	59.0	85
9	48.6	70
10	38.2	55
11	59.0	85
12	38.2	55
13	38.2	55
14	59.0	85
15	59.0	85
16	59.0	85
17	59.0	85
18	59.0	85
Total (Bonriki)	938	1,350
Total (Bonriki + Buota)	1,177	1,695

The above demonstrated the intensive work conducted around the water reserves to ensure its protection and sustainable management, being the main public water supply source for South Tarawa, the seat of the GoK and home to the highest density of the local population.

The KAP III Project, through its non-revenue water reduction programme, conducted meter testing at the Bonriki main transmission line and documented a 16.23% flow variability based on volumetric flow recorded on the main master meter and the discharge recorded on a UFM (see Table 2).

Figure 2: Water meter accuracy test at the Bonriki WTP main meter (Schwalger & Skerjanz, 2014).

Table 2: Result from the above test at Bonriki WTP (Schwalger & Skerjanz, 2014).

Discharge recorded by - installed meter	Discharge recorded by ultrasonic flow meter	Difference	Difference in %
1,085.433	909.312	176.121	16.23%

These previous findings raised a lot of questions on the reliability and accuracy of all historical abstraction data currently used for modelling purposes and triggered the need to re-run this meter testing at the Bonriki Water Treatment Plant (WTP) and extend it to the operating galleries on Bonriki. The PUB, together with the KAP III leak detection team conducted a flow meter validation exercise in December 2014 around the Bonriki water reserve, with the summary of the results presented in Table 3.

Table 3: Results from the meter testing run in December 2014 by PUB and KAP III leak detection team.

Date	Meter name	Existing meter			UFM reading			Difference in discharge m^3 existing meter and UFM	% difference in discharge existing meter and UFM
Date	Meter name	Recorded hours hh:mm	Discharge recorded by FFM (m^3)	Flow rate (L/s)	Recorded hours hh:mm	Discharge recorded by UFM (m^3)	Flow rate (L/s)		% difference in discharge between FFM and UFM
17/12/2014	3	1:00	6	1.67	1:04	4.065	1.06	1.935	32%
21/12/2014	4	1:00	5	1.39	1:00	4.608	1.28	0.392	8%
17/12/2014	5	1:00	5	1.39	1:00	3.704	1.03	1.296	26%
17/12/2014	8	0:52	5	1.60	1:00	3.688	1.02	1.312	26%
20/12/2014	9	1:00	4	1.11	1:00	3.274	0.91	0.726	18%
20/12/2014	10	1:00	2	0.56	1:00	2.31	0.64	-0.31	-16%
20/12/2014	11	1:00	5	1.39	1:00	4.556	1.27	0.444	9%
21/12/2014	13	1:00	2	0.56	1:00	2.403	0.67	-0.403	-20%
18/12/2014	14	1:00	5	1.39	1:00	4.172	1.16	0.828	17%
17/12/2014	15	1:00	1	0.28	1:00	1.638	0.46	-0.638	-64%
21/12/2014	16	1:00	1	0.28	1:00	2.856	0.79	-1.856	-186%
18/12/2014	17	1:00	2	0.56	1:00	1.445	0.40	0.555	28%
20/12/2014	18	1:00	4	1.11	1:00	2.467	0.69	1.533	38%
17/12/2014	19	1:00	4	1.11	0:59	2.822	0.80	1.178	29%
18/12/2014	20	1:00	4	1.11	1:00	2.354	0.65	1.646	41%
18/12/2014	21	1:00	2	0.56	1:00	2.149	0.60	-0.149	-7%
18/12/2014	22	1:00	5	1.39	1:00	3.793	1.05	1.207	24%
17/12/2014	WTP	8:25	720	23.76	8:15	604.588	20.36	115.412	16%
18/12/2014	WTP	8:57	765	23.74	8:53	645.291	20.18	119.709	16%

Table 3 showed that, after testing the operating galleries for around 1 hour, the flow discrepancy was estimated to be between -186% and 41%. The Bonriki WTP main meter, tested twice for more than 8 hours, recorded an over-estimated flow of 16%. The recurring high-flow variability raised a lot of concern on the confidence in the flow readings recorded by the existing flow meters, which in turn can adversely affect the management of groundwater in the water reserve.

5 Test methodology, instrumentation and survey team

5.1 Current flow meter

Abstraction rates at the Bonriki Water Treatment Plant main outlet and at each gallery are continually registered on fixed flow meters and instantaneous flow readings are recorded by either the PUB water technicians or the Ministry of Public Works and Utilities (MPWU) water technicians on a systematic basis. Figures 3 and 4 below show the FFM used in the WTP outlet and the galleries, respectively. The FFM are permanent features in the infrastructure system in the infiltration gallery housing and at the WTP main. Seven (7) FFM out of the twenty-two (22) Bonriki sites were replaced and installed during the Bonriki Inundation Vulnerability Assessment (BIVA) Project between September 2013 and January 2014 (Figure 5). The remaining 15 FFM were installed from early to mid 2000s**.**

Figure 3: ***FFM at the WTP outlet in Bonriki reading 8311631.77 m^3.***

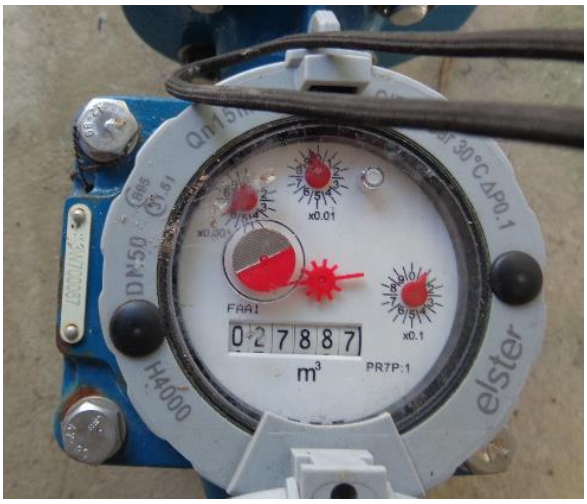

Figure 4: FFM at gallery 13 pump house reading 27887.096 m^3.

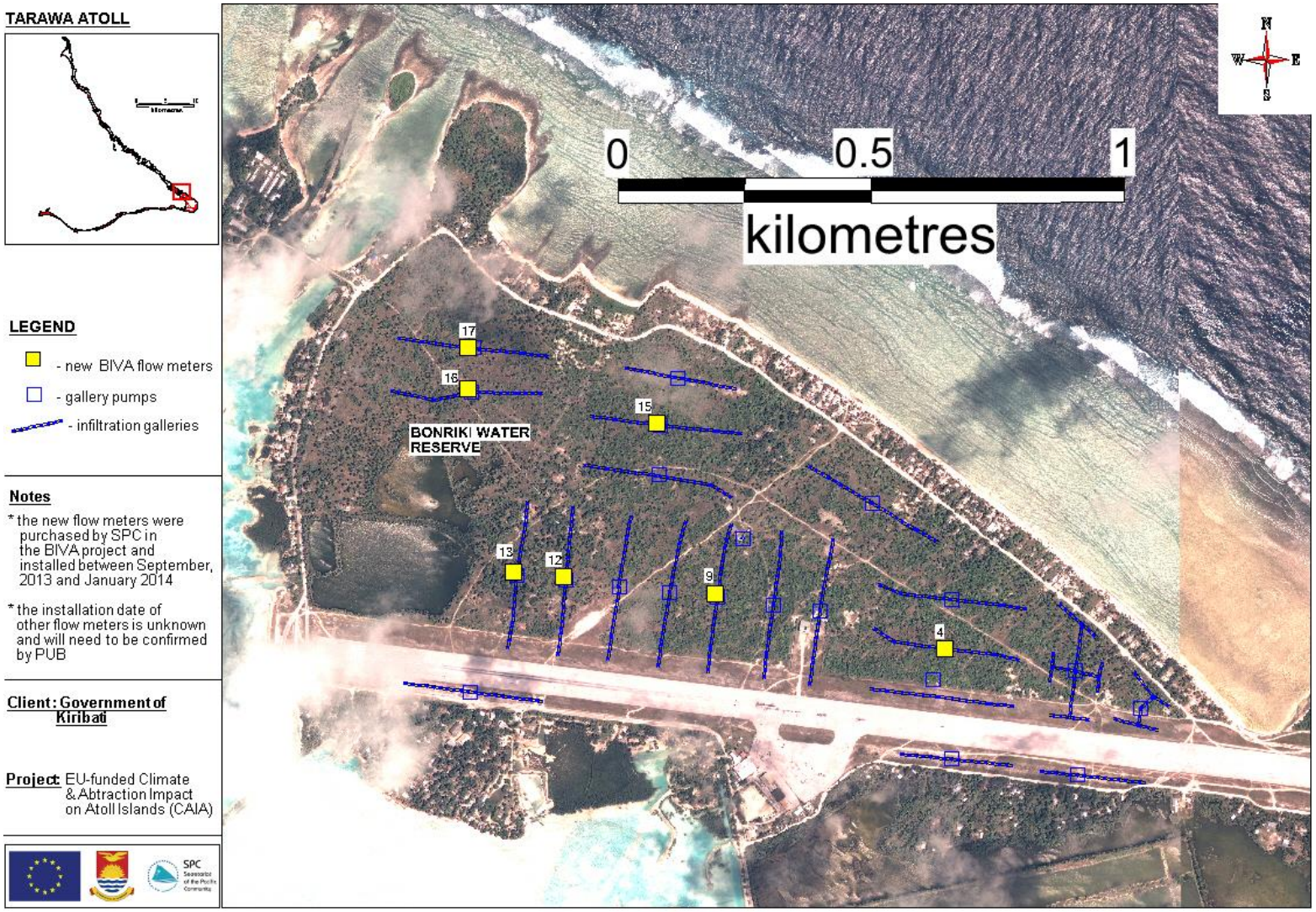

Figure 5: Location of new FFM installed by SPC during the BIVA Project, between September 2013 and January 2014.

5.2 Test instrumentation and procedure

The following water flow meters were tested:

1. FFM – these refer to the existing flow meters located at the Bonriki WTP (Figure 1) and in the gallery pump housing (Figure 1) and attached near the gallery pump motor to register the continuous volumetric discharge. The turbo-bar flow meter (Figure 1), installed at the WTP, meets the ISO 4064 class B standard and is manufactured within ±2% accuracy (Bermad, n.d). The elster "H4000 DM50" flow meter, installed at the galleries, are composed of materials meeting the Australian Standard AS 4020 and manufactured at ±2% accuracy (Elster Metering Ltd, 2015).

2. UFM – these refer to two (2) units of portable "flexim" ultrasonic, manufactured at ~ 5% accuracy (Ultrasonic flow meter technology, 2012), that are attached to the transmission pipes of pumping mains or galleries once the pipes are exposed through excavation.

The methodology was agreed between SPC and PUB staff ahead of the testing and is described below. It includes two types of tests for the main outlets in Buota and Bonriki and for the individual infiltration galleries, as described below:

1. A 48-hour test at the Bonriki and Buota main FFM attached to the transmission lines. This included the following:
    - Determining the orientation of transmission lines and locating the excavation area
    - Excavation and exposure of transmission pipes at least 10 m away from the main FFM to minimise the influence of turbulent flow and frictional effects associated with all the connections.
    - Attachment of both the UFM units to the transmission pipes.
    - Setting up and running the UFM in parallel to the FFM for a minimum of 48 hours.
    - Capturing photos from the display of both test meters at the beginning and end of tests for documentation.
    - The difference of the flow readings between the start and end period represents the volumetric discharge during the test period, which can later be converted into m^3/h and L/s for a discharge or flow rate.
2. A 4-hour test at each of the 22 gallery pump lines for the Bonriki water reserve only. This entailed:
    - determining of the orientation of drainage pipe from the pump house.
    - Excavation and exposure of drainage pipes outside the galley pump house where laminar flow can be expected and to avoid the influence of turbulent flow associated with all the bending and connections around the pump house (Figure 6).
    - Attachment of both the UFM units to the transmission pipes.
    - Setting up and running the UFM in time series relative to the FFM for at least 4 hours.
    - Taking photos and flow readings similar to the testing of the main transmission flow meters above.

Figure 6: Typical layout in a gallery pump house, comprising the pump motor, FFM, non-return valve and a gate valve. The numerous pipe bending and connections are likely to cause turbulent flow and generate erroneous flow readings.

Figure 7: Team digging the test hole outside the Bonriki WTP approximately 10 m away from the FFM.

Figure 8: PUB technician setting up UFM unit 2 to test the Bonriki WTP main transmission line.

Figure 9: Gallery 2 showing no pump due to previous electrical failure.

Figure 10: Excavation team digging down to the drainage line for gallery 16.

Figure 11: PUB personnel setting up UFM at gallery 12. Note that access into the pump house was prevented by the two concrete slabs.

Figure 13: UFM device attached onto the polyethylene drainage outside gallery 15.

Figure 12: UFM device attached onto the PVC drainage pipe outside gallery 21.

5.3 Survey team and schedule

The assessment was conducted by the PUB and Kiribati Adaptation Project Phase III (KAP) leak detection team, namely Evire Banrie, Boata Paulo and Mamara; and Aminisitai Loco from SPC's GSD. A team of 4 casual workers from the Bonriki community was hired to conduct the excavation digging for the underground pipes.

The survey schedule presented in Table 4 was proposed so that the PUB/KAP leak detection team undertook the initial meter testing, with the remaining work to be completed with the support of SPC.

Table 4: Agreed work schedule between PUB and SPC.

Pumps to be completed	Dates	Meter testing duration (hrs)	Responsible Officers
Bonriki WTP Main	4th - 6th June	48	PUB/KAP team
Buota Main	8th - 10th June	48	PUB/KAP team
Gallery 8	11th June	4	PUB/KAP team & SPC staff
Gallery 9	11th June	4	PUB/KAP team & SPC staff
Gallery 10	11th June	4	PUB/KAP team & SPC staff
Gallery 11	11th June	4	PUB/KAP team & SPC staff
Gallery 12	12th June	4	PUB/KAP team & SPC staff
Gallery 13	12th June	4	PUB/KAP team & SPC staff
Gallery 14	12th June	4	PUB/KAP team & SPC staff
Gallery 15	12th June	4	PUB/KAP team & SPC staff
Gallery 16	15th June	4	PUB/KAP team & SPC staff
Gallery 17	15th June	4	PUB/KAP team & SPC staff
Gallery 18	15th June	4	PUB/KAP team & SPC staff
Gallery 19	15th June	4	PUB/KAP team & SPC staff
Gallery 20	16th June	4	PUB/KAP team & SPC staff
Gallery 21	16th June	4	PUB/KAP team & SPC staff
Gallery 22	16th June	4	PUB/KAP team & SPC staff
Gallery 4	16th June	4	PUB/KAP team & SPC staff
Gallery 5	17th June	4	PUB/KAP team & SPC staff
Gallery 6	17th June	4	PUB/KAP team & SPC staff
Gallery 7	17th June	4	PUB/KAP team & SPC staff

The assessment was significantly delayed as the initial tests, which included Bonriki WTP main, and galleries 5, 6, 7, 8, 9, 10 and 11 did not comply with the agreed methodology. The Bonriki WTP main meter and the gallery meters were all tested for 1 hour instead of the agreed 48 and 4 hours, respectively. For the tested galleries, the UFM was attached where adequate pipe lengths were exposed as found within the pump house (Figure 6) – as mentioned, this is where a lot of bending and connections are installed and where turbulent flow will be inherent. As per the methodology, the transmission pipe should be excavated and exposed outside the pump house, where laminar flow can be expected.

The deviation from the agreed methodology necessitated the restarting of the entire program on 12th June, which in turn, was completed on 20th June. Due to time constraints, the team ended up installing only one (1) UFM unit at each of the main FFM at Bonriki and Buota, as opposed to the agreed two UFM units at each site.

The sequence of excavation and meter testing at the pumping main meters and galleries are presented in Annex 1.

6 Results and data analysis

The main transmission lines in Bonriki and Buota yielded an average flow discrepancy of 18% and 9%, respectively. The tested galleries showed a flow variation range of 6 – 43 %. The results are summarised in Table 5 and further calculation details of test results are presented in Annex 2.

Table 5: Summary of flow rates and variability recorded by FFM and UFM at the Buota and Bonriki main meters and Bonriki galleries.

Meter	Test duration	Average FFM flow rate(L/s)	Average UFM volumetric discharge (L/s) [1]	Average UFM flow rate (L/s) [2]	% difference between FFM and UFM volumetric discharge
Bonriki WTP	67.3	18.18	14.86	18.15	18%
Buota main	49.60	2.94	2.68	2.69	9%
Gallery 1	NA	there was no pump[3]			NA
Gallery 2	NA	there was no pump			NA
Gallery 3	0.5	flow meter was giving erroneous reading – need to be re-tested[4]			NA
Gallery 4	4.12	1.19	1.06	1.08	10%
Gallery 5	5.08	1.47	1.20	1.20	19%
Gallery 6	4.7	0.00	0.40	0.41	NA
Gallery 7	4.22	0.99	0.67	0.65	32%
Gallery 8	4.15	1.48	1.16	1.21	22%
Gallery 9	4.1	1.15	0.92	0.91	20%
Gallery 10	4	0.71	0.62	0.62	12%
Gallery 11	4	1.45	1.14	1.15	22%
Gallery 12	0.2	Pump was not working [5]			NA
Gallery 13	4.3	0.61	0.57	0.57	6%
Gallery 14	4	1.56	1.19	1.20	24%
Gallery 15	4	0.48	0.42	0.42	12%
Gallery 16	0.3	FFM showed very slow movement and UFM showed negative flow[6]			NA
Gallery 17		0.45	0.39	0.39	12%
Gallery 18	NA	there was no pump			NA
Gallery 19	4	1.14	1.06	1.06	7%
Gallery 20	4	0.78	0.49	0.49	37%
Gallery 21	4.2	1.30	0.75	0.74	42%
Gallery 22	4.55	1.27	0.81	0.81	36%

Notes:

[1] Average cumulative volumetric discharge (m^3) which is later converted to L/s by multiplying the instantaneous volume difference by 1000 for litre conversion and dividing this product by the instantaneous time difference, in seconds

[2] The discharge recorded on the UFM display panel

[3] Galleries 1, 2 and 18 did not have pumps during the test period

[4] Gallery 3 was giving erroneous and unstable discharge reading with a (?) sign; re-testing by the PUB team recommended

[5] Pump at gallery 12 was not working even though the motor was on

[6] UFM showed negative flow data and FFM was moving extremely slowly, probably due to proximity of the gallery to the transmission line from Buota from where more pressure was being exerted in the pipe resulted in minor back flow as expressed by the negative reading

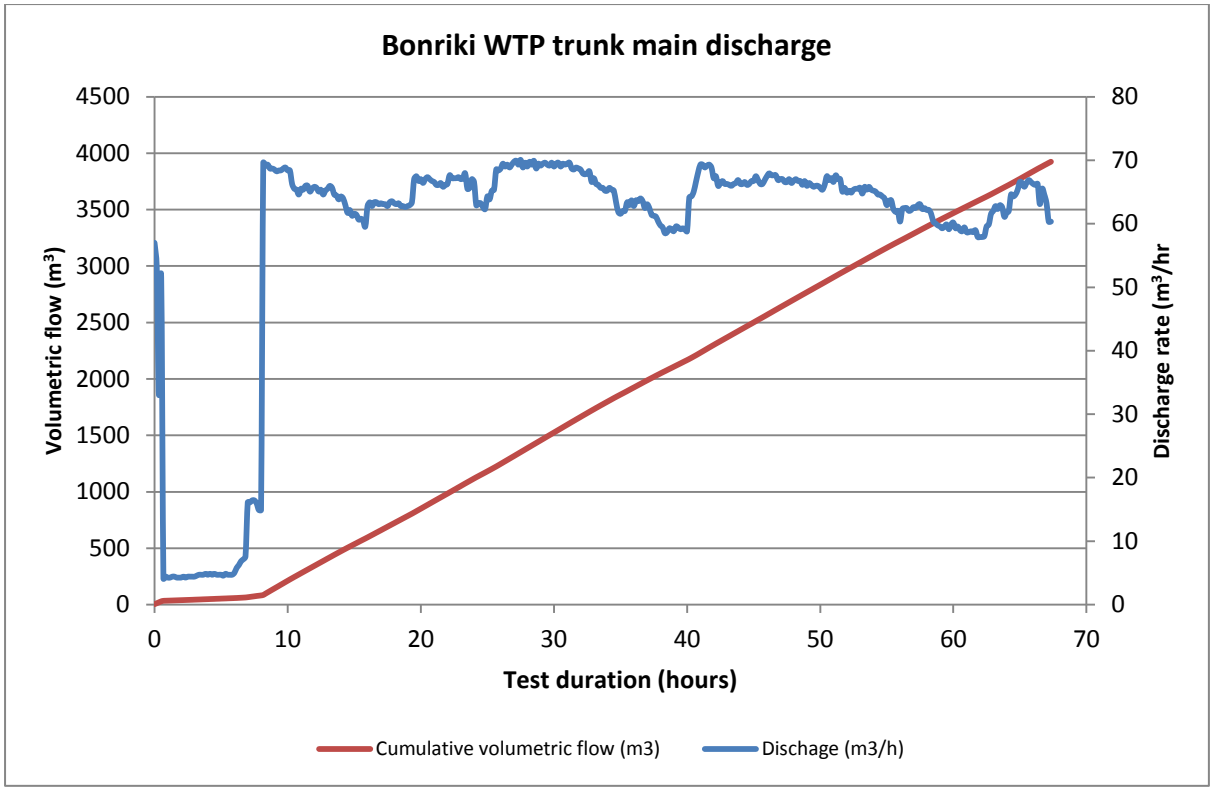

Figure 14: Water flow discharge and cumulative volumetric flow measured at the Bonriki WTP main, commencing at 2.54 pm on Friday, June 12th, 2015.

Notes:

- The significant flow reduction in the early stage of the tests attributed to the accidental bursting of one of the pipes connecting galleries 4, 5 and 6, by the bulldozer for the nearby solar project.
- The main meter was tested for more than 60 hours as opposed to the agreed 48 hours to accommodate delays in both the meter testing at the Buota main (which commenced a day late) and the digging of gallery drainage pipes on Monday morning.

Figure 15: FFM at gallery 19 reading 319656.862 m^3 at the beginning of the test.

Figure 16: UFM #1 gallery 19 reading 0.056 m^3 and 3.84 m^3/h, equivalent to 1.07 L/s.

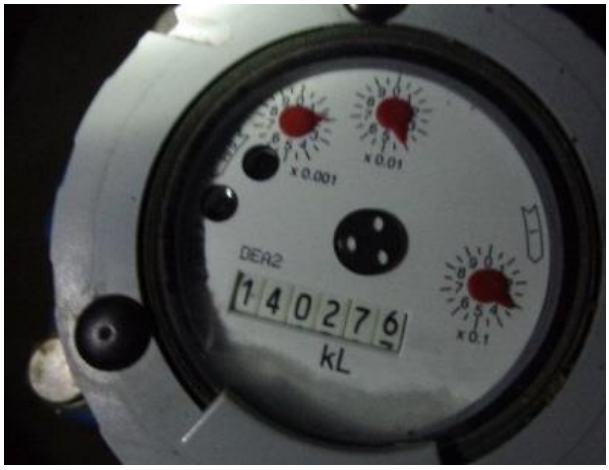

Figure 17: FFM at gallery 5 reading 140276.342 m^3 at the end of the meter test at 10.25 pm (18th June 2015).

Figure 19: FFM at gallery 12 showing 7789.994 m^3 at the start of the test.

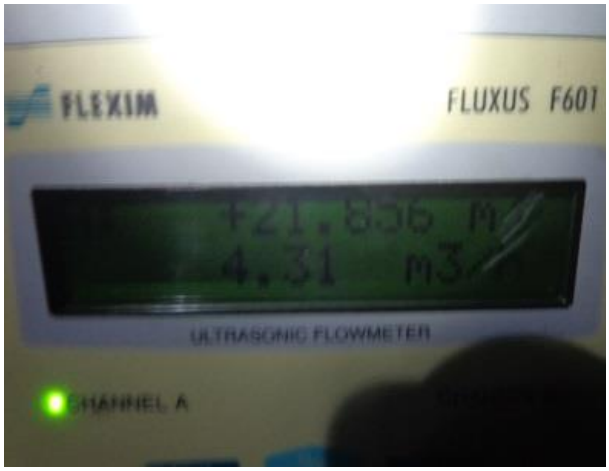

Figure 18: UFM at gallery 5 reading 21.856 m^3 and 4.31 m^3/h, equivalent to 1.20 L/s, at the end of the meter test at 10.25 pm (18th June 2015).

Figure 20: FFM at gallery 12 showing 7789.994 m^3 several minutes after photo at Figure 17 was taken, indicating that there was no water flow and suggesting that the pump may not be working, even though the motor was on.

Figure 21: UFM displaying 0 volumetric flow and 0 discharge rate at gallery 12 suggesting that the pump may not be working even though the motor was observed to be on.

Table 6: Tested gallery design yield (Falkland, 2003b) and estimated flow data and variability from June 2015.

Gallery	Safe pumping rates (m^3/d)	FFM reading – June 2015 (m^3/d) *	UFM reading – June 2015 (m^3/d) *	June 2015 Percentage discrepancy (FFM vs UFM)
4	85	103	93	10.50%
5	70	127	104	18.60%
7	55	86	56	32.10%
8	85	128	105	21.70%
9	70	99	79	20.10%
10	55	61	54	12.00%
11	85	125	99	21.60%
13	55	53	49	6.50%
14	85	135	104	23.60%
15	85	41	36	12.20%
17	85	39	33	11.80%
19	85	98	92	6.90%
20	85	67	42	37.00%
21	55	112	64	42.10%
22	85	110	70	36.00%

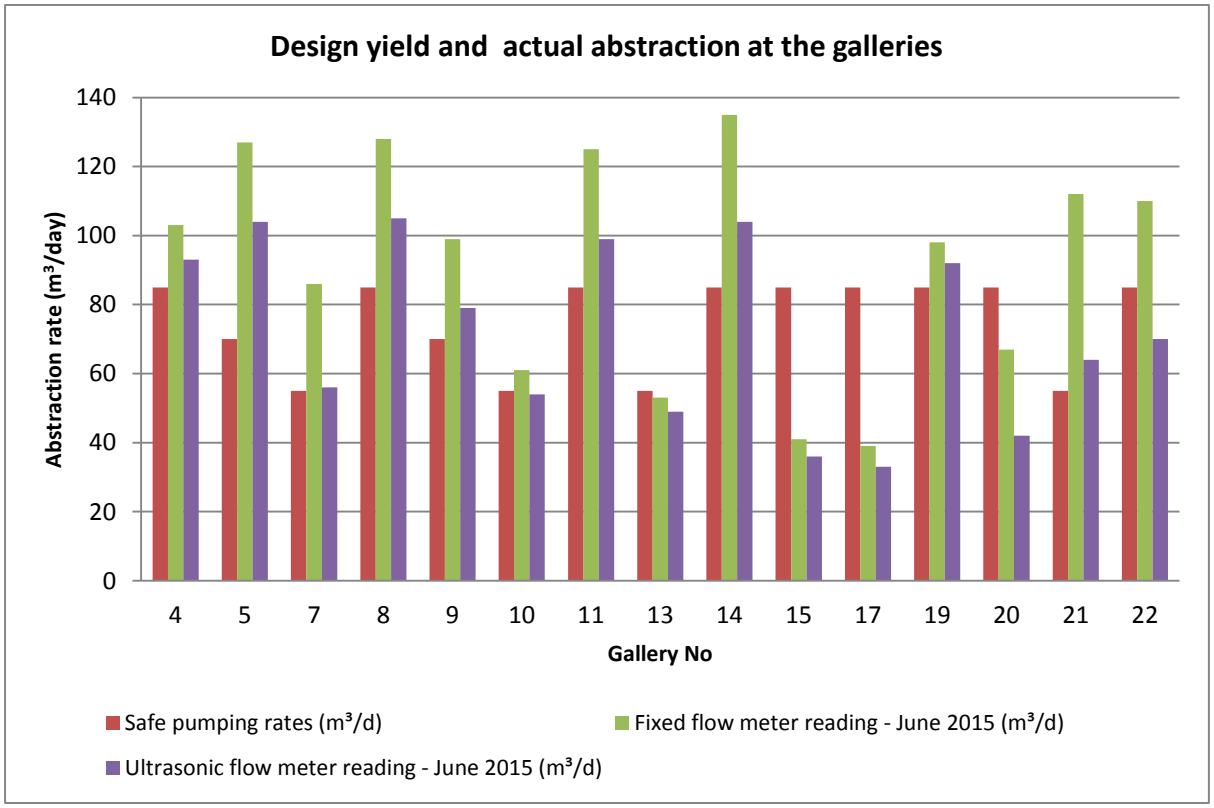

Figure 22: Design yield versus actual flow rate at the tested galleries showing increased abstraction at 9 galleries based on UFM readings.

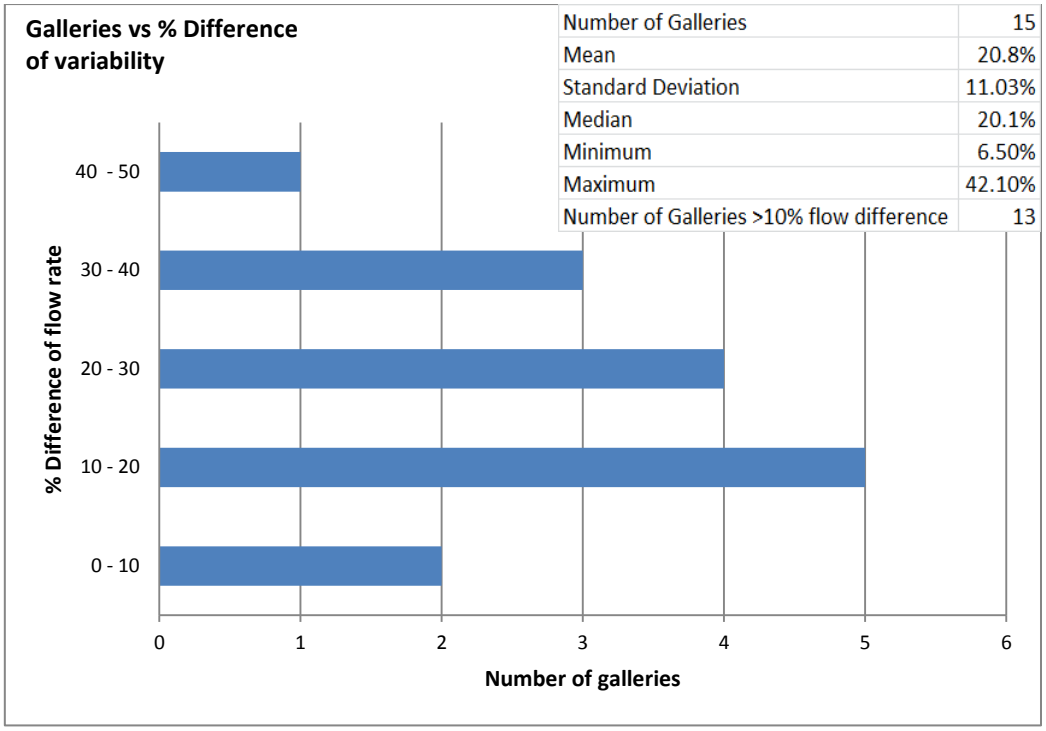

Figure 23: Statistical analysis of tested galleries in Bonriki showing more than 85% of the tested gallery meters showing flow discrepancy of more than 10%.

7 Major observations

1. *Establishment of flow variation in the Bonriki and Buota mains*
   The Bonriki main transmission recorded 18% flow over estimation whilst the Buota main showed 9% over-reading. These prove that the meters are showing over-estimated flow data; and applying the discrepancy factor shown in Table 5 should improve the accuracy of flow and abstraction data for groundwater modelling and management purposes.

2. *Over-estimated flow recorded at the galleries*
   The tested galleries showed flow over registration of between 6 and 43%. Figure 23 shows the magnitude of this discrepancy with over 85% of the tested galleries recording a flow variability of more than 10%. Applying the offset factors in Tables 5 and 6 should improve the accuracy of the gallery abstraction rates. Further, it is worrying to notice that even the recently installed flow meters (Figure 23 and Annex 2) show similar trends in flow discrepancy, which may suggest that the all flow meters were incorrectly installed and/or set up. It is apparent that the piping layout within the gallery pump-houses needs to be modified to reduce turbulent flow and yield laminar flow (Annex 3).

3. *No pumps in some galleries*
   Galleries 1, 2 and 18 did not have pumps during the survey. This was due to electrical faults. PUB personnel were trying to rectify the problems during the test.

4. *Increased abstraction at some of the galleries*
   Table 6 and Figure 22 show that nine (9) galleries (namely 4, 5, 7, 8, 9, 11, 14, 19 and 21) were operating above their respective safe yield pumping rates (Falkland, 2003b) – this conclusion is based on the UFM flow rate data. Further investigation is needed, as the existing pumps are operating at a fixed rate and may have adverse groundwater impacts during prolonged dry periods.

5. *UFM showing anomalous reading*
   Both galleries 3 and 16 displayed strange readings on the UFM when tested. Gallery 3 recorded unstable discharge readings with the (?) sign, whilst gallery 16 was showing negative (–) reading. The assessment team was unable to deduce what the (?) sign meant whilst the (–) sign was probably due to the proximity of the pump house (and tested portion of pipe) to the Buota main transmission line, resulting in minor backflow from the added pressure.

6. *On-going leakage*
   This was observed in gallery 16 where leakage was noticed in the pump house. This suggests that the flow information registered by the FFM will always underestimate the actual abstraction. Hence, minor repair and replacement work will be needed in the piping systems and connections to minimise and/or stop this leakage.

7. *FFM not working*
   It was observed that flow meter at gallery 6 was not working. It will need to be repaired or replaced to start registering the flow data readings.

8. *Pumps not working*
   Pump 12 was not working even though the motor was on. This was substantiated by taking instantaneous photos of the FFM and the installation of the UFM. The former showed that the meter was not moving whilst the latter showed zero (0) flow reading (Figures 19 - 21).

8 Recommendations

1. *Re-testing of several galleries*
   The re-testing of Galleries 1, 2, 3, 12, 16 and 18 by PUB will be required to ascertain the abstraction data and flow-data variability at each of abstraction point.

2. *Testing of individual galleries in the Buota water reserve*
   It is suggested that all the galleries in Buota be tested by PUB to determine the actual abstraction and flow variability, and to ascertain if there is any leakage happening along, and prior to, the main transmission line FFM.

3. *Replacement of FFM*
   The FFM at gallery 6 was not working during the testing exercise. It is suggested that the FFM be either repaired or replaced, and re-tested by PUB to permit the measurement of flow data from the gallery.

4. *Improvement of FFM set up*
   The significant flow-rate variability recorded at the galleries, particularly with the recently installed FFM (Figure 5), suggests that most meters were incorrectly installed as per manufacturer's specification. The correct installation of these gallery meters is critical to their optimum performance. Thus, the modification of piping works in gallery pump houses is imperative, which should reduce the effect of turbulent flow. Annex 3 shows the suggested changes in piping layout in a gallery pump house..

5. *Regulation of sand mining and household encroachment around the water reserves*
   Although beyond the scope of the flow meter testing exercise, it is worthwhile to note that improper sand mining has continued, and may have intensified in some areas around the water reserves. Active sand mining was observed around galleries 1, 2 and 3. This will need to be assessed and monitored by the government, through MELAD and MPWU, to regulate these activities and to uphold proper land-use practices around the water reserve.

   Further, the encroachment of households within the water reserve seemed to continue. Tougher actions should also be explored and introduced to warrant the removal of the offending households and to prohibit any further offenders.

6. *Assessment of major vegetation and land-use change associated with the solar construction project around the Bonriki WTP*
   It is critical to note the significant extent of the solar construction works adjacent to the Bonriki WTP. Figure 1 shows the project's spatial coverage extending towards galleries the 8, 9 and 10 pump houses and resulting in massive vegetation clearance. It is anticipated that reduced evapotranspiration and increased groundwater recharge can result from these changes. Furthermore, it will be critical to determine how groundwater recharge around galleries 8, 9 and 10 will be affected through various climatic conditions in the future.

9 Summary and Conclusion

The validation of existing FFM against two (2) portable UFM units has permitted the:

1. determination of actual flow rate data at the transmission lines in Bonriki and Buota, together with the Bonriki galleries; and the
2. calculation of a flow-variability factor to improve accuracy and confidence in abstraction data collected by FFM for groundwater modelling and management purposes.

Despite the logistic challenges, the assessment identified a flow-rate discrepancy of 18% and 9% for the Bonriki and Buota mains, respectively, whilst the Bonriki gallery flow meters showed an error margin between 6 and 43%. 85% of the tested meters yielded flow discrepancy of more than 10%. These were relatively consistent with previous tests and hence the abstraction data can be confidently utilised for modelling purposes.

The Bonriki galleries 1, 2, 3, 12, 16 and 18 will need to be retested to ascertain accurate registration of abstraction and flow-variability data, whilst several gallery pumps will need to be replaced and adjusted to perform within the safe yield parameters of each site. It is also suggested that the Buota galleries be tested to determine the actual abstraction data and flow variability within the Buota water reserve.

The improvement of FFM installation and set up as per the manufacturer's specification is critical to permit the optimum performance of flow meters. This may include the modification of pipe work in the gallery pump house to reduce turbulent flow, whilst consideration should also be made on the replacement of pumps at galleries where increased abstraction was recorded.

In conclusion, the flow meter testing exercise, through its improved field approach and technology, has resulted in the calculation of a flow discrepancy factor that can be confidently used to estimate the flow or abstraction data at the tested localities around the water reserves.

10 References

Alam K., Falkland A. and Mueller N. 2002. Sustainable yield of Bonriki and Buota freshwater lenses, SAPHE Project, Hydrogeology Component, Tarawa, Kiribati.

Bermad, n.d. *BERMAD Irrigation.* [Online]
Available at: http://www.bermad.com/Data/Uploads/WPH_1.pdf?_sm_au_=iRV5fZnFVq80qDf7
[Accessed 17th September 2015].

Elster Metering Ltd, 2015. *Elster metering solution.* [Online]
Available at: http://www.elstermetering.com/assets/products/products_elster_files
[Accessed 17th September 2015].

Falkland, A., 2003a. Review of groundwater resources management for Tarawa, Kiribati SAPHE project: Mid-term review. ECOWISE Environmental, March 2003.

Falkland, A., 2003b. Report on increased pump rates for Bonriki and Buota. ECOWISE Environmental, June 2003.

Schwalger, F. and Skerjanz, R., 2014. *Kiribati Adaptation Program III Component C1.2. Non-revenue water reduction - Leak detection and reduction program, D-2 Report,* Tarawa: Posh + Partners consuting Engineers.

Ultrasonic flow meter technology, 2012. *THe Ultrasonic Flow meters.* [Online]
Available at: http://theultrasonicflowmeters.com/flowmeas.htm
[Accessed 17th September 2015].

Annex 1: Flow meter testing schedule

Test Locality	Test-hole Excavation		Flow meter test			Additional comments
	Date	Duration (hours)	Start date	Time	Test Duration (hours)	
Bonriki master meter (WTP)	12/06/2015	2.5	12/06/2015	2.58 PM	67.3	Test hole was dug 10 m away from Water Treatment Plant master meter. Note that the meter test was extended more than 48 hours mainly as it seemed sensible not to terminate the test on Sunday afternoon but to continue until Monday morning so as to capture as much flow data as possible. The UFM run was terminated once the next gallery (i.e. gallery 8) was ready for testing.
Buota master meter	13/06/2015	2	13/06/2015	11.33 AM	49.60	Test hole was dug 10 m away from Buota master meter.
Gallery 1	NA	NA	NA		NA	Pump not working due to electrical fault – electricians and casuals where working hard to find where the faults were.
Gallery 2	NA	NA	NA		NA	Same problem as gallery 1.
Gallery 3	19/06/2015	0.5	20/06/2015	3.00 pm	0.5	Pump was recently replaced and tested but was giving unstable discharge readings with (?) sign – recommended that PUB team re-do the test.
Gallery 4	18/06/2015	2.5	19/06/2015	8.19 am	4.12	
Gallery 5	18/06/2015	1	18/06/2015	5.20 pm	5.08	
Gallery 6	18/06/2015	1.5	19/06/2015	10.02 am	4.7	Flow meter was not working. UFM was used to generate some flow measurements.
Gallery 7	19/06/2015	1	20/06/2015	9.56 am	4.22	
Gallery 8	13/06 & 15/06/2015	5	15/06/2014	12.23 pm	4.15	Digging took so much time and effort due to incorrect advice given by PUB technicians, who used a dowsing (brass) rod.
Gallery 9	15/06/2015	1	15/06/2014	2.48 pm	4.1	
Gallery 10	15/06/2015	1	16/06/2015	8.38 am	4	
Gallery 11	15/06/2015	1	16/06/2015	9.2 am	4	
Gallery 12	15/06/2015	1	19/06/2015	9.00 am	0.2	Pump was not working, even though the motor was on – UFM registered 0 discharge.
Gallery 13	16/06/2015	1.5	18/06/2015	3.14 pm	4.3	
Gallery 14	16/05/2015	1	16/06/2015	1.11 pm	4	
Gallery 15	16/06/2015	1	16/06/2015	1.44 pm	4	
Gallery 16	16/06/2015	1.5	18/06/2017	8.30 am	0.3	Pump was working but leakage was observed in the pump house. Flow meter was moving very slowly and ultrasonic meter was recording negative (–) flow. Test was terminated after 20 minutes.
Gallery 17	16/06/2015	1	18/06/2017	10.17 am		
Gallery 18	NA	NA	NA	NA	NA	There was no pump – advice was given that the pump had been shifted to gallery 3.
Gallery 19	19/06/2015	1.5	18/06/2015	12.53 pm	4	
Gallery 20	19/06/2015	0.5	19/06/2015	2.30 pm	4	Excavation was restricted to 1 m from the pump house discharge, as the Aviation Authority demanded minimal disturbance around the runway area.
Gallery 21	19/06/2015	0.5	19/06/2015	3.07 pm	4.2	Same as gallery 20.
Gallery 22	19/06/2015	0.5	20/06/2015	8.37 am	4.55	Same as galleries 20 and 21.

Annex 2: Field test results for transmission main meters and gallery meters

Table A2.1: Flow data recorded by FFM and UFM at the Bonriki WTP main. Note the reduced flow at the early stage induced by the accidental breaking of one of the gallery transmission lines resulting in reduced flow into the main reservoir.

Date	Meter name	Existing fixed flow meter (FFM)				Ultrasonic flow meter (UFM)						Difference in instantaneous discharge registered (L/s) between FFM and UFM	% Difference in instantaneous discharge (L/s) of FFM and UFM
		Recorded hours hh:mm	Test duration (minutes)	Discharge volume recorded by installed FFM (m^3)	Instantaneous discharge rate by FFM (L/s)	Recorded hours hh:mm	Test duration (minutes)	Discharge volume recorded by UFM (m^3)	Instantaneous discharge rate by UFM (L/s)	Discharge rate recorded by UFM (m^3/hr)	L/s		
12/06/2015	BON MM	2.58 pm	0.00	8306854.37		3.00 pm	0	1.638		47.61	13.23		
12/06/2015	BON MM	4.50 pm	112.00	8306904.35	7.44	4.57 pm	117	39.295	5.36	4.27	1.19	*2.07*	*27.9%*
13/06/2015	BON MM	3.33 pm	1475.00	8308275.18	16.05	3.36 pm	1476	1153.282	13.00	62.81	17.45	*3.05*	19.0%
14/06/2015	BON MM	8.07 am	2469.00	8309590.82	18.47	8.11 am	2471	2242.018	15.11	68.91	19.14	*3.36*	18.2%
14/06/2015	BON MM	8.17 am	2479.00	8309604.23	18.49	8.21 am	2481	2253.665	15.13	69.35	19.26	*3.36*	18.2%
15/06/2015	BON MM	10.17 am	4039.00	8311631.78	19.71	10.20 am	4040	3921.787	16.17	60.43	16.79	*3.54*	18.0%
AVERAGE					18.18						18.16		18.35%

Table A2.2: Flow data recorded by FFM and UFM at the Buota main.

Date	Meter name	Recorded hours hh:mm	Test duration (minutes)	Discharge recorded by installed FFM (m^3)	Discharge (L/s)	Recorded hours hh:mm	Test duration (minutes)	Discharge volume (m^3) recorded UFM	Instantaneous discharge rate recorded by UFM (m^3/hr)	Discharge rate recorded by UFM (m^3/hr)	Discharge (L/s)	Difference in instantaneous discharge (L/s) between FFM and UFM	% difference in discharge of FFM and UFM
13/06/2015	BUO MM	11.33 am	0.00	313511.577		11.36 am	0	0.038		9.63	2.68		
13/06/2015	BUO MM	4.17 pm	284.00	313561.692	2.94	4.20 pm	284	45.652	2.68	9.61	2.67	0.26	9.0%
13/06/2015	BUO MM	8.42 am	1269.00	313735.543	2.94	8.44 am	1268	203.726	2.68	9.71	2.70	0.26	9.0%
15/06/2015	BUO MM	1.09 pm	2976.00	314036.55	2.94	1.13 pm	2977	478.966	2.68	9.68	2.69	0.26	8.8%
AVERAGE					2.94						2.69		8.93%

Table A2.3: Flow data recorded from FFM and UFM at the tested Bonriki galleries.

Gallery number (UFM number)	Date	Existing fixed flow meter (FFM)				Ultrasonic flow meter (UFM)						Instantaneous discharge variation	
		Recorded hours hh:mm	Test duration (minutes)	Discharge recorded by installed FFM (m^3)	L/s	Recorded hours hh:mm	Test duration (minutes)	Discharge recorded by UFM (m^3)	Instantaneous discharge (L/s)	Discharge rate recorded by UFM (m^3/hr)	L/s	Difference in instantaneous discharge (L/s) between FFM and UFM	% difference in discharge of FFM and UFM
8 (2)	15/06/2015	12.23	0	133574.915		12.23	0	2.412		4.34	1.21		
	15/06/2015	16.31	250	133597.134	1.48	16.31	248	19.672	1.16	4.35	1.21	0.321	**21.7%**
9 (1)	15/06/2015	14.48	0	42825.216		14.52	0	0.21		3.29	0.91		
	15/06/2015	18.56	248	42842.274	1.15	18.57	245	13.676	0.92	3.28	0.91	0.230	**20.1%**
10 (1)	16/06/2015	8.38	0	58605.227		8.39	0	0.003		2.26	0.63		
	16/06/2015	12.39	241	58615.455	0.71	12.39	240	8.968	0.62	2.23	0.62	0.085	**12.0%**
11 (2)	16/06/2015	9.20	0	204083.712		9.21	0	0.287		4.09	1.14		
	16/06/2015	13.22	242	204104.753	1.45	13.22	241	16.713	1.14	4.13	1.15	0.313	**21.6%**
14 (1)	16/06/2015	13.11	0	175433.567		13.11	0	0.108		4.28	1.19		
	16/06/2015	17.14	243	175456.295	1.56	17.14	243	17.472	1.19	4.31	1.20	0.368	**23.6%**
15 (1)	16/06/2015	13.44	0	35276.07		13.45	0	0.012		1.42	0.39		
	16/06/2015	17.57	247	35283.215	0.48	17.57	252	6.409	0.42	1.51	0.42	0.059	**12.2%**
17 (2)	18/06/2015	10.17	0	18813.86		10.17	0	0.014		1.41	0.39		
	18/06/2015	2.56	279	18821.341	0.45	2.56	279	6.612	0.39	1.42	0.39	0.053	**11.8%**
19 (1)	18/06/2015	12.53	0	319656.862		12.54	0	0.056		3.84	1.07		
	18/06/2015	4.54	241	319673.353	1.14	4.54	240	15.348	1.06	3.81	1.06	0.079	**6.9%**
13 (1)	18/06/2015	3.14	0	27887.196		3.15	0	0.015		2.07	0.58		
	18/06/2015	7.34	260	27896.728	0.61	7.34	259	8.896	0.57	2.04	0.57	0.040	**6.5%**
5 (2)	18/06/2015	5.20	0	140249.427		5.21	0	0.011		4.32	1.20		
	18/06/2015	10.25	305	140276.342	1.47	10.25	304	21.856	1.20	4.31	1.20	0.273	**18.6%**
4 (2)	19/06/2015	8.19	0	44733.852		8.20	0	0.008		3.89	1.08		
	19/06/2015	12.26	247	44751.447	1.19	12.27	247	15.758	1.06	3.88	1.08	0.124	**10.5%**
6 (1)	19/06/2015	10.02	0	22248.442		10.03	0	0.003		1.47	0.41		
	19/06/2015	2.46	284	22248.442	0.00	2.47	284	6.879	0.40	1.46	0.41	Fixed flow meter not working	
20 (2)	19/06/2015	2.30	0	247166.313		2.30	0	0.128		1.76	0.49		
	19/06/2015	6.32	242	247177.682	0.78	6.32	242	7.293	0.49	1.77	0.49	0.290	**37.0%**
21 (1)	19/06/2015	3.07	0	368266.349		3.09	0	0.02		2.72	0.76		
	19/06/2015	7.17	250	368285.816	1.30	7.18	249	11.242	0.75	2.66	0.74	0.547	**42.1%**
22 (1)	20/06/2015	8.37	0	393420.82		8.38	0	0.01		2.42	0.67		
	20/06/2015	1.10	273	393441.562	1.27	1.11	273	13.293	0.81	2.93	0.81	0.455	**36.0%**
7 (2)	20/06/2015	9.56	0	56668.155		9.57	0.00	0.03		2.93	0.81		
	20/06/2015	2.09	253	56683.224	0.99	2.10	253.00	10.262	0.67	2.35	0.65	0.319	**32.1%**

Annex 3: Gallery pump house piping layout

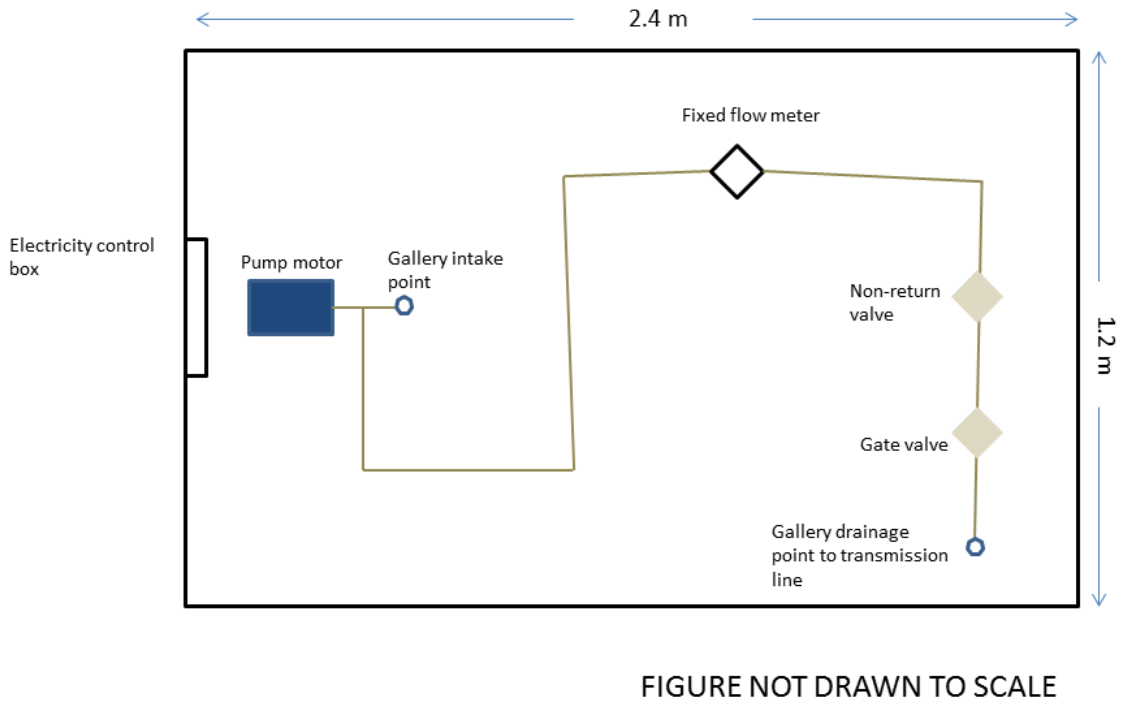

Figure A3.1: Current piping layout in the gallery pump-house with numerous connections and bending, yielding highly turbulent flow, a contributing factor to flow over-reading at the FFM.

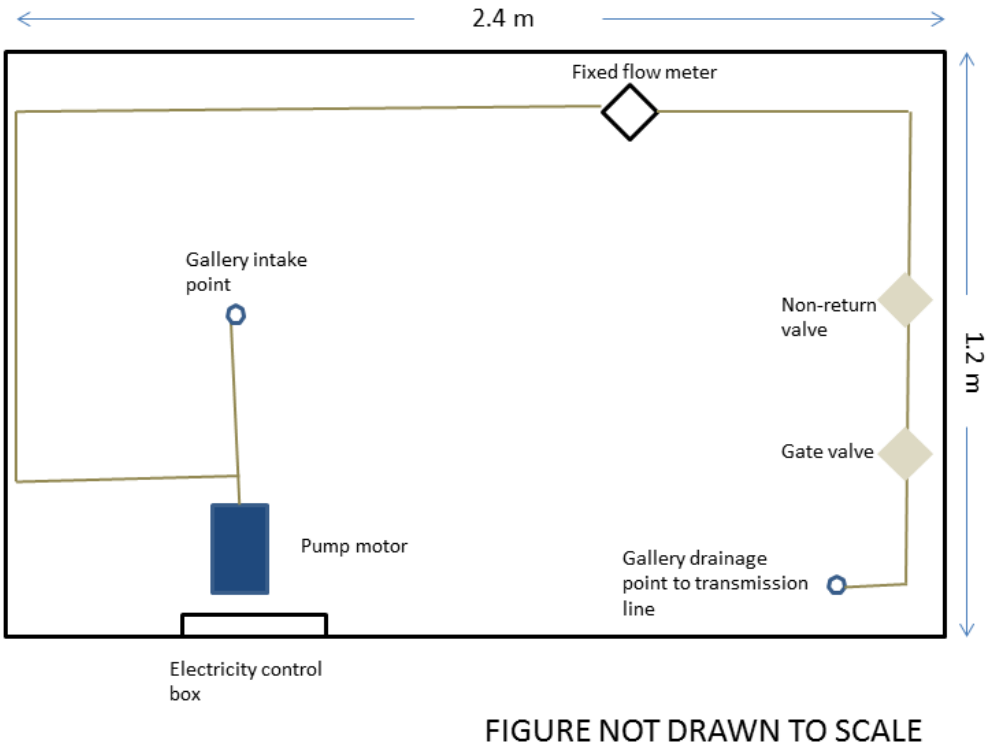

Figure A3.2: Proposed changes in the piping layout with less connections and bending that may reduce turbulence and allow more laminar flow, which should improve the accuracy of flow measurements at the FFM.

Annex 4: Field photos

Figure A4.1: Survey team digging to locate the transmission pipe 10 m away from the Bonriki WTP master meter.

Figure A4.2: PUB staff cleaning the Bonriki transmission pipe before installing the UFM.

Figure A4.3: Survey team digging to locate the transmission pipe 10 m away from the Buota master meter.

Figure A4.4: Temporary shelter erected for the security officer and UFM, prior to the 48-hours test at Buota.

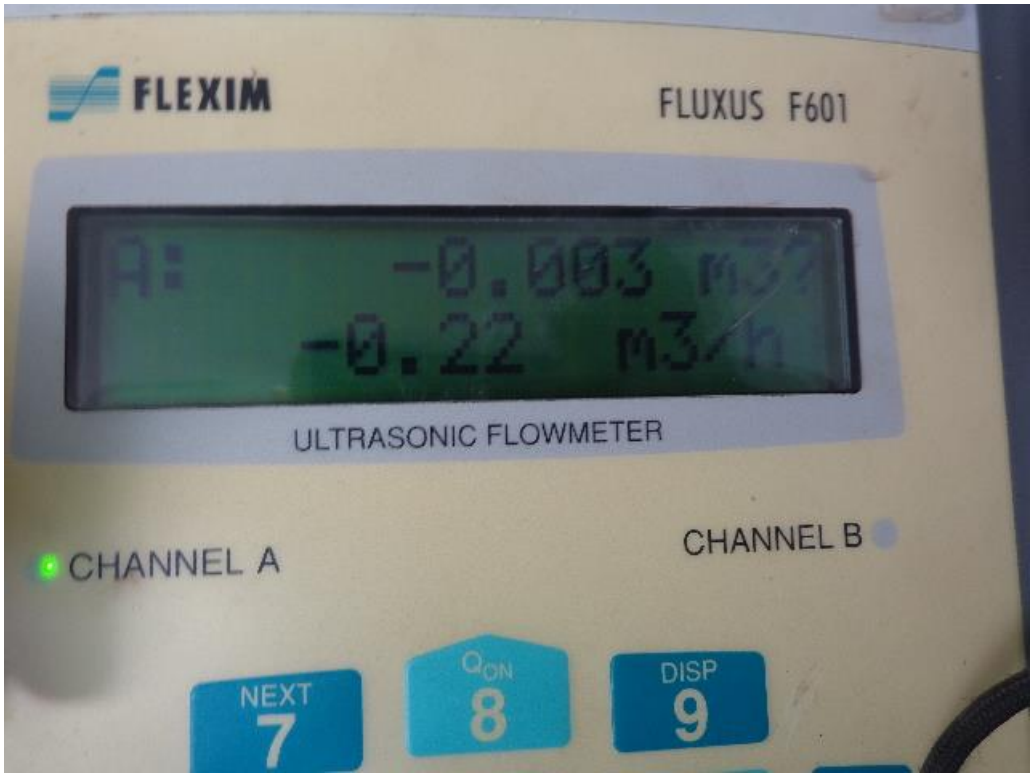

Figure A4.5: UFM showing –0.022 m^3/h at gallery 16 sugesting flow in the opposite direction.

Figure A4.6: Typical pipe work set up in the gallery pump house characterised by numerous bending and connections and causing highly turbulent flow. These will need to be modified to allow more pipe length before the FFM installation to allow more laminar flow and to permit the accurate estimation of discharge flow.

Figure A4.7: PUB staff installing UFM and taking photos at the beginning of the meter test at gallery 10.

Figure A4.8: PUB staff and a casual labourer digging and exposing the gallery 19 pipe.

Figure A4.9: PUB staff attaching the UFM device onto the gallery 9 pipe prior to the meter test.

CONTACT DETAILS
Pacific Community

SPC Headquarters
BP D5,
98848 Noumea Cedex,
New Caledonia
Telephone: +687 26 20 00
Fax: +687 26 38 18

SPC Suva Regional Office
Private Mail Bag,
Suva,
Fiji,
Telephone: +679 337 0733
Fax: +679 337 0021

SPC Pohnpei Regional Office
PO Box Q,
Kolonia, Pohnpei, 96941 FM,
Federated States of Micronesia
Telephone: +691 3207 523
Fax: +691 3202 725

SPC Solomon Islands
Country Office
PO Box 1468
Honiara, Solomon Islands
Telephone: + 677 25543 /
+677 25574
Fax: +677 25547

Email: spc@spc.int
Website: www.spc.int

EUROPEAN UNION
The project is co-funded
by the European Union

Pacific Community
Communauté du Pacifique

The project is implemented
by the ACP group of states