KIRIWATSAN Water Resources Assessment
Makin Island, Kiribati

Peter Sinclair, Aminisitai Loco, Amit Singh, Laavaneta Juliano

EUROPEAN UNION

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KIRIWATSAN

Water Resources Assessment

MAKIN ISLAND, KIRIBATI

Secretariat of the Pacific Community, Suva

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IMPORTANT NOTICE

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Abbreviations and symbols

ADB	Asian Development Bank
AUD	Australian dollars
CV	Coefficient of Variation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EC	Electrical conductivity
EDF	European Development Fund
EM	electromagnetic
ENSO	El Niño – Southern Oscillation Index
GoK	Government of Kiribati
HYCOS	Hydrological Cycle Observation System
IC	Island Council
KIRIWATSAN I	Kiribati Water and Sanitation Phase 1 for outer islands
KAP	Kiribati Adaptation Program (Phases I, II & III)
KMS	Kiribati Meteorological Service
KPC	Kiribati Protestant Church
MDGs	Millennium Development Goals
MELAD	Ministry of Environment, Land, and Agricultural Development
MIA	Ministry of Internal Affairs (formerly known as the Ministry of Internal & Social Affairs)
MPWU	Ministry of Public Works and Utilities
NIWA	(New Zealand) National Institute of Water and Atmospheric Research
NWRIP	National Water Resources Implementation Plan
NWRP	National Water Resources Policy
NWSCC	National Water and Sanitation Coordination Committee
NZAID	New Zealand International Aid and Development Agency
OI(s)	Outer Island(s)
OICWSP	Outer Island Community Water Supply Project
OIWT	Outer Island Water Technician
PE	polyethylene
PfWG	Programme for Water Governance (EU)
PUB	Public Utilities Board (within MPWU)
RWH	Rainwater harvesting
SAPHE	Sanitation, Public Health and Environment Improvement Project
SOPAC	Pacific Islands Applied Geoscience Commission (now known as the Applied Geoscience & Technical Division (AGTD) of SPC)
SPC	Secretariat of the Pacific Community
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Program
UNDTCD	United Nations Department of Technical Cooperation for Development
UNICEF	United Nations Children's Fund
VWAP	Village Water Action Plan

VWSC	Village Water and Sanitation Committees
WASH	Water, sanitation and hygiene
WEU	Water Engineering Unit (within MPWU)
WHO	World Health Organization
WRA	Water Resources Assessment

Measurements

EC	electrical conductivity (measure of salinity)
KL/day	Kilo litres per day
L	Litres
L/sec	Litres per second
L/p/day	Litres per person per day
m^2	Square metres
m^3	Cubic metres
mL	millilitre
ML/day	Mega litres per day
μS/cm	Microsiemens per centimetre (unit for EC and used as an indicator of salinity)
mbgl	Metres below ground level
mS/cm	Millisiemens per centimetre
mg/L	Milligram per litre

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- Kiribati Meteorological Service for the use of its historical rainfall data.
- National Statistics Office for the census data on village population and water supply and sanitation facilities.

We acknowledge the support from the UNICEF staff in Tarawa and Suva in the logistics and their input into the review of the document. Finally, we would like to thank the people of Makin for allowing us access to their land and for their generous hospitality during our stay.

1.0 EXECUTIVE SUMMARY

As part of the EDF10 KIRIWATSAN I Project, Makin Island was visited from 25th to 27th October 2012 for water resources assessment (WRA). The survey was conducted at Kiebu Village and included the following:

- A survey of existing and potential rainwater harvesting (RWH) facilities.
- A survey of wells to record their condition, construction, potential sources of contamination, and water quality.
- A geophysical survey to estimate the spatial extent and thickness of the freshwater lens beneath the village.

Nine (9) permanently roofed buildings were surveyed for rainwater harvesting potential and improvements. Of these, four (4) were communal buildings, namely churches and *maneaba*. These communal buildings are considered suitable for rainwater harvesting improvements, due to their substantial roof catchment and accessibility to community members. Recommendations for improvements include the following:

- Installation of proper guttering to cover the entire roof.
- Installation of down pipes, transmission pipes and inlet screens.
- Installation of additional tanks, with outlet taps.
- Removal of overhanging vegetation to prevent potential roof catchment contamination from falling leaves and other organic matter, and access by animals.
- Installation of first-flush elements, where suitable, to minimise the contamination from dust.
- Installation of screens on tank inlets to protect freshwater from organic matter, and access by mosquitoes.
- Construction of fencing around the storage and outlet areas to minimise damage.

Two (2) wells were assessed for infrastructural status and groundwater quality. The assessment of water table depth and salinity showed an average of 2.4 mbgl and 5.9 mS/cm. Most wells:

- use bailers for abstraction;
- are inadequately constructed using coral rocks;
- are uncovered without a suitable lid;
- do not have a parapet; and
- are close to contaminant sources, namely toilets, general household rubbish, *bwabwai* pits and piggeries.

Bacteriological sampling and analysis, through the Colilert-18 ‘presence and absence’ procedure, indicated the presence of E.coli bacteria in all the rainwater tanks sampled. Tests for nitrate indicated a low level of contamination. To ensure the protection of wells and improved groundwater quality in the short and medium term, the following are suggested:

- Installation of screens on rainwater tanks’ entry points to avoid the introduction of E.coli bacteria from the roof tops and from surrounding vegetation cover.
- Trimming of overhanging vegetation to minimise the likelihood of leaves dropping onto the roofs and tanks.
- Installation of taps on tank outlets to avoid the usage of contaminant laden bailers, which are commonly placed on the ground when unused.
- Construction of fencing to regulate access on to the rainwater storage tanks.

Real-time monitoring for groundwater level, conductivity and temperature at selected village wells yielded the assessment of tidal lag and tidal efficiency. Results suggest reasonable hydraulic connection between the groundwater system and the adjacent tidal/oceanic environment compared with Bonriki measurements, further suggesting higher permeability of, and possibly shallower depths to, the underlying limestone than found in Bonriki.

EM34 geophysical surveys identified the extent and thickness of the freshwater lens underlying the area around the village. Kiebu Village showed extremely limited fresh groundwater lens – it is unlikely that the villlage's water demand will be supported by groundwater under normal conditions, with severe groundwater salinisation expected during dry periods.

Freshwater development options in Kiebu Village will focus on rainwater harvesting improvements for communal building, with emphasis on the installation of increased storage, including the construction of cisterns. Groundwater development in the village is likely to be restricted to infrastructural improvement of the community well through the communal well option; including the installation of a single *Tamana* pump to regulate access and abstraction, and to minimise the effect of saline intrusion. These options are designed to improve storage capacity and ensure the sufficiency of drinking water throughout the year.

Dry compost toilet is strongly recommended as the appropriate sanitation option because it uses no water, and has minimal impact on the groundwater resource. Additionally it produces a valuable by-product that can be used safely to improve soil fertility and food production.

Collective and coordinated community involvement, through an effective village action plan, with sanitation marketing will be required to ensure the sustainable operation and management of sanitation systems. A village action plan, addressing operation, management, accessibility, and maintenance aspects of sanitation systems, is suggested as a necessary prerequisite for potential infrastructural assistance.

Monitoring and evaluation of freshwater resources and the systems that are used to access the resource will be an important component of the projected implementation. A monitoring system should be established which engages both villagers and national government alike with defined roles and responsibilities. This will permit the assessment of the changes in freshwater quality and quantity under different climatic regimes. Monitoring and evaluation will encourage the community to take ownership, and encourage correct operation and maintenance of systems.

2.0 INTRODUCTION

2.1 European Union EDF10 – KIRIWATSAN

The European Union in consultation with the Government of Kiribati developed the KIRIWATSAN Project under the 10th European Development Fund (EDF10). The KIRIWATSAN Project will focus on improving water and sanitation systems in outer islands in the Gilbert Group and in fostering community engagement in the project and ownership of the installed systems. The project is being undertaken in two phases. Phase I of the project has the following three components:

(1) Assessment and design – Assessment of freshwater resources in thirty-five (35) target villages across eight (8) islands, and design of sustainable groundwater, rainwater, and sanitation facilities.
(2) Rainwater harvesting installations for specific buildings in target villages.
(3) Capacity building and governance which includes adapting WASH guidelines and introducing cost-recovery mechanisms and training of community-based water supply caretakers in the outer islands.

Phase II will include the construction of the water-supply and sanitation systems for selected villages.

This report provides the results for the water resources assessment carried out in Makin Island, under component 1 of the KIRIWATSAN Phase I Project. Field investigations for Makin Island were undertaken from 25th to 27th October 2012. The assessment was conducted in Kiebu Village and included the following:

- A survey of 9 buildings to assess the existing and potential RWH systems.
- A survey of 2 groundwater wells to determine their condition, construction type, and risk to water safety.
- An electromagnetic (EM)34 geophysical survey to estimate the thickness of the freshwater lens beneath Kiebu Village.

The overall objectives of the assessment in target villages were to:

(1) assess the conditions, construction, potential sources of contamination and water quality for groundwater wells.
(2) Survey existing and potential rainwater harvesting facilities.
(3) Estimate the thickness of the freshwater lens beneath the islet.
(4) Determine the feasibility of developing freshwater resources and their vulnerability to population growth and climate change.
(5) Design suitable water-supply options for the target communities.

This report summarises the assessment's methods, major findings and recommendations for the Kiebu Village on Makin Island.

2.2 Survey Team and Schedule

The survey team for Makin comprised Peter Sinclair and Amit Singh from the GeoScience Division (formerly known as SOPAC) of the Secretariat of the Pacific Community (SPC); Laavaneta Juliano from the Water Engineering Unit (WEU) of the Ministry of Public Works and Utilities (MPWU); and the Makin Island Water Technician, Matauea Rakobu. Eight casual day labourers assisted with the surveys, and were selected from the target village. Summary of the survey schedule is appended as Annex 1.

3.0 BACKGROUND

3.1 Location and Geography

Makin Island, located between longitudes 172°57'E and 173°00'E and latitudes 3°17'N and 3°24'N, is part of the Gilbert Group (Figure 1). The island, with a land area of 7.9 km^2, has five main islets with the largest two, namely Makin and Kiebu, inhabited (Office of te Beretineti & T'Makei Services, 2012). The islets are arranged in a linear formation with a NNE-trend, with Makin situated on the northern-most tip.

Vegetation on Makin is dominated by coastal strand plants, mangroves, coastal marsh vegetation and inland minor atoll forests. Coconut palms and swamp taro *(bwabwai*) play important roles in agricultural activities mainly because copra is the major cash crop in the villages, whilst *bwabwai* has a special place as traditional food.

The target village, Kiebu, is located south of Makin Islet and has a large water pond located in the middle, with *bwabwai* cultivated in pits surrounding the pond. Figure 2 is a map showing the location of Kiebu.

The summary description of Kiebu Village is presented in Table 1 below.

Table 1. Summary description of the target village Kiebu. (Source: National Statistics Office)

Village	Population National Statistics Office, 2012	Population density pers/km^2	Land Area (m^2)	Description
Kiebu	434	498	871,370	The village accommodates 76 households, together with Abaewewe Primary School and a Health clinic. The houses are concentrated on the central- western shore line with a large water pond located on the central-eastern shoreline. The maximum islet width was ~600 m.

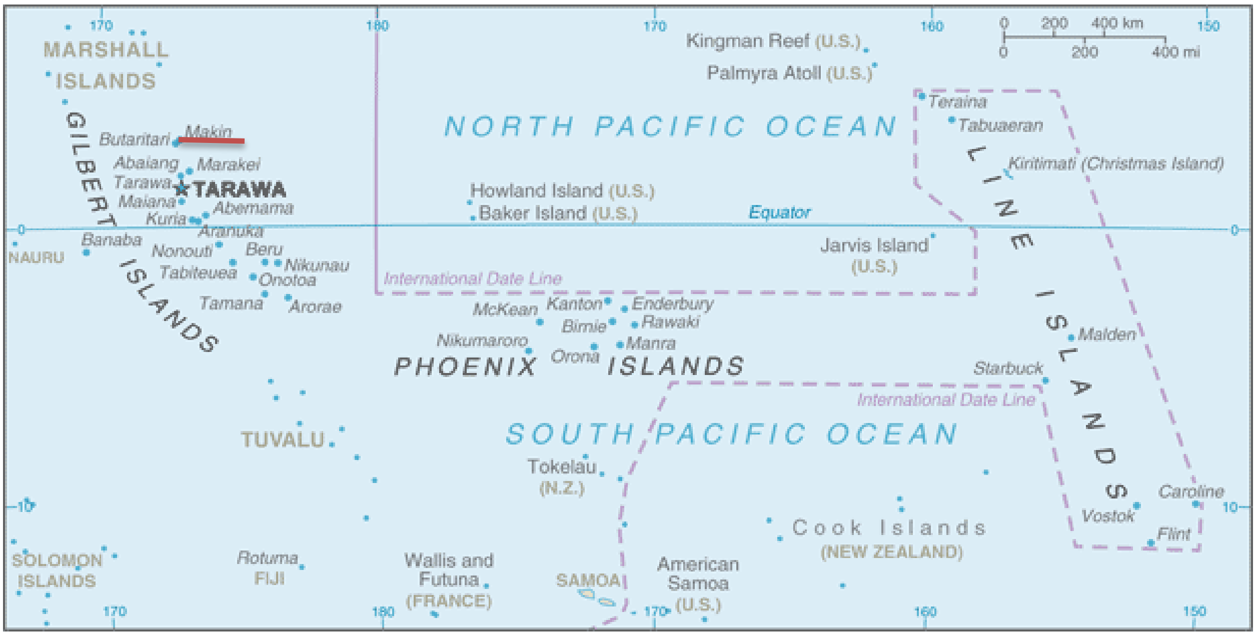

Figure 1. Location map of Makin Island in the Gilbert Islands group. Source: [***https://www.cia.gov/library/publications/the-world-factbook/geos/kr.html***](https://www.cia.gov/library/publications/the-world-factbook/geos/kr.html)

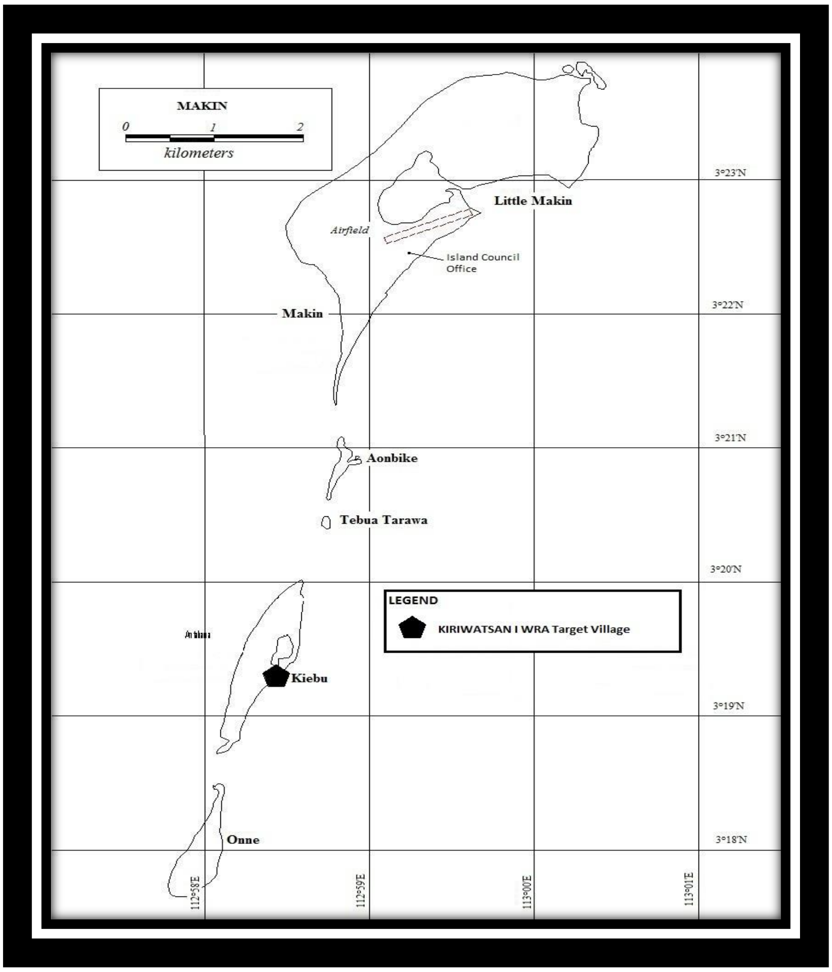

Figure 2. Location of KIRIWATSAN 1 water resources assessment target village (Map Source: Makin Island profile, UNICEF 2012 profiling report).

3.2 Population

Population on the island over the last two decades has, according to census data, showed moderate to considerable fluctuation between villages and over time. Minor fluctuations were registered in 1990, 1995 and 2000, prior to a significant increase recorded in 2005. The period 2000-2005 yields an estimate annual growth rate of 8.2% and recorded a maximum population of 2385. This was followed by 4.9% negative annual growth rate in 2010, with 1798 people.

Table 2 shows the annual growth rates between each two census dates and the average annual growth rates for both villages. It should be noted that there is significant variation in growth rate between censuses suggesting that the data should be treated with caution for planning purposes.

Table 2. Population data for Makin from census periods during 1990-2010. Target villages in bold. (Source: National Statistics Office)

Village	Census Data					Annual Growth Rate					Estimated Population
	1990	1995	2000	2005	2010	1990-1995	1995-2000	2000-2005	2005-2010	**1990 - 2010**	2030
Makin	1359	1339	1345	1834	1364	-0.3%	0.1%	7.3%	-5.1%	0.5%	**1496**
Kiebu	403	491	346	551	434	4.4%	-5.9%	11.8%	-4.2%	0.6%	**483**
Total	**1762**	**1830**	**1691**	**2385**	**1798**	**0.8%**	**-1.5%**	**8.2%**	**-4.9%**	**0.6%**	**2026**

Note that the projected 2030 population is estimated through the mean of all the annual growth rates calculated between each two census dates from 1990 to 2010.

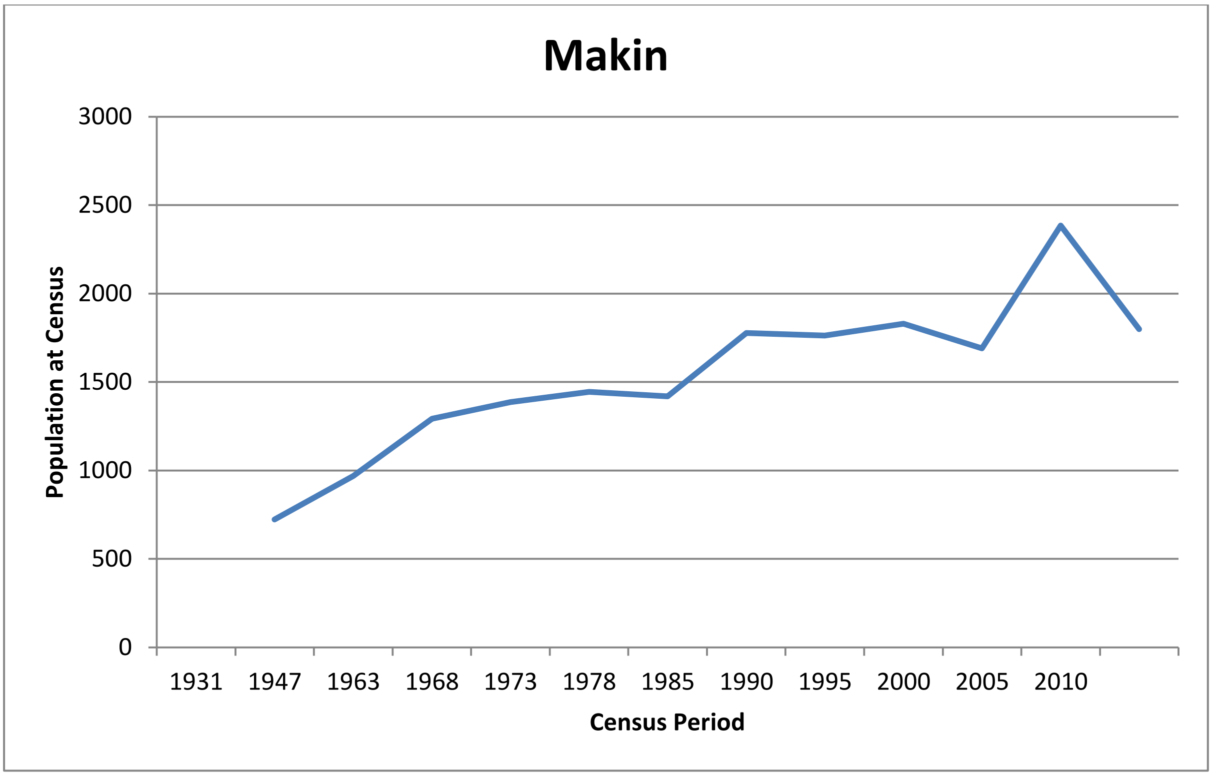

Figure 3. Population growth on Makin Island 1931-2010 (Source: National Statistics Office).

The population trend from 1931 to 2010 indicates an increasing population from 1947 to 2000, with an anomalous increase recorded in 2005 (Figure 3).

The different growth rates in Kiebu Village will affect land use and the exploitation of the underlying freshwater resource. Additional water demands will accompany any increase in population, plus increased wastewater disposal; and should sanitation practices remain poor, increased contamination potential of the groundwater will result. The community will need to consider the impacts of population pressure on water resources, in addition to climate variability influences.

3.3 Rainfall Analysis

Monthly rainfall data for Makin are available from 1955 with gaps (Annex 2). The bulk of the complete rainfall data are within the periods from 1955 to 1974 (19 years), and from 1979 to 1987 (8 years). Some records are available, with 54% of monthly rainfall from 1975 to 1978 (4 years), 30% from 1988 to 1990, 40% of monthly records from 1998 to 2003, and 77% of recent monthly rainfall from 2010 to 2014. Rainfall records were mostly unavailable in two periods, namely from 1991 to 1997 (11 years) and from 2004 to 2010 (7 years). Recent daily rainfall records are mostly available from the manual rainfall stations installed under the joint support of the EU-funded Hydrological Observing Systems (HYCOS Project, 2006-2010) and the Kiribati Adaptation Program (KAP).

The daily rainfall is currently recorded manually by the island water technicians into a purpose designed rainfall recording book with carbon copies sent to the Water Engineering Unit within the Ministry of Public Works and Utilities, and the Kiribati Meteorological Service (KMS) in Tarawa, with a copy kept on the island.

Climate stations are maintained by the Kiribati Meteorological Service for selected islands and in these locations, datasets with longer rainfall records are available along with parameters other than just rainfall. The climate stations for the Gilbert Islands are:

- Betio, South Tarawa
- Butaritari
- Beru

The available monthly rainfall data for Makin are compiled with data from the Kiribati Meteorological Service with some gaps filled by Taylor (1973), 'An Atlas of Pacific Islands Rainfall'. The climate data are summarised in Table 3 and the monthly records as Annex 2. The maximum monthly rainfall during this period occurred in April 1966, reading 1240 mm; with zero monthly rainfall recorded sometimes for January, August, September, November and December. Makin, as with other islands within the Gilbert Group, has on average a 5-month 'wetter' December to April period, and higher mean rainfall, followed by a 7-month 'drier' May to November period, with lower mean rainfall. Comparison between the mean and the median values shows that the rainfall distribution is positively skewed towards higher rainfall. The variability of monthly rainfall is moderate between wet and dry seasons. It is noted that rainfall in July is on average slightly higher than surrounding dry months possibly due to some high rainfall events in 1962, 1972, 1980, 1981, 1982, 1983, 2001, 2011 and 2012 (Annex 2).

Table 3. Statistics of monthly rainfall in Makin for the period 1955-2014 (with gaps).

Months	January	February	March	April	May	June	July	August	September	October	November	December	Total
Mean (mm)	292	269	335	341	281	250	290	209	184	166	199	309	**3,098**
Standard deviation (mm)	216	163	253	249	124	122	149	88	117	116	131	207	**958**
CV*	0.74	0.61	0.76	0.73	0.44	0.49	0.51	0.42	0.64	0.70	0.66	0.67	**0.31**
Maximum (mm)	1,072	593	1,216	1,240	647	599	776	388	463	498	508	953	**5,560**
Minimum (mm)	0	6	29	42	66	65	50	0	0	17	0	0	**1,405**
Median (mm)	258	249	274	269	274	209	303	214	165	143	177	304	**3,198**
No. Years	38	38	40	38	39	40	37	37	34	36	35	35	**28**

***CV: Coefficient of variation = standard deviation/mean**

A comparison between mean annual rainfall and latitude for Gilbert Islands was undertaken. There is a discernible trend indicating that the further from the equator the island is, the more rainfall to be expected; and the further that islands are situated north of the equator the more likely there are to have more annual rainfall than islands of similar latitude south of the equator. Notable outliers are Butaritari and Makin, showing significant increase in rainfall for their latitude, within a ‘rainbelt’, whilst Aranuka, Marakei and Tamana indicate a ‘rain shadow’ with less mean annual rainfall than suggested by the trend line (Figure 4).

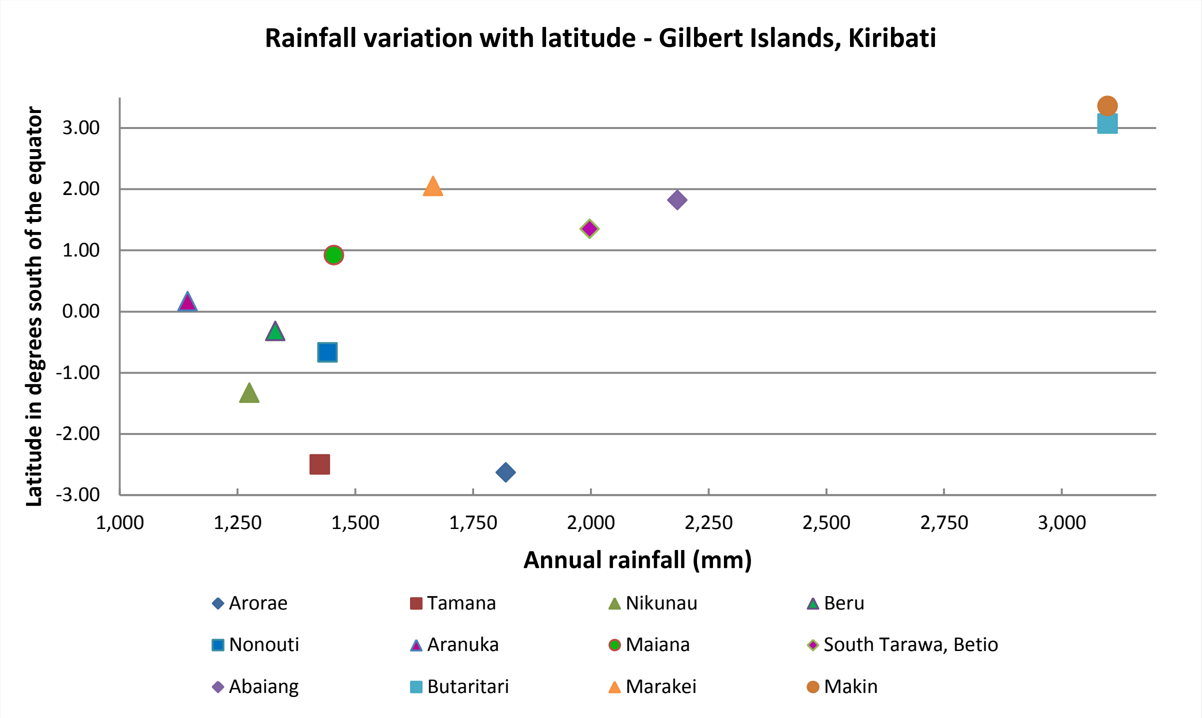

Figure 4. Mean annual rainfall (1950- 2014) variation with latitude for the Gilbert Islands group.

A comparison of islands with regards to their monthly variation indicates some common seasonal variation for rainfall between islands, with the seven months May to November being a 'drier' season (Figure 5). Seasonal rainfall statistics, specifically for Makin, are contained in Table 4.

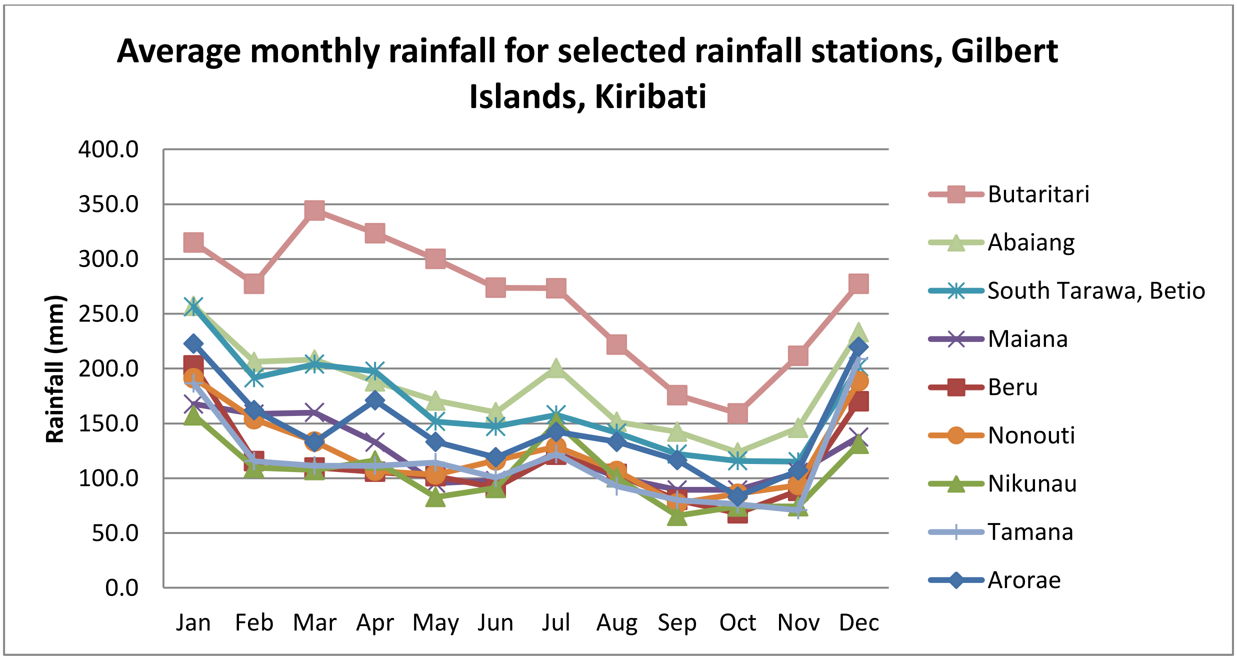

Figure 5. Variation in monthly rainfall for selected islands 1945-2014 (available records). Generally, the months from May to November are considered the driest months whilst the months from December to April, the wetter months, for Gilbert Islands.

Table 4. Annual rainfall (mm) 'drier' May to November (7 months) and 'wetter' December to April (5 months) seasonal rainfall statistics for Makin, 1955 to 2014.

Statistic	Annual	May-November	December-April
Mean	3098	1541	1598
Standard deviation	958	488	663
CV	0.31	0.32	0.42
Maximum	5560	2452	3259
Minimum	1405	752	328
Median	3198	1561	1584
Number of years of records	28	31	31

It is noted that in the 'drier' 7 months, from May to November, Makin received less rainfall than the 5 'wetter' months from December to April for the period 1955-2014.

The Coefficient of Variation (CV) = the standard deviation/mean, and is a measure used to indicate the variance of rainfall away from the long-term average. The higher the CV the greater the range of variability in rainfall and the greater the departure from the long-term annual average rainfall that can be expected. A lower CV indicates a lesser range of variability in rainfall and greater confidence in receiving rainfall for any given year close to the long-term annual average. The CV of rainfall can be considered as an index of risk, the higher the CV, the higher the risk that rainfall will be less reliable. Because CV considers deviations from averages, it can be used for relative comparisons of variability within and between regions.

The CV for Makin being 0.31 indicates that rainfall in any one year, for about 68% of the time, can be expected to vary ±31% from the long-term annual average rainfall of 3098 mm.

The Makin CV of 0.31 indicates a moderate temporal variability of rainfall. It is also noted that the seasonality of the rainfall with such CV suggests moderate variability of rainfall away from the long-term seasonal average of rainfall, indicating that rainfall is moderately reliable with consideration to any particular season. This is an important water security consideration especially with regard to assessing the reliability of rainwater harvesting to supplement or supply freshwater in the future.

The relatively large gaps in the Makin rainfall dataset preclude further analysis of the rainfall data. The Tarawa rainfall station has good quality long-term data and a comparison between the two datasets indicates that monthly rainfall on Makin is on average 61% higher than on Tarawa, although there is great variability within any one year and between months for the two islands (Figure 6). Caution is required when attempting to transpose the rainfall from Tarawa for Makin.

It is recommended that the daily rainfall recordings for each island continue to be supported by the Government of Kiribati as it provides critical datasets for water resource management by providing an indication of climate variability both temporally and spatially.

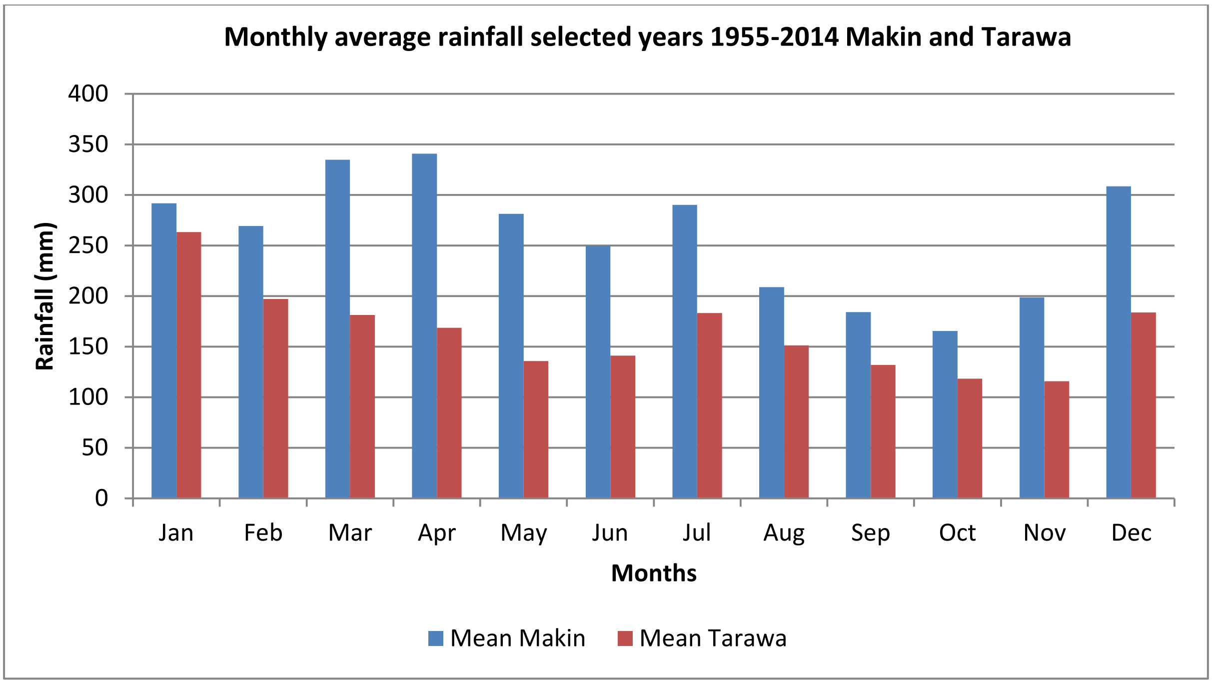

Figure 6. Average monthly rainfall for common years between Makin and Tarawa for the period 1955-2014.

ENSO has a dominant effect on the rainfall distribution on Gilbert Islands and the Pacific. An El Niño event will generally result in increased rainfall for the Gilbert Islands, whilst a La Niña event will result in reduced rainfall.

The Pacific Climate Change Science Program funded by the Australian Government undertook comprehensive research into the climate and ocean projections for 14 Pacific nations. The projections for temperature, rainfall, and sea-level rise are based on the output from 24 global climate models and the Coupled Model Intercomparison Project Phase 3 (CMIP3) (Meehl et al., 2007), and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Hennessey et al., 2007), focusing on projections for 2030, 2055, and 2090 under high, medium and low greenhouse-gas emissions scenarios. The projections and predictions are the result of joint research by the Australian Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (Australian Bureau of Meteorology and CSIRO, 2011).

The summary of predictions for Kiribati include the following:

- Annual average air temperatures will increase. By 2030 it is predicted to increase by 0.7°–0.8° C (moderate confidence).
- There will be a general increase in rainfall > 5% by 2030 (low confidence).
- Intensity of extreme rainfall and frequency of days on which it occurs are projected to increase (high confidence).
- Drought is expected to decrease (moderate confidence).

- Sea level will continue to rise. By 2030, sea-level rise is expected to be 5-14 cm (moderate confidence).

A rising sea level will increase the effect of coastal inundation from extreme wave and seawater levels, with potential impact on the freshwater lens from inundation (Australia Bureau of Meteorology and CSIRO, 2011).

3.4 Geology and Hydrogeology

No detailed geology of Makin is available but general observations confirm the presence of two major geological units, namely surficial, poorly sorted and unconsolidated gravelly-silty coral sands unconformably overlying an older well-indurated, weathered, and moderately fractured and porous limestone. Previous studies by Falkland and Woodroffe (1997) and Falkland (2004), suggest that the geological framework for Makin is similar to that in Tarawa, with unconsolidated Holocene sediments unconformably overlying the more permeable Pleistocene limestone.

The thickness of the unconsolidated sediments for Makin and the depth to the unconformity on the more porous limestone is not known with confidence without drilling of investigation boreholes. It is assumed that the depth to the more permeable Pleistocene limestone will be similar to that on Tarawa, which is 12-21 m.

The occurrence of freshwater underlying atoll islands like Makin has been well documented elsewhere (Falkland and Woodroffe (1997), Alam et al., (2002), Falkland (2003), Hunt and Peterson (1980)), and the reader is directed to these documents. Figure 7, after Falkland (2003) illustrates the generally accepted conceptual model for groundwater occurrence in atolls, with the expected position and stratified nature of the freshwater lens relative to basal sea water and the transitional zone.

For resource assessment purposes in the Pacific, electrical conductivity is used as a measure of groundwater salinity. An electrical conductivity of 2.5 mS/cm, or 2500 µS/cm, is widely accepted as the base or upper limit of the freshwater zone, and will be used as guideline value for freshwater lens salinity.

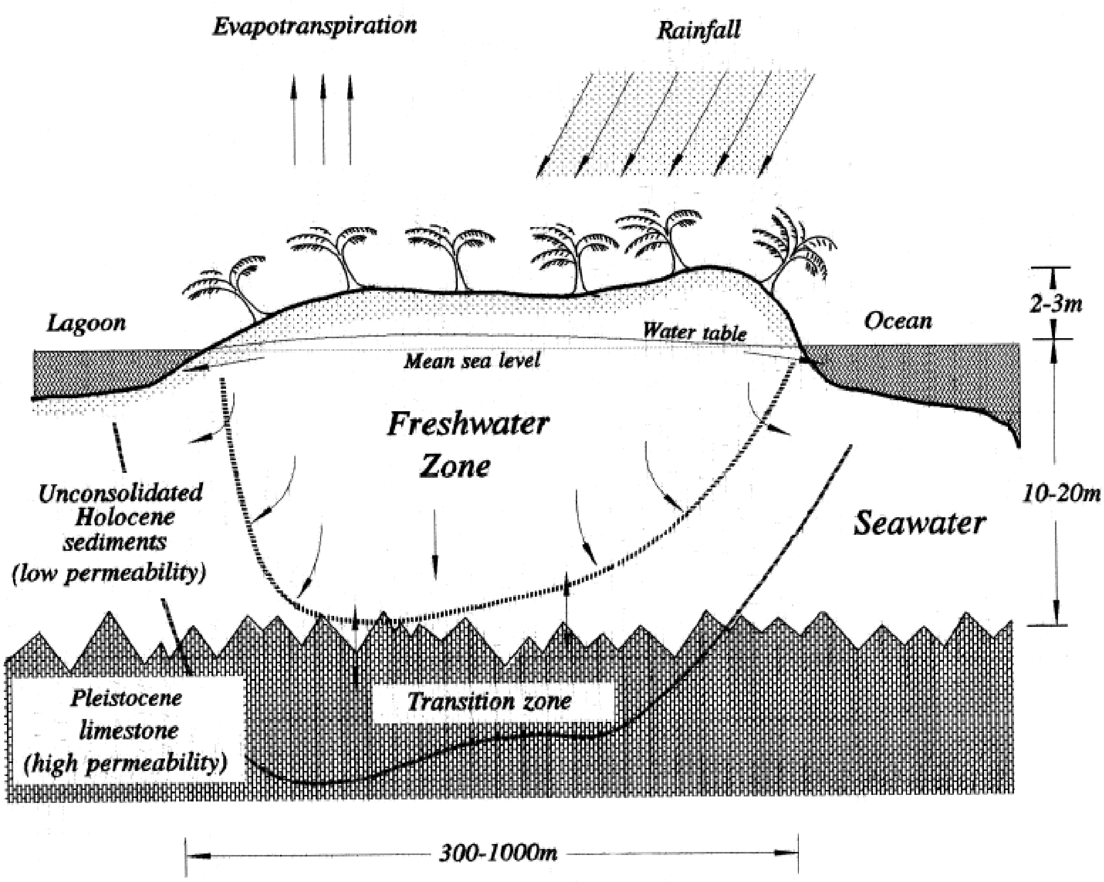

Figure 7. Freshwater lens configuration typical in atoll environments like Makin Island (Falkland, 2003).

Estimates of annual rainfall recharge and sustainable yield for Kiribati islands had also been made by previous studies, where a simple relationship between annual rainfall and annual recharge can be made based on water balance studies on a number of islands UNESCO (1991), Figure 8. A first estimate of recharge using data collected from recharge studies for several atoll and coral islands, including Tarawa has been used to derive an empirical relationship between mean annual rainfall and calculated mean annual recharge for a number of low-lying islands. Falkland (2003), in using this approach, developed a spreadsheet based on the resulting polynomial equation from the plotted data to allow the estimation of recharge 'Rainfall vs Recharge.xls' for the islands of Kiribati. Using the average annual rainfall for Makin (3098 mm), the estimated mean annual recharge for Makin was 1750 mm, which accounted for an estimated 56% of annual rainfall.

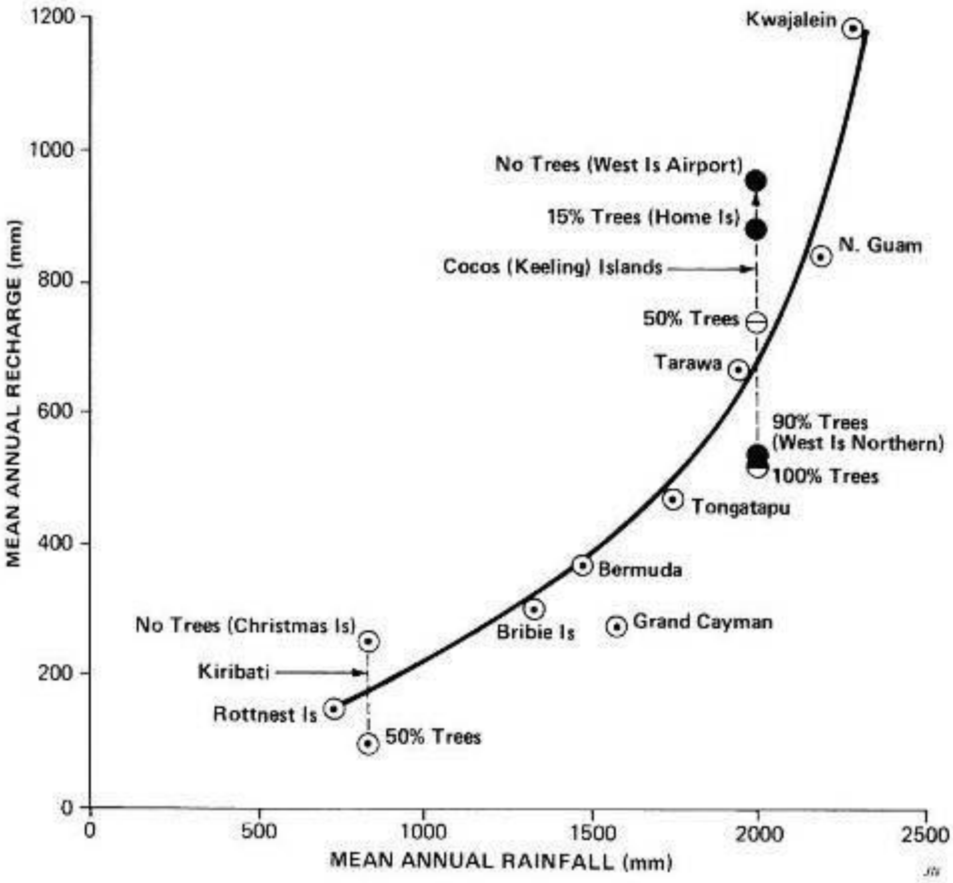

Figure 8. Annual rainfall – recharge relationship for a few studied small islands (UNESCO 1991).

Falkland (2003) has also developed a conservative assessment of sustainable yield, based on a relationship between sustainable yield and recharge, whereby the sustainable yield increases as the percentage of recharge increases, and is based on modelling studies in high-rainfall areas and a study of Christmas Island in 1993. The relationship being:

y = x-10

whereby: x = recharge (% of rainfall)
y = sustainable yield (% of recharge)

Applying this approach for Makin with a mean annual rainfall of approximately 3098 mm and an estimated mean annual recharge of 1750 mm with 56% of rainfall; a conservative preliminary sustainable yield of 46% of annual recharge is determined which correlates with the estimated sustainable yield for Makin by Falkland (2003).

It should be noted that this is a conservative approach to the estimation of sustainable yield, but it is useful as a first estimate in lieu of specific studies.

3.5 Water Supply and Sanitation

Groundwater is the primary water source for drinking and domestic purposes on Makin (91%), whilst rainwater is used as the primary drinking water source for 9% households (Table 5, National Statistics Office, 2012).

Table 5. 2010 Census data on primary drinking water sources commonly used on Makin atoll (National Statistics Office, 2012).

Village	Makin	Kiebu	Total
Rain water tank	9	23	**32**
Pipe system (PUB)	0	0	**0**
Open well water	239	53	**292**
Protected well water	23	0	**23**
Total	271	76	347

The 2010 census also indicates that 33**% of households on Makin practice open defecation** – 114 households were recorded to defecate on the beach and bush. Pit latrines are used by 50% of the families whilst flush toilets and the sea are used by 11% and 6% of the households, respectively.

Table 6. Sanitation systems in use on Makin Island. (National Statistics Office, 2012)

Sanitation technology	Flush toilet pub system	Flush toilet own septic	Pit latrine	Atollete	Beach	Bush	Sea	Total
2005	**0**	**3**	**173**	**6**	**194**	**54**	**107**	**328**
2010	**0**	**37**	**173**	**0**	**113**	**1**	**23**	**347**

A comparison of the sanitation systems indicated in the census data over time suggests that there is an increase of improved sanitation practices and a general move away from open defecation. The greatest significance is the trend of increased flush and pour-flush toilets. This trend towards flush and pour-flush toilets is likely to increase the usage of water per capita. The potential for groundwater contamination is increased where poorly designed flush and pour-flush toilets are used.

Falkland (2003) undertook an inspection of the water supply systems in most settlements in Makin, providing a summary of the status of the water supply systems at the time of that inspection. As part of the water resources assessment, an update of the status of the water supply systems for Kiebu Village under KIRIWATSAN I has been undertaken and the original table updated for those systems inspected (Table 7).

Table 7. Updated water supply systems summary table (after Falkland 2003).

Village / School	General Description of the Water Supply System (after Falkland 2003)	Condition of the Water Supply System 2012 (KIRIWATSAN)
Makin	42 Southern Cross hand pumps were installed during UN project – all were not operating. 3 wells surveyed and 26 tank stands (9 not working). 4 Tamana pumps were installed.	Not surveyed.
Kiebu	Improved rainwater catchment system with 17 poly tanks (5000 L), 2 higher tanks fed from guttering on a church to feed 13 other tanks; 2 tanks fed from primary school – Existing groundwater systems were replaced.	Two groundwater wells (1 showed very high salinity). One well has a solar pump abstraction system attached but not working – the other one uses bailers to abstract groundwater. Nine buildings with 29 rainwater tanks attached to the roof catchment. Significant roof improvements in all these buildings will improve water storage and ensure water security during dry periods.

3.6 Previous Work

The first of the previous studies undertaken in Makin was under the United Nations Capital Development Fund for Outer Islands Community Water Supply Project in the 1990s. The project resulted in the provision of a wide range of water supply infrastructure in over 70 villages on 13 islands in the Gilbert Group. The summary of these infrastructural assistances on Makin, together with the project's major challenges and conclusions, are presented in Tables 8 and 9 below:

Table 8. Water supply assistances on Makin Island (Water Unit, 2002).

Village	Wells Excavated	Well Rings	Hand pumps	Pipe lengths (m)
Kiebu	4	24	12	2200
Makin	-	-	60	3000

It is clear that Kiebu Village has had previous experience and some awareness for water supply improvements.

Table 9. Summary of the UNCD Project challenges and conclusions (Water Unit, 2002).

Major challenges	Major conclusions
Unreliability of flight schedules to the outer islands for about 60% of the project period resulting in difficulty in project supervision and implementation	The value and benefit of having very competent and dedicated local staff resulted in the project's overall satisfactory achievement
Difficulty in mobilising volunteer labour through the island and village councils caused significant delays	The installation of water supply systems in schools had a positive impact on the health of school children through the observed usage of hand washing facilities
Considerable shortage of staff in 1996 hampering production progress	The establishment of Water Technicians on every outer island by the Ministry of Works and Energy has facilitated the project implementation and maintenance of the water supply
Difficulty in securing adequate ship space for material shipment to the islands caused slow progress in project implementation	Noticeable improvement in water quality was observed through the bacteriological sampling and tests whereby protected wells installed by the project showed no E.coli bacteria, in contrast to all the unprotected (existing) wells, testing positive for E.coli

Mourits (1996) conducted further investigation on the status of freshwater resources in Kiebu (Makin) and Butaritari. Summaries of the groundwater salinity and E.coli analysis are presented in Tables 10 and 11 below.

Table 10. Salinity levels of groundwater wells in Kiebu Village (Mourits, 1996).

Measurement location	Well 1	Well 2	Well 3	Well 4
Salinity at water table (µS/cm)	900	950	600	700
Salinity at well base (µS/cm)	2000	5000	10,000	7000
Depth of water (m)	0.45	0.5	0.55	0.7

Table 11. E.coli results of tested groundwater wells in Kiebu Village (Mourits, 1996).

Sample location	Hand pump from well 1	Hand pump from well 1	Hand pump from well 2
Volume filtered (ml)	50	100	100
Count	130	>200	9
Thermotolerant Coliform/100ml	260	>200	9
Contamination	Yes	Yes	Slight

Mourits (1996) concluded that the freshwater lens underlying Kiebu Village was very thin with electrical conductivity measuring 900 µS/cm at the top of the water table and 5000 µS/cm at a depth of 50 cm. This was supported through the *Tamana* pump trial whereby placing footvalves near the bottom of freshwater wells resulted in the rapid abstraction of brackish water. Further, the degree of bacteriological contamination in the wells was related to the number of containers used in the wells, in conjunction with the hand pumps, and of floating objects in the wells, as both wells were not covered.

It is worth noting that many of these observations were also observed by this survey team and remain valid.

4.0 FIELD SURVEY

This section presents the results from the current water resource assessment investigations undertaken, using geophysics and water resource assessment techniques to determine the status of:

- rainwater harvesting systems;
- well infrastructure and reliance; and
- groundwater potential for water supply purposes.

Investigations were undertaken jointly by SPC and the Water Engineering Unit staff of the GoK Ministry of Public Works and Utilities.

4.1 Survey Methodologies

The assessment methods are outlined below.

1. Survey of existing rainwater harvesting infrastructure involving the:
    - measurement of roof catchment dimensions and effective roof areas;
    - assessment of the condition of guttering, fascia board and down pipes; and
    - assessment of storage condition and estimation of dimensions.

2. Survey of well infrastructure included:
    - describing construction features and materials, abstraction types;
    - measurement of water salinity and depth to water table;
    - water sampling from selected wells and rainwater tanks for microbiological analysis; and
    - identifying well features which reduce the potential risk of contamination to the well and the groundwater.

3. Cross-island transects with EM34 electromagnetic equipment to determine the lateral variability in bulk ground conductivity as a guide to estimation of fresh groundwater thickness.

4. Conduct community awareness meeting on identified water resource and sanitation issues and discussions on potential strategies to improve water resource management.

The field information was collected using GPS-enabled Trimble Juno 3 series handheld computers, and project-developed standardised templates, attached in Annexes 3 and 4

The data were compiled and uploaded into a web-based spatial database, developed under this project <http://ict.sopac.org/kiriwatsan/login/index>. The site is currently hosted and maintained by SPC with administrator rights held by SPC and WEU staff. It is proposed that the database will be cloud based in the future with read-only accessibility available for all users logging onto the site with the exception of assigned administrators.

A non-editable standalone version on a DVD is available for use where internet connectivity is difficult.

4.2 Rainwater Harvesting Assessment

A total of nine (9) buildings were surveyed in Kiebu Village on Makin atoll, for assessment on the suitability and potential for RWH and its improvements (Table 12). The assessment included:

- effective catchment area and condition;
- transmission type and efficiency;
- storage condition and dimensions; and
- contamination potential.

The main groups of buildings were:

1. Schools near and/or within target village boundary

Abaewewe Primary School was surveyed. The school had considerable potential for increasing RWH for water supply with good roofing materials and substantial catchment area, but will need significant improvements in infrastructure, such as down pipes, fascia boards, guttering, and additional storage.

2. Churches

Both the Kiribati Protestant Church (KPC) and Catholic Church were surveyed for their existing rainwater harvesting status and potential. Two (2) church buildings were surveyed. These buildings are suitable communal RWH centres due to their accessibility and substantial roof catchments but need considerable improvements to fascia boards, guttering, down pipes, tanks and taps.

3. *Maneaba*

Two (2) *maneaba* (both church-owned) were surveyed for their existing RWH status and potential. Similar to the churches, *maneaba* are suitable as communal RWH centres because of their communal accessibility and substantial roof catchment but similarly require fascia boards, guttering, down pipes, tanks and taps as indicated above. The low roof height of many *maneaba*, 1.4 m, requires special consideration when designing or selecting appropriately sized rainwater storage tanks for RWH.

4. Village clinics

The newly constructed village health clinic at Kiebu was surveyed and does not require any immediate infrastructural improvements.

5. Private buildings

Several privately-owned buildings were also surveyed because of their adequate roofing materials/ conditions. As the rainwater harvested from private buildings would be used by the owners and their families, with limited communal access, it is expected that costs of any infrastructural improvements to these buildings for RWH would be borne by the household owner.

Table 12. Summary of surveyed buildings in Kiebu Village.

Village	Kiebu
Number of buildings surveyed	9
Buildings with good roofing condition	5
Buildings without facia board	1
Buildings without guttering	0
Buildings without down pipes	1
Buildings with overhanging vegetation	5
Buildings with tanks	2
WATER QUALITY – E.COLI CONTAMINATION	
Number of samples taken	5
Number of samples showing E.coli bacteria	4
Percentage of contaminated samples	80%

It was assessed that:

- 55% of the buildings have good roof conditions – with the remaining 45% requiring minor repairs to total replacement of roofs.
- 11% of the suitably roofed buildings do not have fascia boards, all the buildings have guttering, and 11% do not have down pipes, demonstrating the heavy reliance on RWH for both potable and non-potable water.
- 55% appear to be partially covered with vegetation raising the potential of rainwater contamination, and guttering blockages and overflow.
- 22% of the buildings have storage tanks, suggesting that most buildings will require suitably sized rainwater tanks to be installed for secure and adequate storage/conservation.

It should be noted that inspections of roofing conditions are limited to what could be observed from the ground at the time of the survey. Experience suggests that some roofs may require additional repairs and/or replacement that cannot be identified without a more detailed inspection.

Suggested upgrades to improve rainwater harvesting potential are as follows:

- Repair or replacement of roofing materials with preferably corrugated zinc-aluminium coated steel.
- Repair or replacement of fascia board and guttering to cover the entire roofing edge.

- Installation of standard design guttering, vertical down pipes and transmission pipes to improve the flow of rainwater towards the storage tanks, with improved construction and maintenance.
- Where appropriate, the installation of first-flush mechanisms to reduce the transmission of potential contaminants and organic matter into the transmission and storage systems.
- Selection of appropriately sized tanks with proper piping and distribution.
- Construction of standard and protected tank stands and outlet taps to both improve access and manage freshwater.
- Construction of concrete cisterns (1) to store rainwater for low-roof *maneaba* and abstracted via *Tamana* pumps; and (2) as a conservation strategy for areas of poor groundwater potential.
- Inclusion of access points on transmission pipes and storage units to permit periodical system purging and allow blockages to be cleared.

4.3 Groundwater Survey

In Kiebu, groundwater is accessed by shallow wells and unprotected or poorly protected wells[1] with an estimated 50% of households abstracting the groundwater with the use of bailers (Figure 9). Most wells are poorly sited and constructed. Many wells have inadequate casing or are unlined, and constructed with minor consideration to reducing the potential for contamination or with regard to optimal water quality.

The groundwater survey collected information on two (2) wells in Kiebu Village (Table 13). Standard techniques for WRA were used for groundwater survey. These included surveying all wells in Kiebu Village to help determine the following parameters:

- location;
- construction type;
- general condition;
- contamination risk;
- salinity; and
- usage and reliance on groundwater by the community.

The survey information was collected using a handheld field computer (Juno Trimble) which allowed the location details to be recorded with the GPS location; and the data directly entered in digital format.

The 2010 census indicated that 70% of all households in Kiebu Village rely on groundwater for their potable and domestic water needs – 30% of the households rely on rainwater. The lack of freshwater hand-dug wells indicates the:

- negligible fresh-groundwater potential underlying the village, and

[1] Presence of a casing, parapet, cover, fencing, well apron, with increased distance from contamination source will improve well protection in most cases.

- limited dependence on groundwater possibly because of variable quality.

Figure 9. Community well in Kiebu Village assessed by survey team – groundwater from this well is abstracted by bailers (i.e. tins and containers).

Table 13. Summary of the state of groundwater wells surveyed within Kiebu Village.

Village	Kiebu
Number of wells surveyed	2
Number of households (Census 2010)	76
Number of households with access to individual wells	53
% of households relying on groundwater for water needs (Census 2010)	70
INFRASTRUCTURE	
Unlined wells	0
Wells with coral rock casing	0
Wells with cement ring casing	2
Wells without any casing information recorded	0
Wells without parapet	2
Wells without proper cover	1
Wells without proper apron	2
Wells without proper fence	1
ABSTRACTION	
Wells using hand pumps	0
Wells using solar pumps	1
Wells using electrical pumps	0
Wells using bailers	1
Wells not used (Abandoned)	0
CONTAMINATION	
Wells located ≤ 20 m from contaminant sources	1
WATER QUALITY – PHYSICAL PROPERTIES	
Average total depth (m bgl)	2.7
Average depth to water table (m bgl)	2.4
Maximum salinity (mS/cm)	17.4
Minimum salinity (mS/cm)	0.7
Average salinity (mS/cm)	5.9
Median salinity (mS/cm)	2.7
Number of wells exceeding 2.5 mS/cm	2
WATER QUALITY – BACTERIOLOGICAL TESTS[1]	
Number of E.coli samples taken	5
Number of samples showing E.coli present	4
% of samples indicating contamination	80%

Note:

[1]E.coli test was only conducted on rainwater tanks because of heavy reliance on rainwater for drinking purpose. The surveyed wells were not sampled as groundwater was not used for drinking.

One of the wells surveyed is located within 20 metres of an identified contamination source increasing the risk to water quality for that well.

4.3.1 Well construction, condition and maintenance

The status of construction, condition and maintenance of surveyed wells, from households, community, church, clinic and schools is summarised below:

- For the surveyed wells, both (100%) had locally-made cement rings as casing materials.
- Neither of them had parapets nor adequate aprons, suggesting that they are at greater risk of surface water ingress and contamination.
- One well did not have a proper cover and one did not have fencing, which are issues for both security and increased potential for algal growth, of the well.

The above shows that wells are poorly constructed increasing their susceptibility to contamination from:

- surface water run-off washing in contaminants from nearby sources such as rubbish, and faecal matter;
- falling debris or side-wall collapse;
- close proximity to faecal sources such as pig pens and pit-toilets;
- organic matter including leaves and coconuts; and
- algal growth.

4.3.2 Abstraction and usage

Abstraction of water from groundwater wells is carried out at:

- 1 of wells using a solar pump – installed but is not working; and
- at the other well using bailers, namely buckets, tins and containers – most bailers were found unprotected, lying on the ground, thereby increasing potential for contamination (Figure 9).

Figure 10. Health Clinic well, which showed brackish water quality, is attached to a solar pump system that was not working during the survey.

Figure 11. Rainwater tank connected to a tap stand in Kiebu Village.

4.3.3 Water sampling and testing

Salinity measurements

Measurements of groundwater salinity are taken using electrical conductivity (EC). Electrical conductivity gives a measure of saltiness and was recorded for all wells in Kiebu Village at both the top of the well and the base of the well using a calibrated portable EC meter (TPS-WP84).

The EC results were used to define the extent of the fresh groundwater resources. Previous studies in Kiribati use the accepted EC limit of 'freshwater resources' to be 2500 µS/cm. This limit is used in many parts of the Pacific (see Table 14).

There are no practical health reasons for imposing an upper limit of salinity on drinking water as it will be determined by the palate sensitivities of the individual. That is, some individuals and communities will be used to slightly more brackish water than others based on what they are accustomed to. At other times a community may be willing to accept slightly more brackish water during extended dry conditions to ensure sufficient water supply for their demands.

The World Health Organization (WHO Guidelines for Drinking Water 4th Edition) states that high concentrations of chloride can give a salty taste to water.[2]

Concentrations in excess of 250 mg/l are increasingly likely to be detected by taste, where the chloride ion concentration of 250 mg/l has an equivalent salinity (EC) of 706 µS/cm (http://www2.vernier.com/sample_labs/WQV-15-COMP-chloride_salinity.pdf, accessed 28/07/2014). WHO does not provide health-based guidelines for chloride in drinking water.

The determination of salinity is therefore, subjective and any guidelines should take into consideration access to alternative supplies as well as include the ability to vary this during times of need, such as extended dry periods based on pre-determined acceptance by the community.

Table 14. Guide to salinity threshold values for consideration by the communities of Makin for management purposes.

Salinity µS/cm	% Seawater	Comments
< 200	< 0.5%	Rainwater
200 – 1100	0.5 – 2.2%	Slight taste of salinity may be perceptible to people at the upper end of this range
1100 – 1500	2.2 – 2.5%	Upper desirable range for drinking water, where salinity in water will be perceptible to most people, but tolerated
1500 – 2500	5%	Salinity (salty) taste in the water will be perceptible to all and unacceptable to many Upper limit of freshwater
50,000	100%	Seawater

[2] http://www.who.int/water_sanitation_health/dwq/guidelines/en/

Summary of the field measurements from surveyed wells are as follows:

- The median average EC value of the 2 wells at the time of the survey was 2700 µS/cm.
- The average depth to the water table is 2.4 m bgl for both wells; and the maximum and minimum depths for the water table based on the two sites are 2.8 and 2.0 m bgl, respectively.

One (50%) of the surveyed wells, exhibited salinity levels in excess of the 2500 µS/cm adopted limit for freshwater resources. The higher salinity is likely to be due abstraction by solar pumps.

The number of freshwater wells present indicates potential of usable groundwater, low reliance on groundwater.

Bacteriological analysis – E.coli contamination

While groundwater is generally used for both drinking and domestic water needs in outer islands, Kiebu Village does not use groundwater for drinking. In order to better understand the vulnerability of stored rainwater to bacteriological contamination, the IDEXX Colilert-18 procedure, an E.coli presence/absence test, was used on samples collected from selected rainwater storage tanks around the village. Sample preparation procedures and results of the Makin analysis are provided in Annex 5, with village contamination maps shown in Annex 6.

Table 13 shows that approximately 80% of the rainwater tanks sampled indicated the presence of E.coli bacteria. This can be attributed to:

- the close proximity of vegetation cover resulting in contamination from falling leaves and other organic matter;
- usage of contaminant laden bailers to abstract water from rainwater tanks; and
- rainwater tanks not having adequate screens to prevent contaminants from falling into the tanks.

The above E.coli result represents the bacteriological status of the rainwater tanks at the time of the survey, and is likely to change over time. Whilst no safe set-back distances from contaminant sources can be confidently assigned for village and drinking water sources, Overmars (2004) suggests a set-back distance of at least 25 m be placed between water sources and contaminant activities.

Whilst this is considered to be an estimate provided for guidance purposes, in lieu of any specific investigations, it would seem a reasonable precautionary distance where groundwater abstraction protection measures are also undertaken. Measures which contribute to the protection of wells from bacteriological contamination include the installation of fitted well covers, well aprons, fencing, well parapets and the use of hand pumps.

For rainwater tanks, it is suggested that:

- all overhanging vegetation are trimmed back to prevent potential roof catchment contamination from falling leaves and other organic matter, and access by animals;

- all tanks inlets are equipped with proper screen to prevent potential contaminants from falling into the tanks; and
- the usage of bailers be prohibited to abstract rainwater, which should be done through the installation of tap stands connected to tank outlets.

Presence/absence testing for indicator bacteria, E.coli, does not provide a quantitative appreciation of the extent of contamination of the water and is therefore limited in its usefulness. It is recommended that a quantitative sampling procedure, such as the compact dry plate filtration membrane method, be used in the future should further microbiological sampling and analysis be conducted on the island. A fact sheet of this methodology and field procedure is provided as Annex 7.

4.3.4 Well improvements

Water supply and water quality from the community's wells can be improved through the use of the following measures:

- Casing materials made from concrete rings ensuring structural integrity to the well and allowing improvements such as the introduction of hand pumps, well parapets, aprons and well covers.
- Construction of a parapet to prevent the ingress of surface runoff.
- Fitted well covers to prevent foreign matter from being introduced into the well and to reduce algae growth.
- Concrete aprons surrounding the wells to prevent the infiltration of surface water from the sides.
- Fencing to restrict access by animals and others trespassing into the well area.
- The installation of hand pumps such as the *Tamana* pump, which
    - is relatively easy to operate and maintain at the community level;
    - uses locally available materials for repairs;
    - permits low-yield abstraction that minimises up-coning and saline intrusion; and
    - reduces the need for activities to be centred around the well, thereby reducing the potential of contamination.
- Bailer stands to keep the bailers off the ground.
- Decommissioning of abandoned wells to reduce their use as waste disposal receptacles that potentially act as a pathway for groundwater contamination.

4.4 Electromagnetic Surveys – EM34

4.4.1 Introduction

The use of electromagnetic (EM) geophysical surveys to map the thickness of the freshwater lens in atoll environments is well established, being successfully used on Kiribati in recent times by Falkland

(2004) and GWP (2011a). A Geonics EM34 electromagnetic instrument was used during the current groundwater resource investigations to provide a rapid assessment of the subsurface ground conductivity, which can be converted to an effective thickness of the freshwater lens.

Geophysical surveys were conducted around Kiebu Village from 26th to 27th October 2012, using the Geonics EM34 unit owned by the Ministry of Public Works and Utility.

A standard approach to EM34 surveys was used to provide consistency between surveys, as outlined in Annex 8.

4.4.2 Survey location

Five (5) EM34 survey lines were completed across Kiebu. The focus for geophysical investigations was the area within the immediate vicinity of the village, as this is the area of most interest for the villagers. Undertaking detailed investigations targeting the village area and surrounds 'localises' the collective village ownership and responsibility for the water source. It has been observed that in general:

- the collective 'village' has more influence over individuals from that village who are benefiting from the water source, which may assist with the access, use and management of the groundwater resources; and
- there is a preference by village communities for water supply infrastructure to be located within or close to the village boundaries, promoting improved ownership and accountability for the operation, maintenance and ongoing management of water supply infrastructure.

The locations of EM surveys in Kiebu are shown in Annex 6.

Traverse lines were undertaken between the lagoon and the ocean at 200-m spacing, using established paths where possible. Readings were taken every 30 m using the 10-m and 20-m cables in the horizontal dipole position (coils vertical). Some survey lines had to be slightly diverted or cut short due to the presence of *bwabwai* pits, dense vegetation and areas of flooding.

4.4.3 Interpretation of results

The relationship derived from the EM34 calibrations of EM34 readings and known freshwater thicknesses from monitoring bores, undertaken during the KIRIWATSAN and SAPHE projects (Table 15) was used to convert all EM34 field measurements in the village (Annex 8). Freshwater thickness contours, based on the estimated freshwater thicknesses using 2.5-m contour intervals, were hand drawn in MapInfo GIS and are presented in Annex 6.

Table 15. EM34 conductivity readings applied for selected freshwater zones are based on the combined KIRIWATSAN and SAPHE field calibration data. (see also Annex 8)

Freshwater zone thickness (m)	EM conductivity (mS/cm) 10 m	20 m
1	32	79
2	27	66
4	22	52
6	20	44
8	18	39
10	16	34

The extent of the freshwater lens underneath the surveyed villages was defined as the area of freshwater with an EC reading of less than 2500 µS/cm or 2.5 mS/cm and estimated thickness of greater than or equal to 2.5 m. This definition follows from the recent groundwater investigations of GWP under KAPII, 2010. Any estimated thickness less than 2.5 m is classified as of 'limited groundwater potential', being more likely to be brackish during prolonged dry periods (Falkland, 2004). The extent of the lens underneath each village is presented in Table 16.

Table 16. Estimated freshwater lens area beneath Kiebu Village.

Village	Kiebu
Surveyed village area (m^2)	704,700
Freshwater lens area (m^2)[1]	0
FW lens/survey area ratio (%)	0
Groundwater potential	Negligible

Note:

[1]Freshwater lens area has an estimated thickness of greater than or equal to 2.5 m, in line with previous groundwater assessments under KAPII.

Clearly, Kiebu Village exhibited negligible fresh groundwater potential. This suggests that the hydrogeological properties of the underlying limestone and surficial deposits are not conducive to the storage of usable fresh groundwater. This is very well expressed by the existence of two groundwater wells of contrasting salinity levels – the community well that showed a freshwater quality of 0.68 mS/cm at its base, whilst the Health Clinic well showed a high salinity reading of 17.3 at its base, which is beyond the drinking water standard.

The communal well (as illustrated in Annex 6), albeit showing freshwater quality, is sited in an area likely to have a freshwater lens of typically less than 1 m thick. The well is poorly sited with regards to the fresh groundwater potential of the island. During dry seasons, the communal well and surroundings, although located inland, will be vulnerable to salinisation and can be expected to become brackish.

Note that the EM34 survey does not provide any indication of potability of the groundwater with respect to pathogens nor to identify its risk of contamination.

Caution is required when applying estimated thicknesses of freshwater for calculations of water demand and water resource potential, as these estimates are relevant to the climatic conditions at the time of the survey and will vary over time in response to recent rainfall events.

Freshwater lenses are dynamic, contracting and expanding in response to climatic variations. El Niño and La Niña conditions have a significant impact on the rainfall in equatorial regions and therefore the freshwater lens. During La Niña drier conditions are experienced in Kiribati, which will have the effect of reducing the freshwater lens thickness whilst during El Niño high rainfall conditions will increase the thickness. It is necessary to monitor the freshwater lens thickness over time, with salinity measurements in selected wells, and where possible with repeated EM34 surveys under different climatic conditions. The monitoring and reporting of rainfall and of salinity variations in wells over time will be important for developing the sustainability of abstraction and drought management plans and actions that village communities can consider.

4.5 Groundwater Monitoring – Tidal Lag and Efficiency

Time-series groundwater monitoring was conducted in selected wells to determine the hydraulic connection between the unconsolidated sediments and oceanic influences, and as guide to the tidal influence on the aquifer. Schlumberger CTD (conductivity, temperature and depth) 'diver' loggers were installed in wells, recording data every 15 minutes for a minimum of one complete tidal cycle to indicate the range of tidal effect and tidal lag observed. The 'divers' were installed at the start of each survey and retrieved upon the completion of the survey in Kiebu Village. The data were downloaded onsite (see Annex 9).

4.5.1 Tidal lag and tidal efficiency

As the tide rises and falls in the ocean and lagoon, it forces the aquifer water to also fluctuate, albeit with smaller amplitude and a time lag. The tidal signal is attenuated or damped by friction as the aquifer water is forced to move through pores in the sands and gravels, and the nature of the aquifer materials determines the efficiency with which the tidal pulse is transmitted from place to place.

Tidal lag is simply the time difference between, for instance, high tide in the ocean and high tide at some location in the aquifer. Tidal efficiency is the ratio of well water-level fluctuation to that of the ocean. For example, on a spring tide with a tidal variation of 1.5 m, the water-level fluctuation in one well might be 0.75 m, with a resulting tidal efficiency of 1.5/0.75 = 50%.

Representative tidal lags and efficiencies for the selected wells in Kiebu Village are provided in Table 17.

Tidal efficiencies and lags reflect the amount of tidal influence or "hydraulic communication" of various portions of the aquifer with either the ocean or lagoon. Higher efficiencies and shorter lags indicate a greater amount of influence, and are expected to be found at sites relatively close to the shoreline; however, this is not always the case. Similarly, tidal efficiencies increase consistently with depth whilst the opposite relationship is expected with tidal lags and depth (Hunt and Petersen, 1980).

Several factors also complicate the tidal picture. These are:

- pockets of heterogeneous material which may produce tidal efficiencies and lags somewhat higher or lower than expected, such as coral rubble and reef rock;
- tidal stresses from both the ocean and the lagoon sides creating complicated interference effects, especially toward the centre of the island;
- permeabilities on the ocean side of the island are expected to be greater than on the lagoon side, creating additional complications in the tidal response; and
- the depth to the underlying geologic/hydrologic unconformity, which separates an underlying high permeability zone from overlying less permeable materials, exists at unknown depths, albeit expected to be between 8 and 25 m.

Tidal measurements are not available for Makin. In the absence of actual measurements, a tidal prediction calculator was used to calculate tides. The spreadsheet was developed by Doug Ramsay (NIWA) at the request of the Ministry of Public Works and Utilities, recognising that current tide predictions for Tarawa are not accurate for other islands in Western Kiribati. The predictions used here are from Version 2, 18 April 2008. Comparisons were made with regard to the calculated values for recorded values in Tarawa and reasonable fit was observed.

Because of the limited harmonic datasets used, the accuracy of the tide predictions for the other atolls will be limited. Times of high and low tides are likely to be within ± 30 minutes. The predictions will also not quite capture the magnitude of the very highest or lowest tides.

A summary of tidal lag and efficiencies for Bonriki water reserve is provided (Table 18) for comparison with the data collected from Makin, together with other islands surveyed for KIRIWATSAN 1 (Figure 14).

The monitoring records from both selected wells in Kiebu Village are presented in Annex 9.

Table 17. A summary of the logger data records and calculated tidal lags and efficiencies for Makin. (See also Annex 9)

Village	Well Owner	Diver number	Distance from closest water body, ocean or lagoon (m)	Start Date and time	End date and time	Length of record (hrs)	Tidal lag (hrs)	Tidal efficiency
Kiebu	Health Clinic	K6813	250	26/10/2012 18:00	27/10/2012 17:00	28	8.4	5%
	Communal well	K6818	100	26/10/2012 18:45	27/10/2012 15:30	20.7	9.4	8%
Average						24.4	8.9	7%

Table 18. Summary of tidal lag and tidal efficiency of monitoring bores in Bonriki.

Location	Name	Distance from closest water body, ocean or lagoon (m)	Tidal lag (hrs))	Tidal efficiency	Estimated Depth of Holocene sands to Pleistocene limestone (mbgl)
Bonriki, Tarawa	BN1B	80	1.85	7.9%	-17.7
Bonriki, Tarawa	BN2B	270	2.25	5.9%	-11.7
Bonriki, Tarawa	BN4C	500	0.5	31.7%	-11.8
Bonriki, Tarawa	BN7B	90	1.5	6.7%	-11.1
Bonriki, Tarawa	BN21	380	0.9	17.0%	-15.1
Bonriki, Tarawa	BN26	260	1.1	14.0%	-11.6
Bonriki, Tarawa	BN36	110	1.25	14.3%	-11.9
Bonriki, Tarawa	BN32	450	0.65	8.9%	-10.7
Bonriki, Tarawa	BN29	90	2	5.5%	-9.0
Bonriki, Tarawa	PS1	130	2.5-3	4.0%	-10.0
Bonriki, Tarawa	PS7	350	2.5	4.0%	-12.8
Bonriki, Tarawa	PS16	275	2-2.25	6.6%	-11.6
Bonriki, Tarawa	PS18	365	2.75	5.0%	-10.9

Figures 12 and 13 present the analysis of groundwater level and the predicted tidal levels at two monitoring wells, namely the communal well and health clinic well, at Kiebu Village (~0.5 km apart).

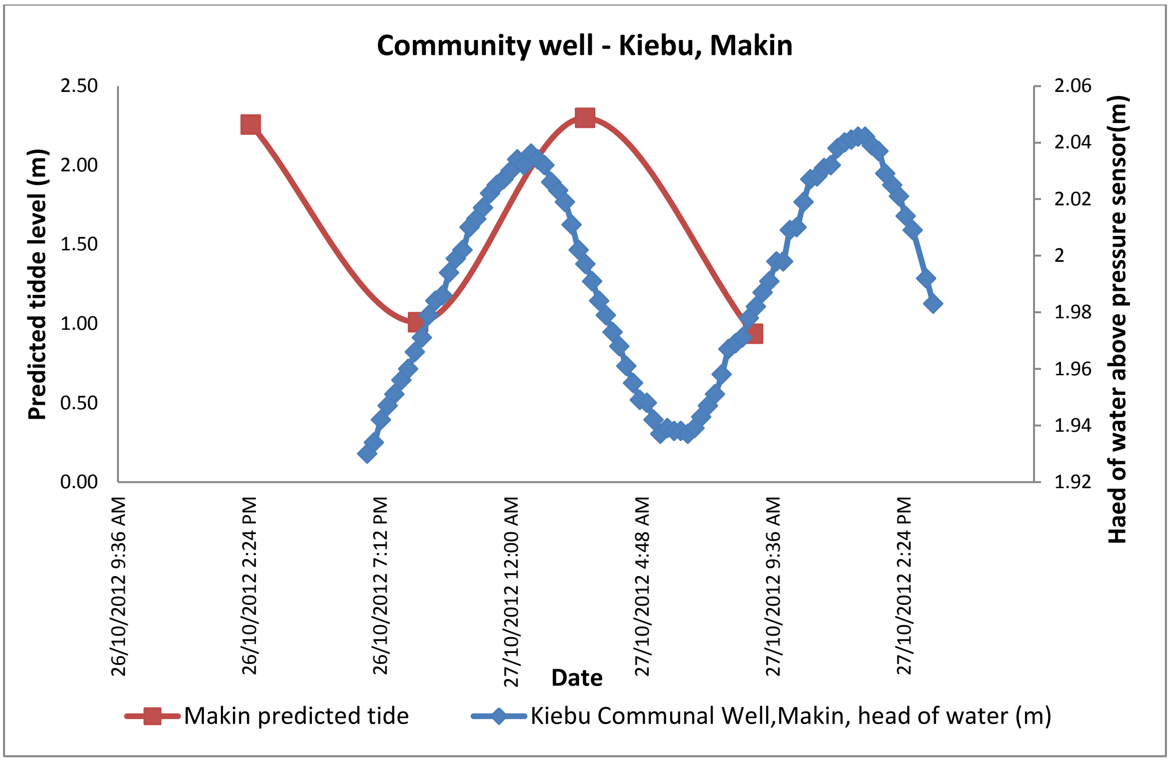

Figure 12. Predicted tidal height and measured groundwater level at the community well at Kiebu Village with groundwater monitoring commencing at 6.45 pm (26th October 2012) and terminated after 20.7 hours.

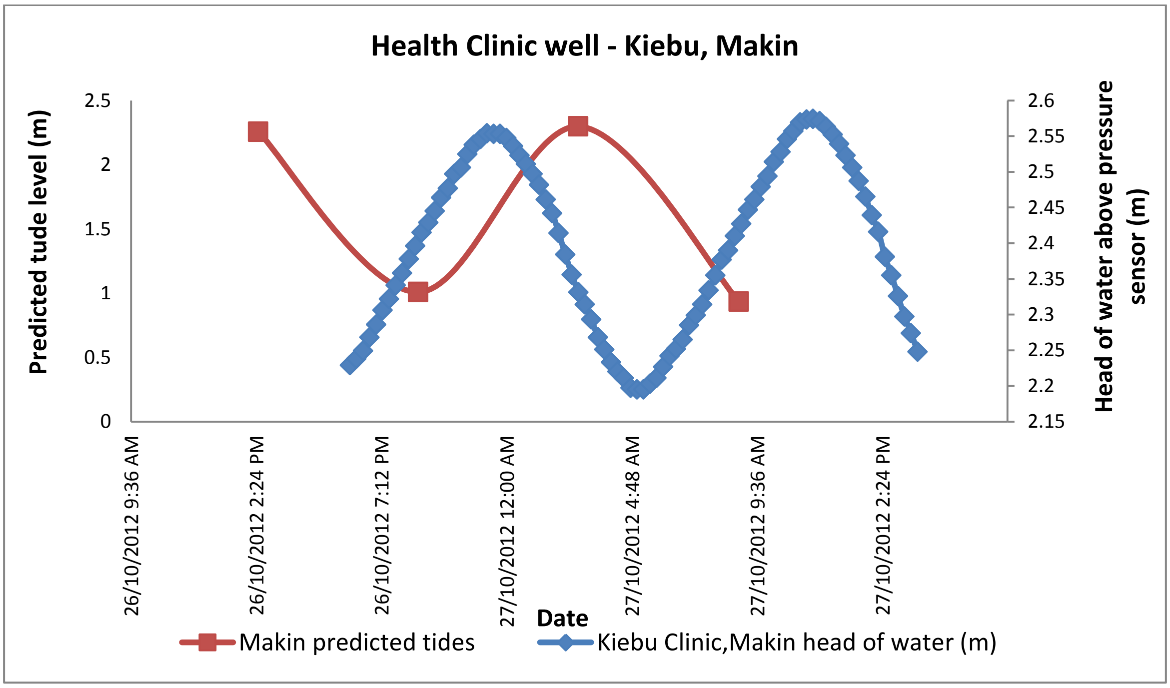

Figure 13. Predicted tidal height and measured groundwater level at the Health Clinic well at Kiebu Village with groundwater monitoring commencing at 6 pm (26th October 2012) and terminated after 28 hours.

It is noted that from the data collected, there is a general relationship of increased tidal lag resulting in a reduced tidal efficiency as distance increases from the lagoon or ocean source. With both the monitored wells accessed by bailers, the impact of abstraction, usually characterised by anomalous spikes in water level, was not noticeable.

Compared with Tarawa, Makin's groundwater response is similar albeit showing higher tidal lag with respect to Abaiang, Nonouti, Maiana, Beru and Nikunau islands. While this suggests a similarity in geology of the islands, the sediments are likely to be less permeable in Bonriki and Makin than those found in other surveyed outer islands, to account for the increased tidal lag (or low tidal efficiency values) with the summed similarity in depths to the Pleistocene limestone. Additional data are required to assess this suggested variation between the islands.

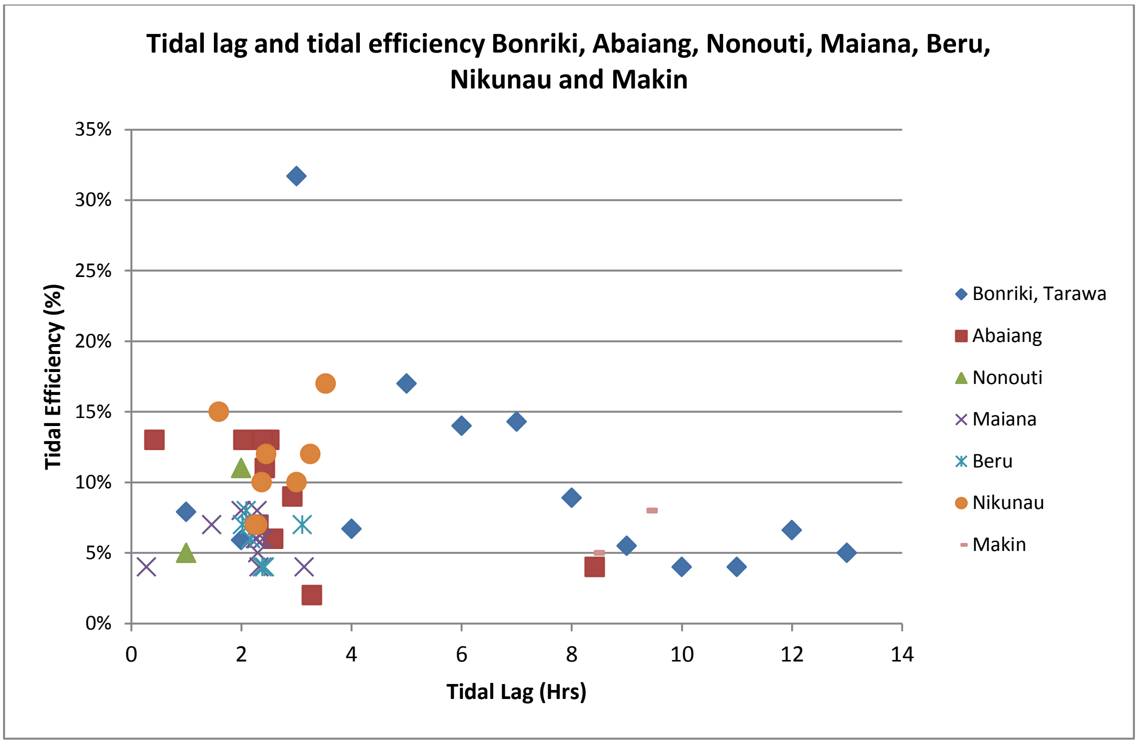

Figure 14. Tidal lag and tidal efficiency for Makin and Bonriki (Tarawa); and also for Abaiang, Nonouti, Maiana, Beru and Nikunau, with anomalous values removed.

5.0 WATER RESOURCES ASSESSMENT

5.1 Rainwater Harvesting

The surveyed buildings were classified as either private or communal buildings. Communal buildings refer to churches and *maneaba,* which can be accessed by the community. These would be considered for improvement for rainwater harvesting, under the KIRIWATSAN Project. The measured roof dimensions of communal buildings were analysed to determine their capacity to collect rainfall, based on the guttering coverage and condition as well as available storage. Using the available Makin discontinuous monthly rainfall record (from January 1955 to May 2014), the rainwater harvesting potential in the communal buildings was assessed using the rainwater calculator developed and utilised by the KAP II Project (White, 2010). (See also Annex 10)

A summary of all the communal buildings and subsequent analyses is presented in Table 19, assuming that all roofs are equipped with proper facilities.

From the data collected, it is clear that most communal buildings need substantial roof improvements to maximise the catchment area and to allow optimum rainwater collection – this will lead to the addition of various storage volumes to optimise water storage and availability for use. Clearly, the estimation of an appropriate storage volume to a given roof area will vary and depend on rainfall, the roof catchment, how much water is needed, and the number of users or population. Since the roof catchment is fixed, the effect of increasing the storage volume to provide an increase in water demanded by a fixed population will gradually decrease once the maximum roof area is reached. An analysis was conducted using the White (2010) rainfall calculator to determine the ideal storage for a range of roof catchment areas in Makin (see Figure 15). This was conducted using:

- a roof area range of 50 – 450 m^2;
- storage tank volumes of 5000 L; 10,000 L; 15,000 L; 20,000 L; 25,000 L; and 30,000 L;
- a fixed number of users at 100; and
- a limit of 84% satisfaction, which will be equivalent to 2 months of failure in any one year.

Table 19. Summary of potential communal rainwater harvesting centres. (See also Annex 10)

Village	Building Type	Owner	[1]Roof area (m^2)	Building ID	Percentage of roof covered by guttering	[2]Collecting Roof Area (m^2)	[3]Guttering Condition	[4]Guttering Efficiency	[5]Effective Roof Area (m^2)	[6]Improved Roof Area (m^2)	[7]Rain Tank Capacity (L)
Kiebu	Church	Catholic church	470	Ki1	100%	470	Adequate	0.55	259	352	11,000
	Maneaba	Catholic church	400	Ki2	75%	300	Adequate	0.55	165	300	8500
	Maneaba	Saint Arobati	409	Ki3	50%	204	Good	0.75	153	307	13,500
	Church	KPC	112	Ki4	100%	112	Adequate	0.55	62	84	20,000
	Village total[8]								639	1043	53,000

Notes:

[1] The product of the measured catchment length and width

[2] The product of the roof catchment area and the current guttering coverage

[3] On-site observation of guttering condition

[4] Guttering efficiency values are derived from White (2010) as shown in Table 20. This assigns 0.75 efficiency to "good" guttering – this also considers the runoff coefficient as specified in the White (2010) rainfall calculator spreadsheet (Annex 10)

[5] The product of collecting roof area and guttering efficiency

[6] Assumes that an improved catchment, through the installation of good guttering material, will yield a 0.75 guttering efficiency; hence this is a product of the roof area x 0.75

[7] Existing rainwater storage volume

[8] Roof analysis aggregate for all the surveyed buildings in Kiebu Village

Table 20. Rainwater harvesting parameters suggested by White (2010).

Attribute	Explanation
Building ID Number	Unique number identifying building
Type of building	Commercial, Community, Government, Other, Residential
Rain Tank Capacity (L)	S = Tank Capacity/1000 (L)
Roof Area (m^2)	A
% Guttering	Percentage of roof edge bordered by guttering
Collecting Roof Area (m^2)	A_{col} = (%Guttering) x A/100
Guttering Condition (Capture Efficiency, C, where ($0 \leq C \leq 1$))	Good (C = 0.75) Adequate (C = 0.55) Repair (C = 0.35) Replace (C = 0.15)
Effective Roof Area (m^2)	$A_{eff} = C \times A_{col}$

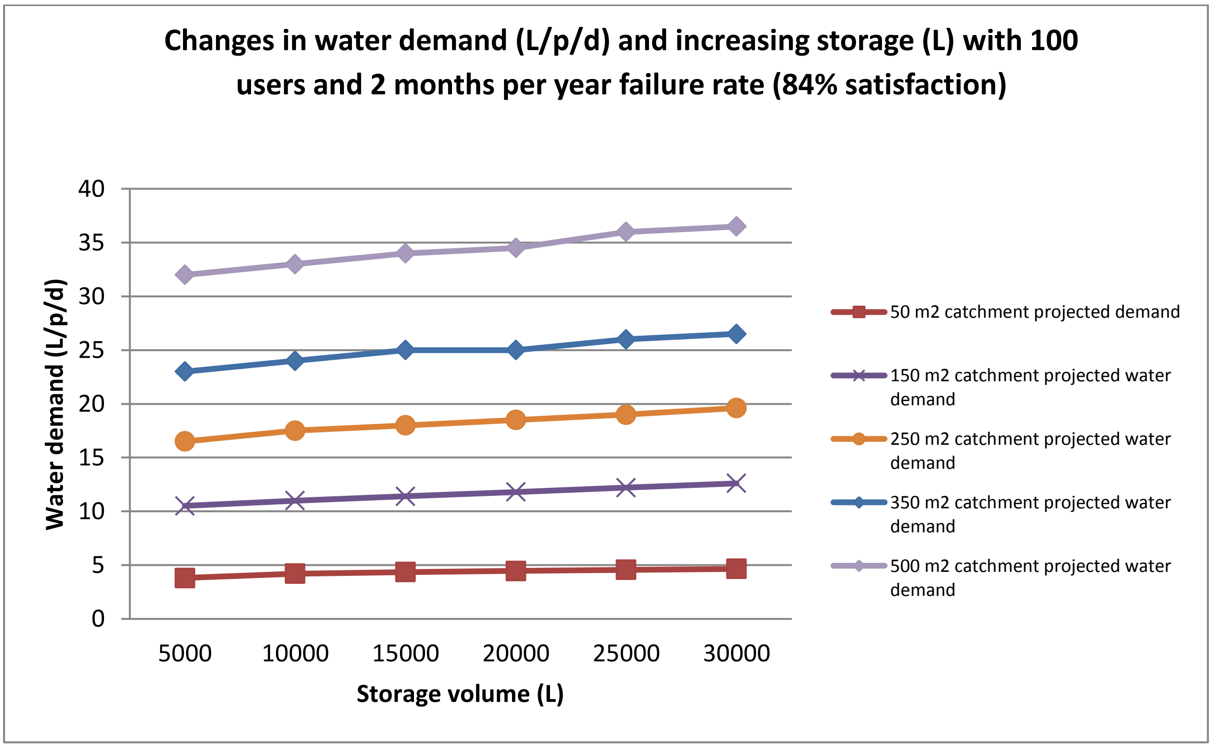

Figure 15. Changes in water demand (L/p/d) in relation to changing roof catchment and increasing storage volume based on 2 months failure rate in any one year (84% satisfaction).

Table 21 and Figure 16 indicate that most of the communal buildings, namely church and *maneaba* have the potential to adequately provide drinking water to the target communities. It is recommended that all the suggested improvements, outlined in Section 4.2, be implemented for optimum rainwater storage and conservation.

Table 21. Analysis of combining all target communal buildings in Kiebu Village to serve the current and future populations (after White, 2010). (See also Annex 10)

Village	Building ID	Population	[1]RWH capacity under current catchment conditions (L/p/d)	[2]RWH capacity under current and improved catchment conditions	[3]RWH capacity with roof improvements and increased storage 20,000 L
Kiebu	Ki1	2010 (434)	4.2	5.6	7.4
		2030 (483)	3.8	5	6.7
	Ki2	2010 (434)	2.7	4.7	5.1
		2030 (483)	2.45	4.2	4.6
	Ki3	2010 (434)	2.7	4.9	5.2
		2030 (483)	2.4	4.4	4.6
	Ki4	2010 (434)	1.25	1.65	1.65
		2030 (483)	1.13	1.4	1.4
	Village Total	2010 (434)	11	17	18
		2030 (483)	10	15.5	16

Note:

[1] Water demand under normal condition uses the current roof condition (effective roof area from Table 19) and the 2010 and 2030 populations from Table 2, and considers a 2 months per year failure rate (84% satisfaction) using the White (2010) rainfall calculator.

[2] Water demand under improved condition uses the improved roof catchment from Table 19 and the 2010 and 2030 populations from Table 2, and considers a 2 months per year failure rate (84% satisfaction) using the White (2010) rainfall calculator.

[3] Water demand under improved condition and storage assigns a 20,000 L storage increase to all buildings and uses Table 19 and the 2010 and 2030 populations (from Table 2), and considers a 2 months per year failure rate (84% satisfaction) using the White (2010) rainfall calculator (Annex 10).

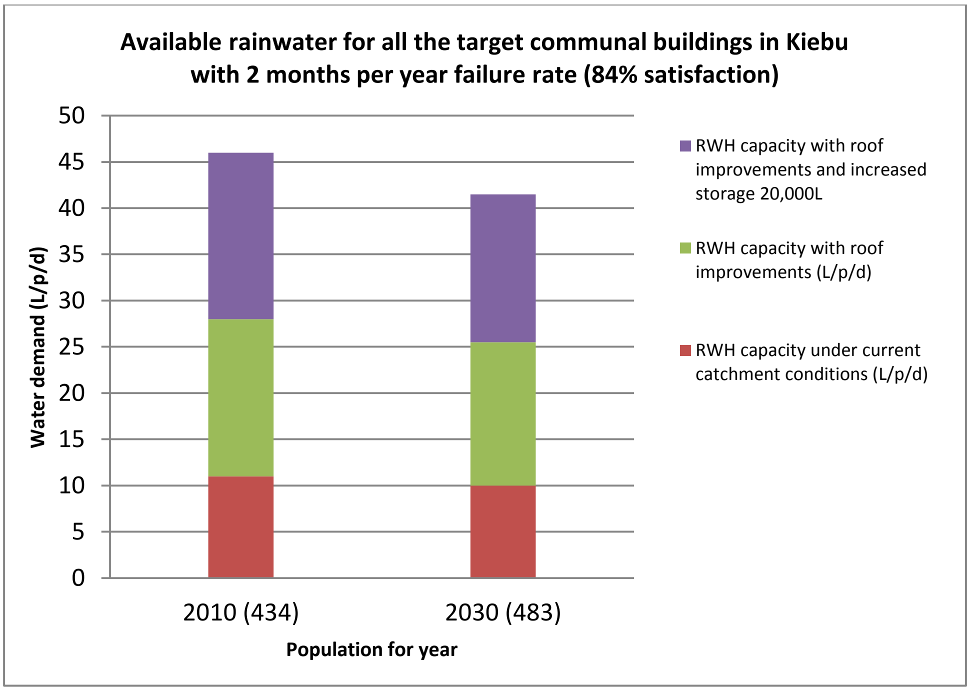

Figure 16. Analysis of water demand for all target communal buildings in Kiebu Village with 2 months per year failure rate (84% satisfaction).

For Kiebu Village, where good quality groundwater is not readily available, rainwater harvesting is the source of drinking water for households.

Figure 17. Women in Kiebu Village using rainwater for washing.

Whilst rainwater often has lower salinity than groundwater, it has limited drought reserve potential and unless well maintained, is susceptible to contamination. In the case of Makin, the moderate CV of 0.31 and the relatively high annual rainfall of 3098 mm (Table 3) suggest that proper conservation strategies will warrant the increased storage and guarantee water security for Kiebu Village. Thus, rainwater harvesting improvements are imperative, with rainwater being considered a primary freshwater source rather than a supplementary resource. Groundwater development, a cost-effective measure with improved water security in most villages in the Gilbert Group, will not be feasible for Kiebu Village.

With the poor groundwater potential estimated, it is recommended that more efforts be placed on the rainwater harvesting infrastructural improvements of communal buildings to warrant increased water storage/conservation, improve water security, and address issues of water source preferences for specific water needs such as drinking and cooking. Groundwater's potential is to be considered only for non-potable purposes. The rainwater harvesting systems should be optimised to provide a minimum per capita requirement for the nominated population with an agreed failure rate of 60-90% dependent on circumstances.

It is also recommended that formal agreements regarding the access, security and protection of rainwater harvesting facilities be developed in consultation with village community groups including

Unimwane, church leaders, women, and youth. This may also include agreed rules for water abstraction and use, with restriction of a maximum of 5 L/p/d or alternatives.

5.2 Groundwater Resources

5.2.1 Freshwater lens location and thickness

The EM34 geophysics principles and survey results as presented in Annex 8, indicate the ground conductivity readings for each survey point and the corresponding estimate of the freshwater lens thickness based on the reference data (refer to Section 4.4).

The estimated freshwater lens thicknesses based on the EM34 survey were hand contoured using 2.5 m contour intervals to delineate the spatial extent of freshwater lens for Kiebu Village (Annex 6).

An average of the freshwater lens thicknesses for the main groundwater resource determined from the EM34 survey was used to calculate the estimated freshwater lens volume. A specific yield of 0.3 for coral sand was assumed to calculate the available groundwater volume that could be abstracted. A summary of groundwater resources underlying the village is presented in Table 22.

It is clear that hydrogeological potential of atoll sediments beneath Kiebu Village is not conducive for fresh groundwater storage – this is as expressed by the high bulk conductivity response and the yielded freshwater lens estimates of 0 metres.

Some uncertainty should be noted in the estimated lens extent as determined from the EM34 surveys. Greater uncertainty in these estimates arises from:

- limited access in some areas due to *bwabwai* pits and dense vegetation restricting survey; and
- time constraints, resulting in planned survey lines not being completed.

The thickness and areal extent of the freshwater lens and associated calculations in Table 22 are based on the survey and ground conditions present at the time of the investigation. Although the freshwater lens thickness is likely to vary over time in response to alternating wet and dry periods, it is unlikely that there will be any significant change on the mapped freshwater lens beneath Kiebu, to yield usable groundwater.

Table 22. Summary of estimated groundwater resources underlying Kiebu Village.

Village	Kiebu
Total land area (m^2)[1]	871,370
Maximum island width (m)[2]	500
RAINFALL RECHARGE[3]	
Average annual rainfall recharge (m/yr)	1.750
Minimum recorded annual rainfall recharge (m/yr)	0.351
2030 predicted annual rainfall recharge (m/yr)	1.942
FRESHWATER LENS[4]	
Freshwater lens area (m^2)	0
Average freshwater lens thickness (m)	0
Lens/Total land ratio	0%
Freshwater lens area > 6 m thick (m^2)	0
Average freshwater lens thickness (m)	0
Lens/total land ratio freshwater lens > 6 m thick	0%
AVAILABLE FRESHWATER ESTIMATION[5]	
Freshwater lens volume (m^3)	0
Available groundwater (m^3)	0
Freshwater lens volume > 6 m thick (m^3)	0
Available groundwater for lens > 6 m thick (m^3)	0

Notes:

[1]the total land area covered by the EM34 survey,

[2]maximum island width estimated from the MapInfo (GIS)

[3]areas having lens thickness equal or greater than 2.5 m, after KAPII (GWP, 2011),

[3]rainfall recharge considers Falkland's rainfall/recharge ratio of 26% (Section 3.3) and takes into account the long-term annual average, minimum annual and the estimated 5% increasing rainfall proposed by the Australian Bureau of Meteorology & CSIRO (2011).

[4] freshwater lens is delineated by selecting all estimated freshwater thickness greater than or equal to 2.5 m, whereas a proposed drought-resilient zone is mapped around areas having the estimated freshwater thickness more than 6 m (Based on the 5-5.5 m drought-induced potential reduction in freshwater-lens thickness,

[5]freshwater lens volume = average freshwater lens thickness x lens area, groundwater volume represent the usable groundwater based on the assumed specific yield of 0.3 for coral sands (Falkland, 2003)

5.2.2 Residence time and sustainable yield estimation

Residence time is an expression of the time taken for water to move through the lens, and can be calculated by dividing the volume of groundwater in the lens by the total annual rainfall recharge (Vacher et al., 1990).

The thickness of the freshwater lens influences the residence time of the groundwater. Residence time is estimated to be 0 years for Kiebu Village based on the poor groundwater potential estimated from the EM34 survey (Table 22).

The sustainable yield is a term often used for planning and management purposes to estimate the range or maximum limit to which abstraction should be restricted to ensure water at sufficient quantity and quality for the social, environmental and economic considerations of the aquifer over the long term.

Sustainable yield in an atoll environment is often restricted to considering the needs of society with the greatest abstraction being for domestic needs, including drinking, washing, cooking and household animals. Agriculture and irrigation is limited and little has been done on the needs and considerations of groundwater dependent environments in atolls. As a first estimate sustainable yield can be calculated as a percentage of the recharge for the lens area.

Falkland (2003) provides the following:

$y = x - 10$

whereby

x = recharge (% of rainfall)

y = sustainable yield (% of recharge)

For Makin, rainfall recharge is estimated using the approach of Falkland (2003) at 56% indicating that sustainable yield is estimated to be 46% of the average annual recharge, or 26% of the annual average rainfall. This approach would appear to be conservative.

A comparison was made between the estimated sustainable yield for Bonriki water reserve using the Falkland (2003) approach, and the modelled sustainable yield for Bonriki after Alam et al. (2002), see Table 23. (Note that Betio rainfall was used for both cases as this is what was used in the Alam et al. (2002) groundwater model).

Table 23. Analysis of previous sustainable yield work by Falkland (2003) and Alam et al. (2002).

	Estimated sustainable yield (after Falkland, 2003)	Modelled sustainable yield (after Alam et al., 2002)
Betio Annual rainfall (mm)	2021 (1984-2013)	1812 (1954-1991) 40% tree cover 1791 (1954-2001) 20% tree cover
Recharge mm/yr	712	926 (Using Watbal program) 980 (Using Watbal program)
Recharge as a % of rainfall	35%	47% (1954-1991) 40% tree cover 50% (1954-2001) 20% tree cover
Sustainable Yield as a % of recharge	SY = 35 – 10 = 25%	SY modelled = 1600 m^3/day = 56% (1954-2001) 20% tree cover
Sustainable Yield as a % of rainfall	9%	28%

Table 23 allows for a comparison between two approaches, estimated and modelled, for the same aquifer, the Bonriki water reserve. The recharge and corresponding estimated sustainable yield as a percentage of rainfall is determined using Falkland (2003) to be 9% of rainfall, while the calculated sustainable yield using the modelling results from Alam et al. (2002) is calculated to be 28% of rainfall – the modelled result being three times the result from the Falkland (2003) methodology.

The Bonriki water reserve in the ensuing 12 years after using the modelled sustainable yield from Alam et al. (2002) has operated successfully with abstraction (on average) slightly above the modelled sustainable yield at about 1700 m^3/day during the period 2002-2014. This suggests that the 'estimated' approach to sustainable yield is likely to be quite conservative and is suggested could be used as the lower estimate of a sustainable yield range.

It is recognised that the Bonriki freshwater lens is a relatively large freshwater lens compared with the other freshwater lenses in the Gilbert Islands. Taking into account the variable sizes of freshwater lenses it is considered prudent to also be conservative in suggesting an upper estimate of the sustainable yield to be twice the 'estimated' sustainable yield for each village water reserve using the Falkland (2003) approach. For larger freshwater lenses, similar in size to Bonriki, this upper estimate could be extended to 2.5 times the 'estimated' sustainable yield.

The resulting range of 'estimated' sustainable yield is useful for planning in the longer-term development of the groundwater resources.

The estimated sustainable yield (m^3/day) for Kiebu village and theoretical sustainable yield per capita in 2010 are summarised in Table 24.

Based on the maximum water demand of 65 L/p/d (Falkland & White, 2009), the poor freshwater lens potential is unable to support the daily demand of the Kiebu Village's current population.

5.2.3 Lens vulnerability to anthropogenic contamination, drought, population growth and climate change

a) Anthropogenic contamination

Intrinsically, freshwater lenses in atoll environments are susceptible to contamination because of the shallow depth to groundwater. The commonly observed contamination sources include pig pens, *bwabwai* pits, poorly sited and constructed sanitation systems, and general household activities such as washing and waste disposal. The E.coli sampling results indicate a large extent of well water contamination. The sampling notes the extent of anthropogenic contamination observed in wells at the time of survey. Unchecked, the contamination of wells has the potential to increase as populations in the villages increase and well design and construction remain unchanged. Contamination of water sources such as groundwater environments that populations are located immediately above is inevitable. Measures to reduce the impact of contamination and increase awareness of the impact of the anthropogenic influences are required to help communities with their own self-management of the groundwater system. These include, but are not limited to, the relocation of contaminant sources to a nominal separation distance of at least 20 m from the wells.

b) Drought

Extended dry periods will result in stress to the freshwater resources in atoll environments in much shorter timeframes than seen in other aquifer systems, in part due to limited storage. The freshwater lens will shrink in response to reduced rainfall and recharge. Long-term monitoring of rainfall, abstraction and the lens thickness will assist in determining the impact on the lens and the capacity of the freshwater lens to provide groundwater of suitable salinity for domestic purposes. Monitoring and modelling of the impact of drought on the Bonriki water reserve and freshwater lens in Tarawa, based on drought conditions from the 1998-2000 observations, predicted a lens reduction in thickness by between 5 m and 5.5 m (Falkland, 2003). These suggest that areas with a freshwater thickness of 6 m or more provide some drought resilience.

The drier season for rainfall is generally from May to November, with an average dry season rainfall being 1543 mm, based on monthly rainfall from 1955 to 2014. The lowest recorded annual rainfall was recorded in 1955, with 1405 mm.

Using these dry-period parameters, the average recharge will reduce to 417 mm (56% of rainfall) and 351 mm for the dry months and for the lowest annual rainfall, respectively.

Table 22 clearly shows that the freshwater lens beneath Kiebu Village is unable to support the approximate daily water demand of 65 L/p/d of the current population. Significant rainwater harvesting improvements will be needed to warrant increased freshwater storage/conservation and ensure water security.

c) Population growth

Table 24 shows that Kiebu Village, with an increased population projected for 2030, is likely to experience severe groundwater shortage because of the hydrogeological constraints. It is recommended that significant rainwater harvesting strategies and improvements be implemented for water conservation and security reasons (Section 4.2).

d) Climate change

The rainfall predictions for Kiribati under models of future climate indicate that wet seasons, dry seasons and annual average rainfall will increase in the coming years (Australian Bureau of Meteorology and CSIRO, 2011). This suggests that an increase in recharge for the groundwater systems can be expected overall. The distribution of this rainfall is not clear, and with increased temperatures, evapotranspiration may also increase.

Falkland and White (2009) have considered applying a 20% reduction in yield for Bonriki by 2030 due to the effects of rising sea level. Following on from this a conservative approach to future sustainable yield is applied to accommodate a 20% reduction in sustainable yield projected for the purposes of planning.

Using the same approach for sustainable yield for the mapped areas of drought resilience (> 6 m of freshwater lens thickness) the sustainable yield per capita estimates are provided in Table 24.

Table 24 (below) indicates that Kiebu Village's poor groundwater potential is unable to support the village's daily potable water needs. Rainwater harvesting, with proper governance and conservation strategies, will provide drinking water to meet both the current and future demands.

These climate calculations, do not take into account:

- the variations in population density, land use and water demand in different parts of the island; and
- future development and subsequent population growth.

Table 24. Estimated sustainable yield considering the current and future population and projected climatic condition.

Village	Kiebu
POPULATION DATA	
2010 population	434
2030 projected population	483
RAINFALL RECHARGE	
Average annual recharge (m/yr)	1.750
2030 predicted annual recharge (m/yr)	1.942
FRESHWATER LENS	
Freshwater lens area (m^2)	0
Average freshwater lens thickness (m)	0.0
RESIDENCE TIME[1]	
Average residence time for freshwater lens (yrs)	0.0
SUSTAINABLE YIELD RANGE[2]	
Sustainable yield range current (m^3/yr)	0
Sustainable yield range 2030 (m^3/yr)	0
Sustainable yield range current per capita L/p/d	0
Sustainable yield range 2030 per capita L/p/d	0

Notes:

[1] residence time estimate = (average freshwater lens thickness x specific yield)/the annual rainfall recharge.

[2] Sustainable yield estimates (m^3/day) = estimated lens area x the calculated sustainable yield (after Falkland, 2003)/365 days. sustainable yield = recharge as a % of rainfall – 10. Sustainable-yield volumetric range considers the measured freshwater-lens area, the long-term annual average rainfall recharge and the minimum annual rainfall recharge, and the calculated sustainable yield as a percentage of recharge. The projected 2030 sustainable volumetric yield uses the predicted 5% increase in rainfall (Australian Bureau of Meteorology & CSIRO, 2011) and the estimated 20% reduction in sustainable yield after (Falkland & White, 2009). The per-capita sustainable yield in the current and 2030 periods uses the 2010 and 2030 populations, respectively. These estimates of sustainable yield are conservative by nature.

5.3 Community Awareness and Consultation

Community consultation and awareness raising meetings were planned for the target community to establish the major water and sanitation problems and/or identify appropriate preferences from the perspectives of the villagers.

The common issues raised at Kiebu Village included the following:

- Brackish groundwater results in the heavy reliance on rainwater.
- Shortage of rainwater is usually experienced once a month when low to no rainfall is received.
- There are three (3) water supply sectors in the village, namely south, north and central. People in the central segment of the village have more water because of increased access to rainwater harvesting facilities near the Catholic Church and *maneaba*.
- There is a need for more water catchments, guttering and storage.
- Concerns over the loss of tank overflow during heavy rainfall events – additional storage is requested to capture this 'lost water'.
- Request for additional storage, such as concrete cisterns, which are found to be more robust than polyethylene tanks, many of which have failed.
- Request on water distribution improvement was made such that the Church should improve water distribution and at the same time retain water for community functions.

The above underscore the heavy reliance on rainwater harvesting and confirm the poor groundwater potential. Hence, significant RWH improvements, coupled with appropriate governance strategies, are needed to ensure the usability and availability of rainwater to community members.

See also Annex 11 for village meeting notes.

6.0 WATER RESOURCES DEVELOPMENT OPTIONS

6.1 Existing Water Supplies

A survey of existing water supplies status was undertaken by Falkland in 2003. This was reviewed at the time of this survey and an updated status of the water supply systems is provided in Table 7 for the Kiebu Village.

As previously described (Section 3.4), Kiebu Village heavily relies on rainwater harvesting for both potable and non-potable purposes. Locally-made *Tamana* or hand pumps are not commonly used because of the very thin freshwater lens (Mourits, 1996), which is strongly supported by the poor freshwater lens potential estimated from the EM34 survey. A solar pump installed near the Health Clinic was non-operational.

Rainwater harvesting is commonly practised on Makin around existing communal buildings, namely churches and *maneaba*, because of the extremely limited groundwater potential.

6.2 Freshwater Development Options

Options for improved water supplies from groundwater and rainwater sources have been considered based on accessibility to water sources and existing infrastructure with consideration given to sustainability, reasonable construction and maintenance costs, social acceptance and gender appropriateness.

6.2.1 Rainwater harvesting

Community buildings, such as *maneaba* and churches, often have permanent roofing with substantial roof catchment areas, and are focal points for the community, making them ideal RWH centres. The proposed target communal buildings for RWH are listed in Table 19 with suggested infrastructural improvements. Designs proposed for RWH systems have been developed in consultation with the Government of Kiribati, villages and with recent practitioners. Refer to KIRIWATSAN Technical Notes on Water Supply Design Principles (Sinclair et al., 2015).

6.3 Groundwater Development

6.3.1 Household well improvements

This option is designed to target the standard improvement and protection of household wells. For Kiebu Village, this option may be considered for the community well as it can be periodically accessed for fresh groundwater, even though the areal groundwater potential is extremely limited. General features of improved groundwater abstraction systems are outlined in Section 4.3.4. Design features for a standard well used at the household level are provided in the KIRIWATSAN Technical

Notes on Water Supply Design Principles (Sinclair et al., 2015). Consideration can also be given to constructing new wells as per the standard guidelines provided in Sinclair et al. (2015) near rainwater harvesting facilities to capture tank overflows. These wells will act as additional storages, which will be beneficial for the community. Formal agreements will be needed to ensure the continued access of these wells by community members.

Note that it is recommended that all drinking water should first be boiled.

6.4 Groundwater Protection

To keep the groundwater abstracted from community well as safe as possible, it is recommended that groundwater protection zones be established around the groundwater abstraction areas. Formalised agreements with communities and landowners will be required to allow continued access; the clearance of vegetation; and the restriction of certain land use practices (e.g. siting of cemeteries and latrines; wastewater disposal; and certain agricultural usage such as pig pens and *bwabwai* pits), to minimise any potential groundwater contamination.

6.5 Sanitation Design Options and Improvements

The shallow groundwater found in many atoll islands of Kiribati is easily affected by certain land-use practices including poor sanitation options. The survey of wells in Kiebu in this study shows that one of the surveyed wells is located within 20 m of an identified contamination source – and that almost all (80%) of the sampled rainwater tanks showed the presence of E.coli in the water supply.

The 2010 census data indicate a growing preference by the community for pit and flush toilets. The census data also indicate that a sizable portion of surveyed households (33%) still practise open defecation. It is appropriate to use this growing awareness for improved sanitation and the recent success of compost toilets in Tuvalu to recommend it for use in the outer islands of Kiribati, which shares similar coral atoll environment challenges with Tuvalu. It is well established that inappropriately designed and sited pour-flush systems will only further exacerbate the groundwater contamination issues of coral atoll environments, contributing to WASH-related diseases.

The selection of appropriate sanitation should also consider the hydrogeological conditions, cultural preferences and affordability of the improved system.

The underlying hydrogeological system is characterised by:

- coarse textured surficial coral sand underlain by porous and moderately fractured limestone;
- shallow water table;
- relatively permeable unconfined aquifer; and
- low hydraulic heads and gradients controlling groundwater movement, depending on the volume and frequency of groundwater abstraction.

These characteristics of the groundwater system suggest that the installation of pit and improperly designed septic toilets has the potential to permit the growth and transmission of pathogens. This, coupled with ambient temperature, moisture content and hydraulic conductivity, will influence the travel time and residence time of pathogens (Dillon, 1997), creating conditions which are favourable for the extended survival and transport of pathogens.

A suitable sanitation design for atoll environments, such as compost toilets, should be considered. As trialled on Christmas Island (Depledge, 1997), it is proposed that dry compost toilets, which utilise dry vegetation to assist decomposition, with adequate aeration vent and urine separator, are suitable and can be successfully introduced as seen in Tuvalu (*"Falevatia: A toilet for our future"* http://www.pacific-iwrm.org/videos/Tuvalu-GEF-IWRM-Composting-Toilets.html).

Common factors contributing to the success of introducing an improved sanitation system include:

- widespread community consultation, education and awareness will be needed to ensure its acceptance in communities and the associated behavioural change.
- Toilets are designed to meet the people's expectations of improvement to their situation.
- Efforts are made to ensure that the technology is affordable for outer island communities.
- Additional benefits to health and agricultural productivity are promoted.

An initial design that has been modified after the success in Tuvalu is proposed and will be considered for implementation in Phase II.

6.6 Water System Management

6.6.1 Village Water Action Plan (VWAP)

Due to the nature of the proposed water supply system, the operation, maintenance and management of each system is best conducted at village and household levels.

A "Village Water Action Plan" ("VWAP" or "the action plan") is considered an appropriate approach for promoting a village-oriented approach. The action plan approach, developed after the Makin WRA survey, is designed by the village to formalise arrangements within the community to permit the protection, operation and sustainable management of water supply systems. The plan should reflect the initiative, support and commitment of each target village to address and eliminate long-standing issues of access; management; operation; maintenance; ownership and responsibility; and fundraising. The VWAP will ideally become a living document and is suggested that it address or include the following:

i. Selection of water supply options, agreed with the community.
ii. Agreed procedure for operation and maintenance of water supply infrastructure.
iii. Nominated caretakers to routinely conduct maintenance.
iv. Accessibility of water supply facilities through:
    a. formal consent of landowners for the conversion of their heritage land into a water reserve for village water supply; and

b. formal agreements for church leaders and *Unimwane* for usage and accessibility of churches' and *maneaba* communal rainwater harvesting centres.

v. Agreed method and schedule of revenue generation, be it communal fundraising activities or household levy collection, to permit the procurement of spare parts and routine maintenance.

vi. Proposed penalties for deliberate water supply damage or failure to meet agreed water management rules.

The action plan can be used as an indicator for the community-based management and governance system, and can be used as a guideline within which the nominated village water committee should operate.

As no village water action plan has been formulated for the villages in Makin, it is suggested that a specific phase of community consultation at Kiebu Village be undertaken prior to any infrastructure assistance. The consultation should target different segments of the village, including youth and women, as well as religious leaders to permit the adequate community participation and support for the village action plan.

6.6.2 Water resources monitoring

The monitoring of freshwater on the island is critical to determine the localised extent of climate variability, expressed through the spatial and temporal changes in groundwater salinity and depth to water level. Guidelines on groundwater and rainwater monitoring in the outer islands (Loco et al., 2015, in prep.) identify the types of monitoring activity and approach for freshwater resource development and management.

A network of wells, selected across the island for periodical and long-term monitoring, will be needed and this will require adequate logistical support, including transport, technical equipment (salinity meters and calibration solutions), and storage of data. Recording the impact of drought and extreme wave or tidal events on the monitoring bores will further assist with understanding the impact to the groundwater resources from these extreme events.

Quantitative microbiological assessment (Annex 7) should also be considered to be conducted on selected wells and rainwater tanks, preferably on six monthly to annual basis, and could be undertaken by the WEU staff with assistance from island water technicians. This could be incorporated as a future training and management programme.

7.0 RECOMMENDATIONS

1) Standard well improvements are recommended for the community well as well as those proposed to be constructed near rainwater harvesting facilities to capture tank overflow during heavy rainfall events.

2) Rainwater harvesting improvements of target communal buildings would augment water storage and conservation for Kiebu Village and meet the expectations and preferences of villagers for increased access to rainwater resources. This will include the construction of concrete cistern for increased freshwater storage and availability. Rainwater harvesting should be considered for communal buildings, where formal agreement between community members and property owners over access to stored rainwater is in place.

3) Periodical groundwater monitoring of wells at selected locations on Makin Island is recommended to provide important information on the variance of groundwater quality over time. Guidelines on the selection and monitoring of wells are provided in Loco et al., (2015). In addition, repeated EM34 geophysical surveys would be useful to indicate variations in the lens over time.

4) Introduction of appropriate sanitation options is essential to the long-term development and health of the communities. Composting toilets are the most appropriate sanitation. The introduction of composting toilets will require extensive community consultation and awareness to ensure that this option is socially and culturally accepted and that the technology is made affordable.

5) It is recommended that another round of community awareness and engagement meetings be conducted to finalise and formalise the Village Water Action Plan prior to any infrastructural assistance. This will be used to confirm the proposed water and sanitation designs that will be considered and ensure that the communities agree to support, safeguard and protect all water supply improvements.

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9.0 ANNEXES

A UNICEF project in partnership with the European Union and SPC for Kiribati

Water and Sanitation in the Outer islands of the Republic of Kiribati (KIRIWATSAN)

MAKIN ATOLL, KIRIBATI

Annex 1. Survey Schedule around Makin Island

Annex 2. Historical Monthly Rainfall Data

Annex 3. Groundwater Well Field Survey Sheet

Annex 4. Rainwater Harvesting Field Survey Sheet

Annex 5. E.coli Collilert-18 Procedures and Makin Survey Results

Annex 6. Village Water Resources Assessment Maps

Annex 7. E.coli Compact Dry Plate and Filtration Membrane Sampling Procedure

Annex 8. EM34 Geophysics Principles and Survey Results

Annex 9. Village CTD Diver Data

Annex 10. Rainwater Harvesting Analysis Calculator and Results

Annex 11. Village Meeting Notes

Annex 12. Selection of Survey Photos

Annex 1

Survey Schedule around Makin Island

This annex presents the water resources assessment schedule around Makin Island as discussed and agreed upon between the Island Council OIC and the SPC survey team.

Table A1-1. Survey schedule around Makin Island between 25th and 28th October 2012.

Date	Village	Activities
25/10/2012		Team travelled to Makin Met with OIC to arrange for logistic needs and discuss assessment plan
26/10/2012	Kiebu	Conducted groundwater well assessment, rainwater harvesting survey and & EM34 geophysics
27/10/2012	Kiebu	Conducted groundwater well assessment, rainwater harvesting survey and & EM34 geophysics Community consultation meeting
28/10/2012		Team travelled to Butaritari

Annex 2

Historical Monthly Rainfall Data

This annex provides the historical monthly rainfall data for Makin Island, together with a basic statistical summary.

Table A2-1. Historical monthly rainfall data on Makin Island from 1955-2014 (with gaps).

Makin	J60700		LAT	01 49N		LONG	173 01E		HT 3M				
RAINFALL		**MILLIMETRES**											
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1955	35	89	118	247	166	65	105	201	170	67	137	5	849
1956	67	103	242	695	264	203	331	137	245	240	56	132	1254
1957	269	135	511	537	563	599	385	168	216	97	399	309	2844
1958	208	334	276	629	647	370	303	290				395	2512
1959	35	532	907	388	386	141	342	148	86	226	233	337	2543
1960	1072	257	274	378	173	180	334	89	64	151	90	353	1981
1961	237	421	116	109	129	99	129	199	74	23	229	253	2022
1962	409	295	240	348	221	322	487	257	239	93	66	187	1800
1963	365	161	34	44	131	217	340	388	320	312	508	724	2164
1964	370	427	293	133	66	149	171	121	101	34	145	66	1545
1965	307	593	401	583	376	326	265	220	329	203	129	371	3574
1966	208	224	1216	1240	455	139	776	227	226	346	81	422	3121
1967	606	388	208	318	154	456	368	170	150	86	177	326	1577
1968	184	328	74	69	110	86	257	93	220	68	464	200	1615
1969	467	561	304	745	334	363	386	215	267	154	181	415	
1970	161	477	276	467	290	299	218	126	47	18	0	45	2003
1971	82	240	243	132	274	252	321	192	118	134	151	589	
1972	168	201	153	153	385	202	404	183	441	498	234	953	2557
1973	451	500	391	550	485	160	50	0	0	17	40	0	1232
1974	0	207	520	239	277	75	223	62	189	64	79	239	
1975	169	200	180	314		273					75	158	
1976	15	6										515	
1977	302					168	183	110		389	294		
1978			212	464	268	165	97	179	88	81	268	292	

1979	237	186	770	175	438	401	108	346	230	249	308	353	2965
1980	590	385	754	242	321	187	331	274	62	301	249	304	3322
1981	504	471	415	727	308	235	306	198	86	134	136	240	
1982	227	135	177	111	233	207	314	243	108	309	153	196	2205
1983	20	39	31	42	228	310	464	274	69	45	216	153	1563
1984	365	187	221	77	232	177	156	280	165	75	204	111	850
1985	277	297	302	155	177	357	172	214		61	100	318	
1986	392	132	202	253	135	191	279	227	244	251	453	664	1843
1987	246	343	273	264	157	396	118	352	82	134	376	491	3535
1988	316	501	647	433									
1989												129	
1990	705					290	247	336	463	194			
1991-1997													
1998		28	29	123	300	127							
1999			250	213	214	211				102	57		
2000					245	170	120	316	103	152	95		
2001			306		273		379		165	179			
2002			737	191	278	433		306					
2003		298											
2004-2010													
2011	71.7	22.6	195.3	273.3	336.5	475.7	481.3	93.5	363.3			147.8	
2012	331.0	115.3	310.4	350.8	299.4	317.6	566.6	229.6	384.3	275.0	379.4		1560
2013	381.2	289.6	151.6		292.5	206.0	224.6	265.1	141.1	199.4	188.6	409.3	2873
2014	242.6	120.5	434.3	542.4	348.4								4568

Table A2-2. Basic statistical analysis of discontinuous 1955-2014 monthly rainfall.

Months	January	February	March	April	May	June	July	August	September	October	November	December	Total
Mean	292	269	335	341	281	250	290	209	184	166	199	309	**3098**
Standard deviation	216	163	253	249	124	122	149	88	117	116	131	207	**958**
CV*	0.74	0.61	0.76	0.73	0.44	0.49	0.51	0.42	0.64	0.70	0.66	0.67	**0.31**
Maximum	1072	593	1216	1240	647	599	776	388	463	498	508	953	**5560**
Minimum	0	6	29	42	66	65	50	0	0	17	0	0	**1405**
Median	258	249	274	269	274	209	303	214	165	143	177	304	**3198**
No. Years	38	38	40	38	39	40	37	37	34	36	35	35	**28**

***CV: Coefficient of variation = standard deviation/mean, a measure or rainfall variability, the higher the CV the greater the variability from the average**

Annex 3

Groundwater Well Field Survey Sheet

Annex 3 - KIRIWATSAN - Well survey

Island name: ☐☐☐ Team number: ☐ Village Name: ______

Well Number: ☐☐ Name of well owner: ______

Location: of well N: ☐☐ ☐☐ ☐☐☐ Date: ☐☐ / ☐☐ / ☐☐

E: ☐☐☐ ☐☐ ☐☐☐ Time: ☐☐ : ☐☐

Well Characteristics - Record the following information for the household survey. CIRCLE the appropriate response code and ENTER in the box (es) provided

1 Casing Type
1. Cement
2. Coral rock
3. Steel
4. PVC/PE
5. Unlined
6. Other

2 Well Covering
1. None
2. Covered
3. Uncovered
4. Partially covered

3 Well Covering condition
1. None
2. Replace/repair
3. Adequate
4. Good

4 Well Covering Material
1. Cement
2. Coral rock
3. Steel
4. PVC/PE
5. Unlined
6. Other

5 Fencing condition
1. None
2. Replace/repair
3. Adequate
4. Good

6 Fencing material
1. None
2. Steel
3. Timber
4. Other

7 Well Apron
1. None
2. <0.3
3. 0.3-0.8m
4. >0.8m

8 Well Apron Material
1. None
2. Cement
3. Coral rock
4. Timber
5. Other

9 Well Apron Condition
1. None
2. Cracked
3. Adequate

24 No. Of photos taken
Photo nos.

10 Abstraction type
1. None
2. Bucket/tin
3. Tamana pump
4. Diesel or electric pump
5. Solar pump
6. Other

11 Pump Status
1. None
2. Working
3. Not working

12 Use of Water
1. Drinking/cooking
2. Washing/gardening/toilet
3. All of the above
4. Not used

13 No of Households using the well ☐☐

14 No. Of people using the well ☐ ☐☐

15 Sanitation Practice
1. Ikiribati pit toilet
2. Imatang - Pour/flush
3. Beach/Bush
4. Other

16 Distance to toilet (m) ☐ ☐☐

17 Contamination source
1. None
2. latrine
3. Pig Pen
4. Rubbish
5. Vegetation
5. Agriculture
6. Fuel depot
7. Other

18 Contamination distance (m)

19 Internal well diameter (m)

20 Parapet height above ground (m)

21 DTWT from parapet measuring point (m)

22 TD from measuring point (m)

23 Salinity Top mS/cm

24 Salinity Bottom mS/cm

25 Bacteriological sample Yes ☐ No ☐

26 Improvements
1. Fencing
2. improved well cover
3. Concrete Apron
4. Increase well parapet
5. Bucket off ground
6. Replace tamana pmp
7. Remove rubbish
8. Cut vegetation back
9. Clean out well
10. Relocate pig pen
11. Relocate toilet
12. Other

24 Comments

KIRIWATSAN - Well survey

Island name: ☐☐☐ Team number: ☐ Village Name: ____________

Well Number: ☐☐ Name of well owner: ____________

Location: of well N: ☐☐ ☐☐ ☐☐☐ Date: ☐☐ / ☐☐ / ☐☐

E: ☐☐☐ ☐☐ ☐☐☐ Time: ☐☐ : ☐☐

Well Characteristics - Record the following information for the household survey. CIRCLE the appropriate response code and ENTER in the box (es) provided

1 Casing Type
1. Cement
2. Coral rock
3. Steel
4. PVC/PE
5. Unlined
6. Other

2 Well Covering
1. None
2. Covered
3. Uncovered
4. Partially covered

3 Well Covering condition
1. None
2. Replace/repair
3. Adequate
4. Good

4 Well Covering Material
1. Cement
2. Coral rock
3. Steel
4. PVC/PE
5. Unlined
6. Other

5 Fencing condition
1. None
2. Replace/repair
3. Adequate
4. Good

6 Fencing material
1. None
2. Steel
3. Timber
4. Other

7 Well Apron
1. None
2. <0.3
3. 0.3-0.8m
4. >0.8m

8 Well Apron Material
1. None
2. Cement
3. Coral rock
4. Timber
5. Other

9 Well Apron Condition
1. None
2. Cracked
3. Adequate

24 No. Of photos taken ☐
Photo nos. ....

10 Abstraction type
1. None
2. Bucket/tin
3. Tamana pump
4. Diesel or electric pump
5. Solar pump
6. Other

11 Pump Status
1. None
2. Working
3. Not working

12 Use of Water
1. Drinking/cooking
2. Washing/gardening/toilet
3. All of the above
4. Not used

13 No of Households using the well ☐☐

14 No. Of people using the well ☐ ☐☐

15 Sanitation Practice
1. Ikiribati pit toilet
2. Imatang - Pour/flush
3. Beach/Bush
4. Other

16 Distance to toilet ☐ ☐☐

17 Contamination source
1. None
2. latrine
3. Pig Pen
4. Rubbish
5. Vegetation
5. Agriculture
6. Fuel depot
7. Other

18 Contamination distance ☐ ☐☐

19 Internal well diameter (m) ☐ ☐☐

20 Parapet height above ground (m)

21 DTWT from parapet measuring point

22 TD from measuring point

23 Salinity Top mS/cm ☐☐ ☐☐

24 Salinity Bottom mS/cm ☐☐ ☐☐

25 Bacteriological sample Yes ☐ No ☐

26 Improvements
1. Fencing
2. improved well cover
3. Concrete Apron
4. Increase well parapet
5. Bucket off ground
6. Replace tamana pmp
7. Remove rubbish
8. Cut vegetation back
9. Clean out well
10. Relocate pig pen
11. Relocate toilet
12. Other

24 Comments

Annex 4

Rainwater Harvesting Field Survey Sheet

Annex 4 - KIRIWATSAN - RWH survey

Island name: Team number: Village Name:

Building Number: Name of well owner:

Location: Building N: Date: / /

E: Time: :

Record the following information for the household survey. CIRCLE the appropriate response code and ENTER in the box (es) provided

Roof Area

1 Length (m)

2 Width (m)

3 Height (m)

4 **Roof material**

1. Metal
2. Thatch
3. Other

5 **Roof condition**

1. Replace/repair
2. Adequate
3. Good

6 **Building Type**

1. Church
2. Manneba
3. Government
4. Private
5. Other

6 **Fascia board condition**

1. None
2. Replace/repair
3. Adequate
4. Good

7 **Guttering condition**

1. None
2. Replace/repair
3. Adequate
4. Good

8 **Guttering coverage of roof area**

1. <25%
2. 50%
3. 75%
4. 100%

9 **Downpipe condition**

1. None
2. Replace/repair
3. Adequate
4. Good
5. House
6. Other

No. Of photos taken

Photo nos.

10 **Screens on tank entry points**

1. None
2. Replace/repair
3. Adequate
4. Good

11 **Abstraction type**

1. None
2. Tap
3. Bucket
4. Pump
5. House
6. Other

13 **Storage dimensions**

Storage Height Diameter Type

eg Plastic, Cement, Steel, Fibreglass, Wood, Other

Storage Height Width Length

14 **Storage condition**

1. None
2. Replace/repair
3. Adequate
4. Good

15 **Overhanging Vegetation** Yes No

16 **Bacteriological sample** Yes No

17 **Improvements**

1. Fencing
2. Drainage
3. Leaking tap
4. Spring loaded tap
5. Clean Gutters
6. Repair gutters
7. Connect downpipe
8. Connect tank
9. Other

18. Comments

KIRIWATSAN - RWH survey

Island name: ☐☐☐ Team number: ☐ Village Name: ________________

Building Number: ☐☐ Name of well owner: ________________

Location: Building **N:** ☐☐ ☐☐ ☐☐☐ Date: ☐☐ / ☐☐ / ☐☐

E: ☐☐☐ ☐☐ ☐☐☐ Time: ☐☐ : ☐☐

Record the following information for the household survey. CIRCLE the appropriate response code and ENTER in the box (es) provided

Roof Area

1 Length (m)

2 Width (m)

3 Height (m)

4 **Roof material**
1. Metal
2. Thatch
3. Other

5 **Roof condition**
1. Replace/repair
2. Adequate
3. Good

6 **Building Type**
1. Church
2. Manneba
3. Government
4. Private
5. Other

6 **Fascia board condition**
1. None
2. Replace/repair
3. Adequate
4. Good

7 **Guttering condition**
1. None
2. Replace/repair
3. Adequate
4. Good

8 **Guttering coverage of roof area**
1. <25%
2. 50%
3. 75%
4. 100%

9 **Downpipe condition**
1. None
2. Replace/repair
3. Adequate
4. Good
5. House
6. Other

No. Of photos taken ☐

Photo nos.

10 **Screens on tank entry points**
1. None
2. Replace/repair
3. Adequate
4. Good

11 **Abstraction type**
1. None
2. Tap
3. Bucket
4. Pump
5. House
6. Other

13 **Storage dimensions**

Storage	Height	Diameter	Type
			eg Plastic, Cement, Steel, Fibreglass, Wood, Other

Storage	Height	Width	Length

14 **Storage condition**
1. None
2. Replace/repair
3. Adequate
4. Good

15 **Overhanging Vegetation** Yes ☐ No ☐

16 **Bacteriological sample** Yes ☐ No ☐

17 **Improvements**
1. Fencing
2. Drainage
3. Leaking tap
4. Spring loaded tap
5. Clean Gutters
6. Repair gutters
7. Connect downpipe
8. Connect tank
9. Other

18. **Comments**

Annex 5

E.coli Collilert-18 Sampling Procedure and Makin Results

IDEXX Collilert-18 Microbiology Sampling and Preparation and Analysis

1. INTRODUCTION

This is a relatively rapid procedure to determine the presence and/or absence of E.coli and total coliforms in any water source as per the WHO guidelines for drinking water.

2. SAMPLE PREPARATION PROCUDURES:

Selected wells and rainwater tanks were sampled for E.coli bacteria assessment. Samples, collected in screw-cap 100-ml bottles, were abstracted using plastic flasks, attached to stainless steel holders, and unto which nylon ropes are tied. Samples were kept in storage before further sample preparation procedures were conducted at a pre-arranged analysis facility, Island Council Guesthouse. Collilert-18 re-agent capsules were then added to the samples, and subsequently mixed to dissolve. The samples were placed in a controlled storage environment (i.e. 34 °C ± 0.5) for at least 18 hours. After adequate storage, the absence/presences analysis of coliforms was conducted through the observation of colour changes in the samples. A colour change from pale yellow to dark yellow signifies the presence of total coliform in the samples. The presence of E.coli bacteria was determined by exposure under the UV light. E.coli bacteria is deemed present when a sample fluoresced under the UV light, otherwise, the tested bacteria is absent.

3. QUALITY ASSURANCE AND QUALITY CONTROL:

To warrant the compliance of this sampling procedure and to avoid secondary contamination, the following steps were followed:

1. Avoid placing the bailers on the ground to prevent any possible contamination.
2. Holding the bailer via the designated steel handle, and avoid touching the bailer, during the sampling abstraction to prevent any possible contamination.
3. Adequately rinsing the bailers with sampled water, prior to filling to sample bottles.
4. Keeping the storage containers dry as possible.
5. Ensure proper labelling of the sampling bottles to avoid any ambiguity.

4. RESULTS

The results are presented in Table A5-1 below with the location of the sampled wells and rainwater tanks shown in Annex 6.

Table A5-1. E.coli and total coliform analysis results from rainwater tanks in Kiebu Village, Makin.

Village	WellTankNumber	Team	Sample Number	Well/Tank Owner	Type	Date	E.coli	Total coliform
Kiebu	RW001	1	RW1	Catholic Church	RW	27/10/2012	Absent	Absent
Kiebu	RW002	1	RW2	Catholic Church – Cistern	RW	27/10/2012	Present	Present
Kiebu	RW003	1	RW3	Northern *Maneaba*	RW	27/10/2012	Present	Present
Kiebu	RW004	1	RW4	Southern *Maneaba*	RW	27/10/2012	Present	Present
Kiebu	RW005	1	RW5	Community tank – North	RW	27/10/2012	Present	Present

Annex 6

Makin Village Water Resources Assessment Maps

Annex 6 presents the water resources assessment maps for Kiebu Village in Makin, including:

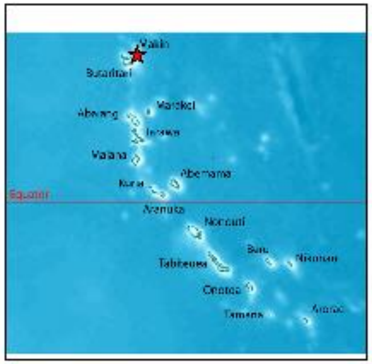
- a survey map showing the locations of buildings, storage tanks, EM34 traverse lines and household wells within the target village area – a distinction is made between freshwater and saline wells based on the 2.5 mS/cm cut-off limit.
- Target rainwater harvesting buildings map showing communal buildings which have potential for rainwater harvesting.
- CTD diver location map showing selected wells in the villages where the data loggers were installed for water level, conductivity and temperature monitoring.
- Freshwater lens map showing the 2.5-m interval freshwater lens contour, with existing saline and freshwater wells to provide constraint for the freshwater body towards the coast.
- Contamination map showing the status of E.coli contamination in tested wells and rainwater tanks (using the compact dry plate filtration membrane procedure) and the estimated freshwater lens contours (as a backdrop) to determine the current status of contamination above and around the projected freshwater body and to aid the community members in the selection of potential groundwater development sites.

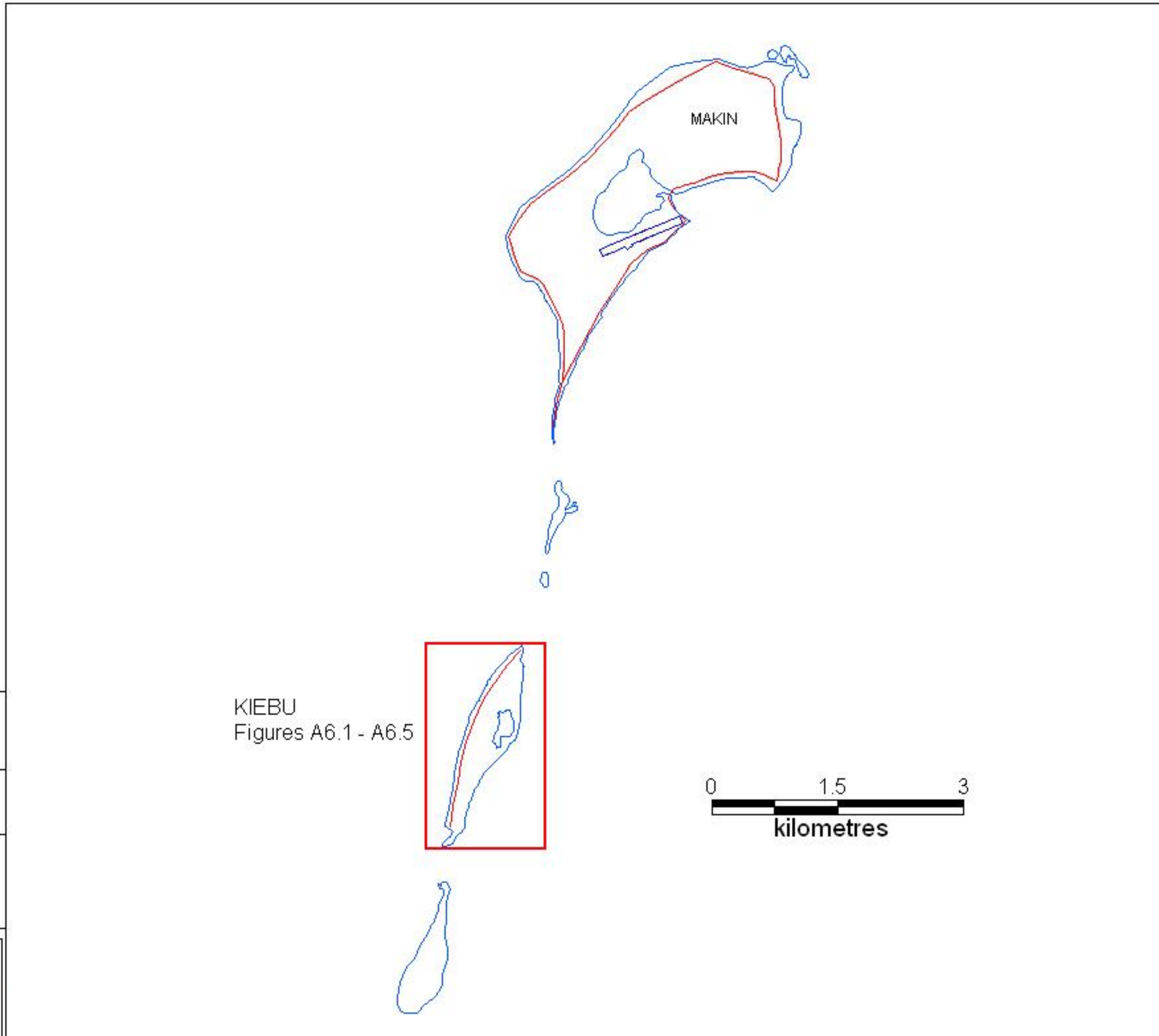
Scalable versions of these maps are available electronically at the following address:

http://ict.sopac.org/kiriwatsan/login/index

Figure A6.0 – MAKIN ATOLL INDEX MAP

GILBERT GROUP





LEGEND:

★ - Makin Atoll

▬ - WRA target villages

NOTES

* index of target village maps

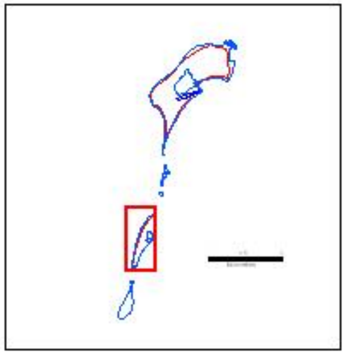
Client: Government of Kiribati

Project: KIRIWATSAN I

Water Resources Assessment
Makin Atoll Index Map

Figure A6.1 – KIEBU, MAKIN – WATER RESOURCES SURVEY MAP

MAKIN ATOLL



LEGEND:

- freshwater wells (salinity <= 2.5 mS/cm)
- saline wells (salinity > 2.5 mS/cm)
- EM34 reading locations
- surveyed rainwater storage tanks
- surveyed buildings

NOTES

* survey was restricted to the target village extent

Client: Government of Kiribati

Project: KIRIWATSAN I

Water Resources Assessment
Kiebu, Makin Atoll

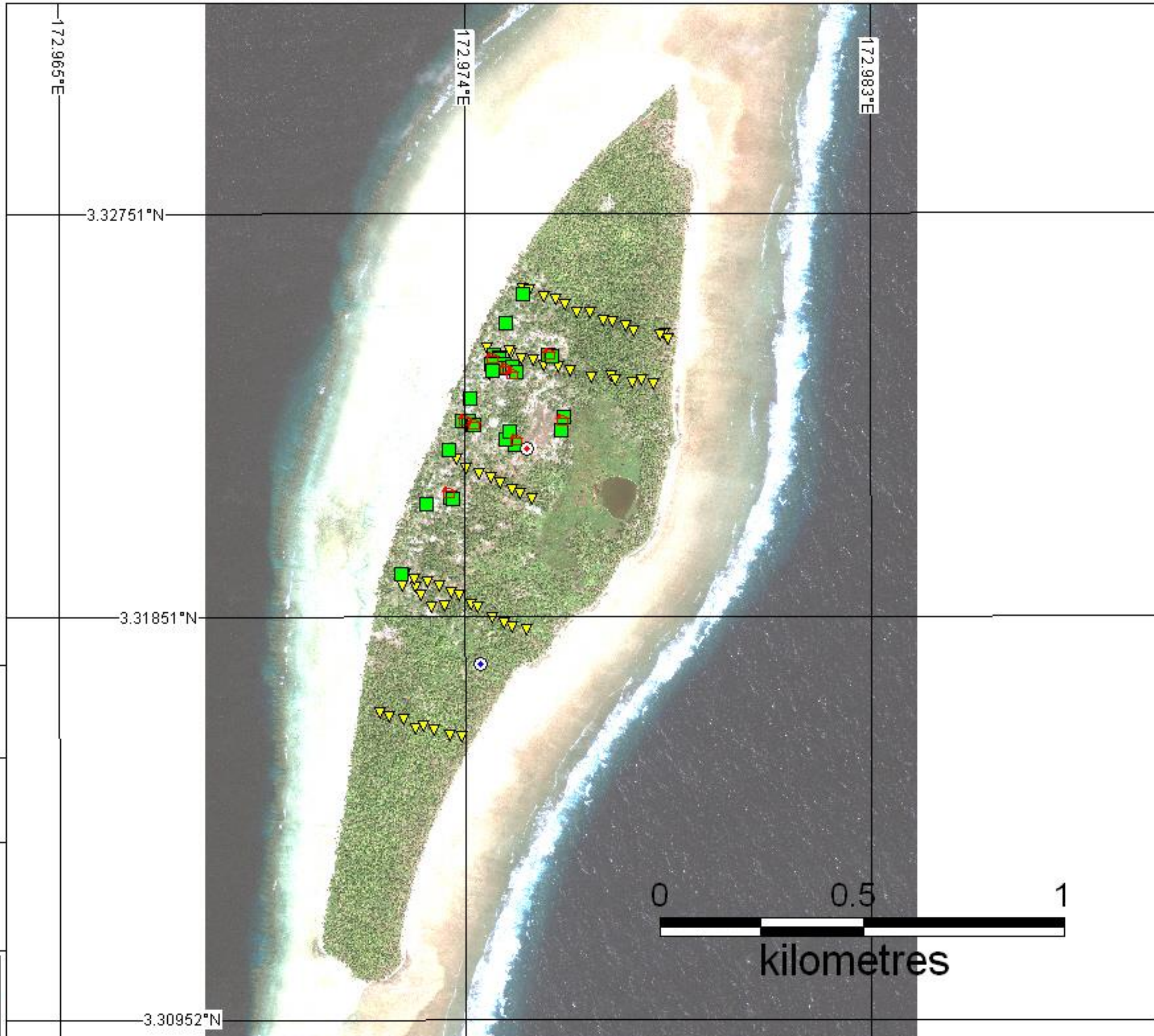


Figure A6.2 – KIEBU, MAKIN – TARGET COMMUNAL BUILDING FOR RWH

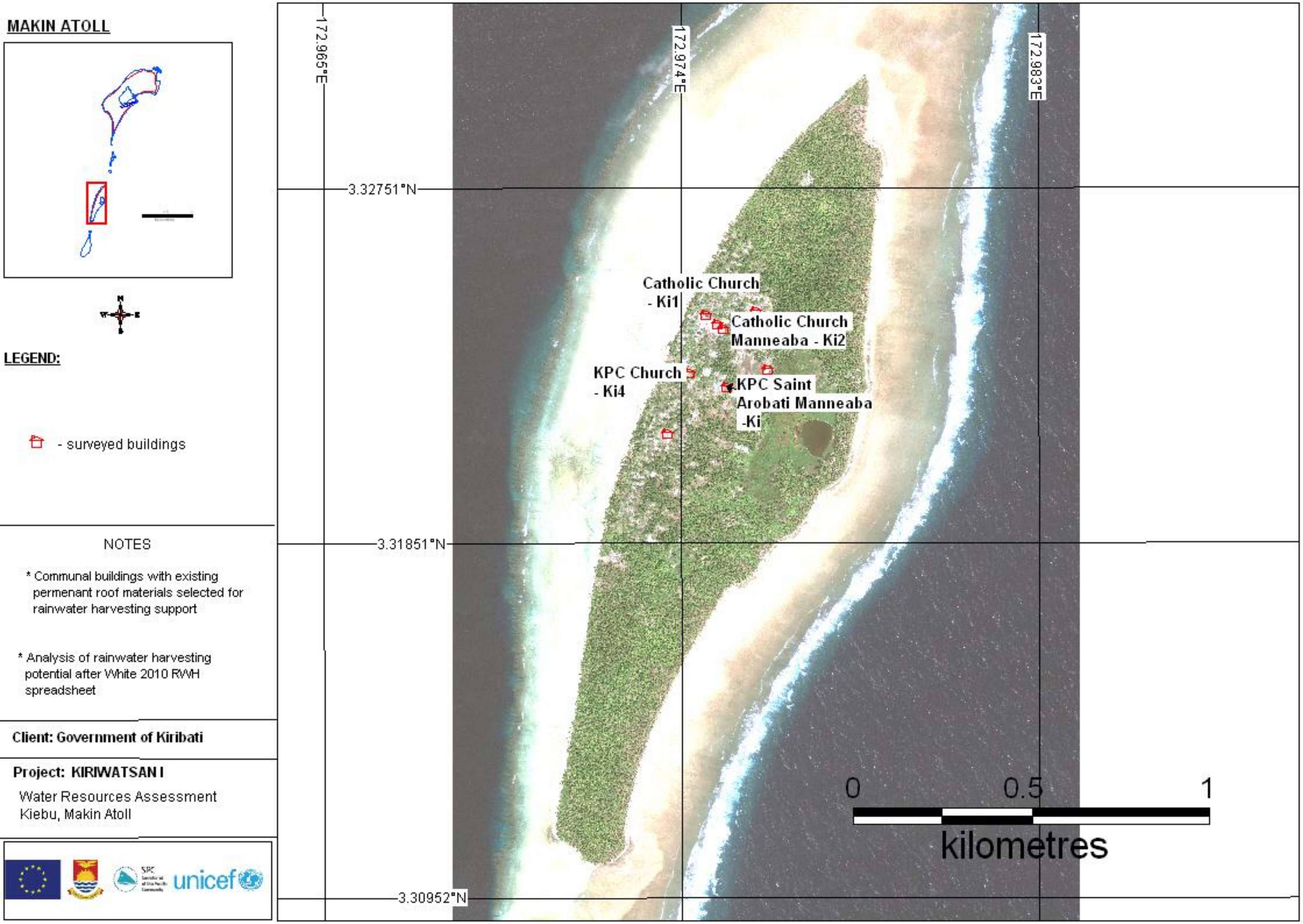


Figure A6.3 – KIEBU, MAKIN – CTD DIVER LOCATIONS

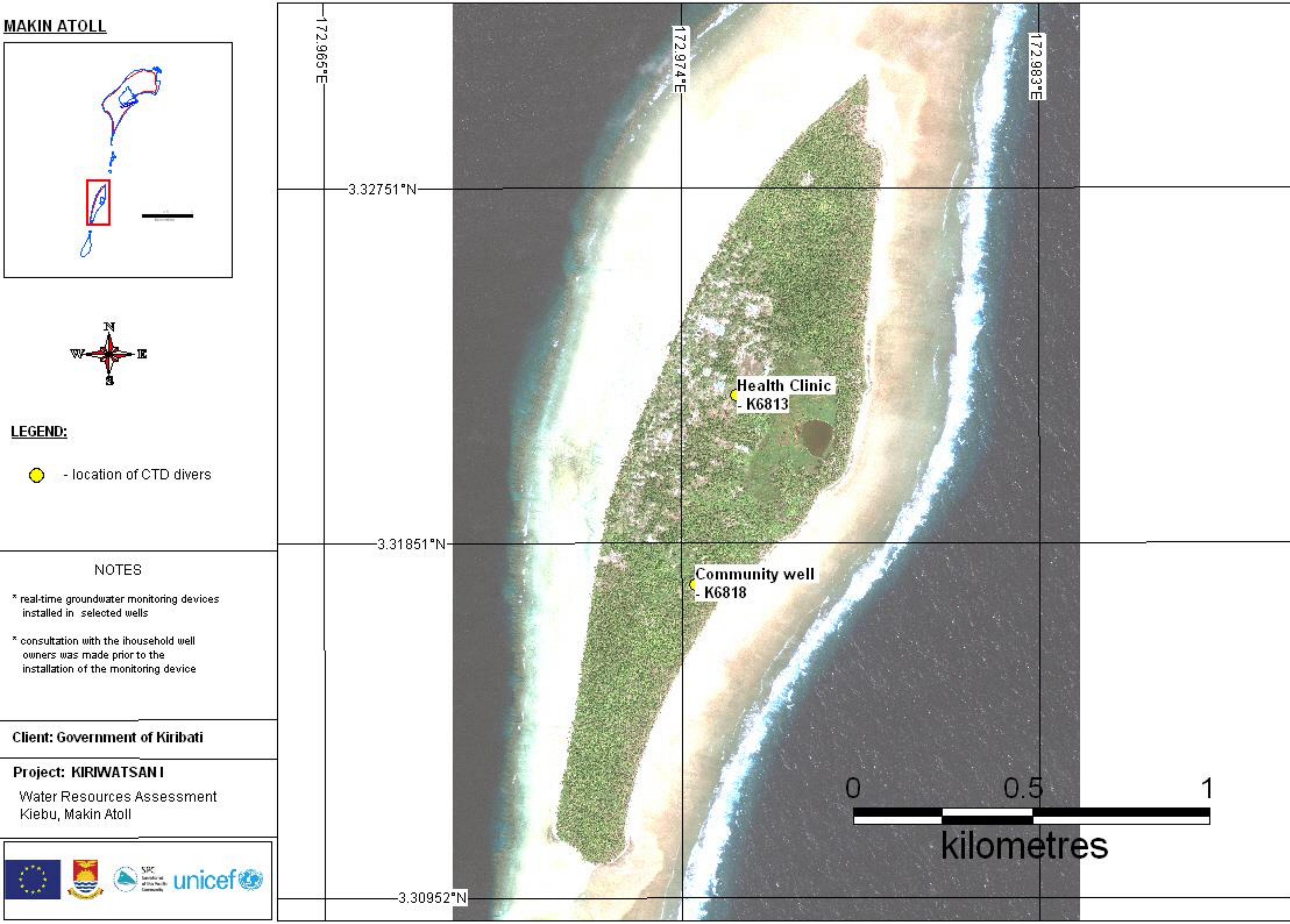
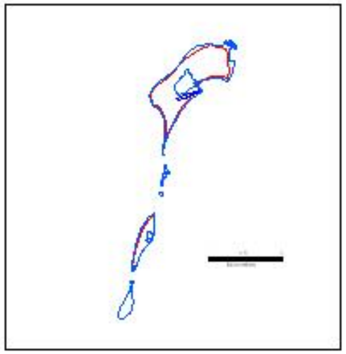


Figure A6.4 – KIEBU, MAKIN – FRESHWATER LENS POTENTIAL

MAKIN ATOLL



LEGEND:

- freshwater wells (salinity <= 2.5 mS/cm)
- saline wells (salinity > 2.5 mS/cm)
- freshwater lens contour (2.5 m interval)

NOTES

* the option and location of water supply development within the village bounds should be confirmed in consultation with the landholders and village council with consideration to freshwater thickness and potential contamination sources

Client: Government of Kiribati

Project: KIRIWATSAN I

Water Resources Assessment
Bubutei, Maiana Atoll

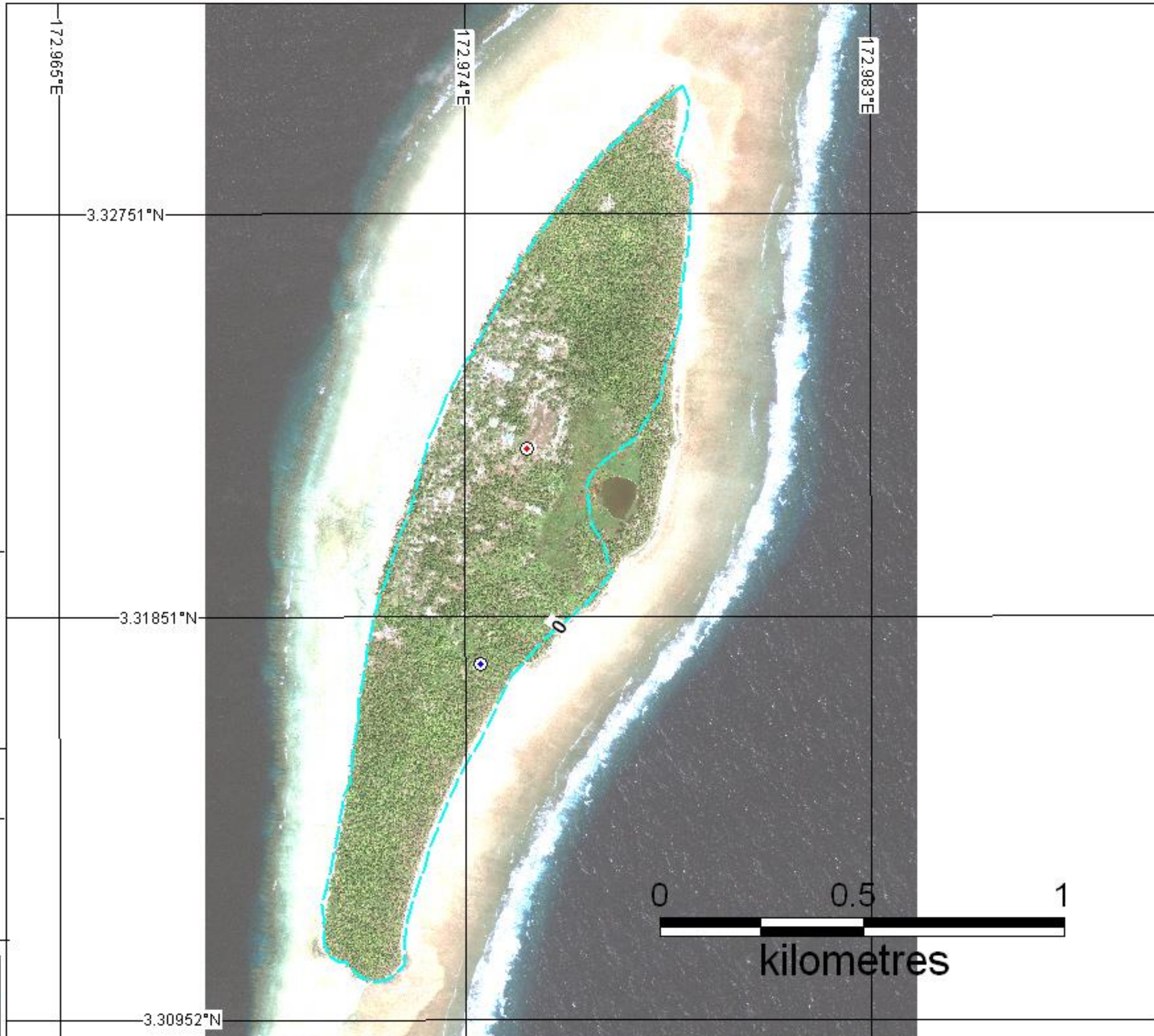
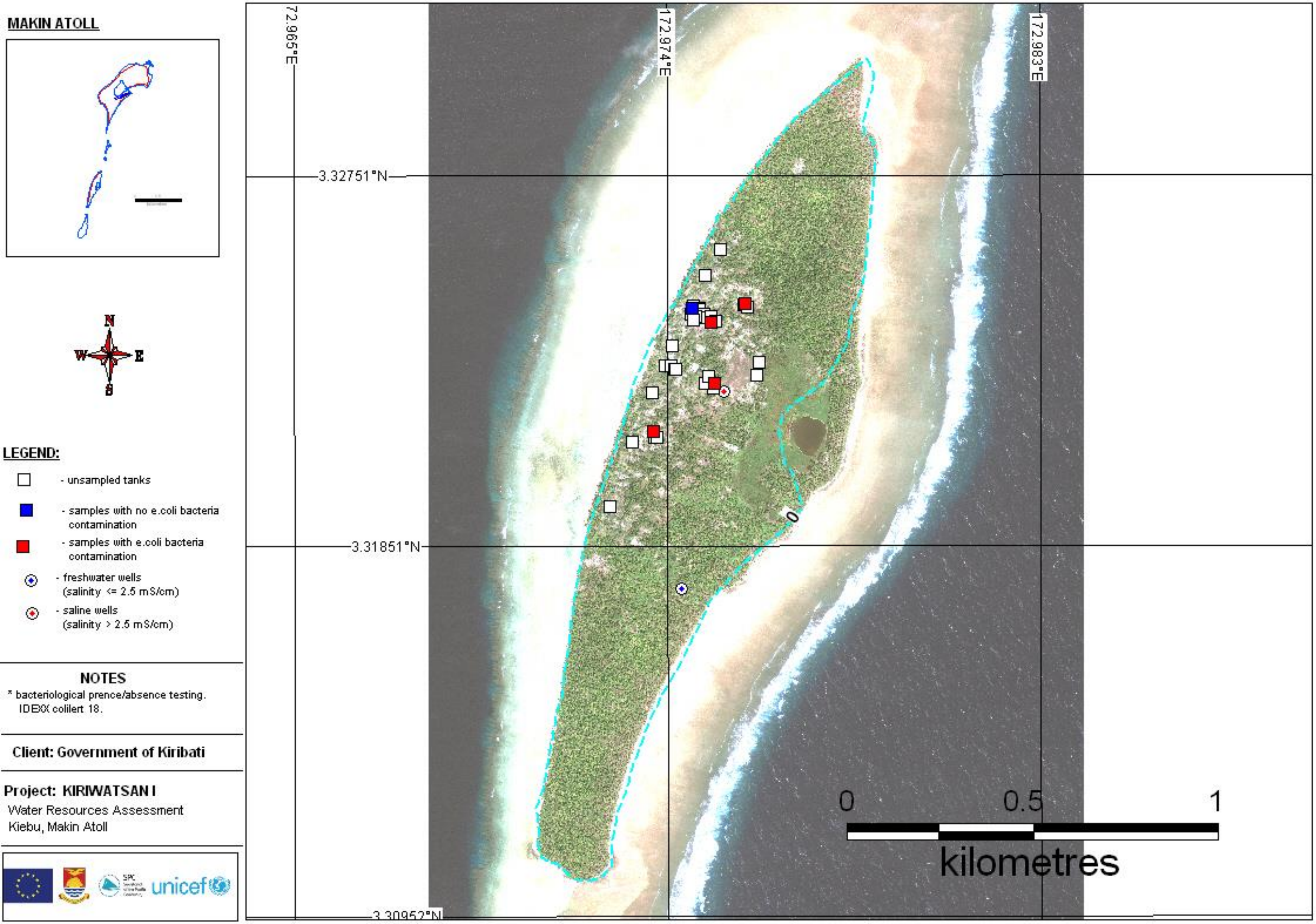


Figure A6.5 – KIEBU, MAKIN – BACTERIOLOGICAL SAMPLING



Annex 7

E-coli Compact Dry Plate and Filtrate Membrane Sampling Procedures

Standard Membrane Filtration Method

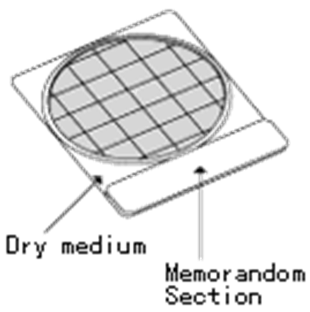
(Adapted from the USA Environmental Protection Agency (EPA) and American Public Health Association methods (APHA) (EPA, 2000; APHA, 1995)

Samples: Collect water samples in sterile bottles (left in boiling water for 10 minutes and cooled) or bottles that have been rinsed three times at the site with well water, rainwater or water to be tested.

Storage: Store samples as cool as possible and in the dark, but not in a freezer. So either in a chilly bin or a bag with cool elements. Samples need to be processed within 12 hours of collection, make sure no melted water comes into contact with the sample.

Equipment:
Need per sample, all sterile (boiled sterile, or three times rinsed with sterile/boiled water between samples):

3 X Compact Dry Plates



These plates contain dehydrated agar that allow the bacteria to grow once rehydrated

1 X 50 ml sterile syringe

1 X 20/15/10 ml syringe

1 X sterile filter housing

2X GN6 Metricell gridded white filters (PallGellman)

Tweezers for filters (not sterile)

Bleach

Sterile/Boiled Water

1X 20/10 ml syringes

Suggested volumes: 1 ml, 10 ml and 50 ml for each sample.

The cleaner the water the more volume you need to filter, never more than 100 ml. If the water is heavily contaminated and you get more than 200 colonies on your 1 ml plate you will need to dilute the sample, e.g. 1 in 10 ml and then filter 1 ml of this (or even 1 in 100 ml). Just remember to add the dilution in your final calculation.

Procedure

1. Field Sampling Procedure

a. Rinse sample bailer three times will sample water before rinsing sample bottles.
b. Fill bottle with sampled water
c. Label sample with water source details (e.g. W001 for well 1 and T001 for rainwater tank 1). Make sure that other relevant details, such as sample collection time, village name and well or tank owner's name is also recorded.
d. Place sample bottle carefully in a cooler box and close lid properly.
e. Samples should be analysed within 12 hours post-sample collection.

2. Pre-sampling procedure (sample bottles sterilisation)

a. Rinse and clean sample bottles thoroughly with clean water (preferably boiled water).
b. Rinse bottles in a covered bucket or cooler box with 5% bleach for at least 30 minutes.
c. Again, rinse bottles thoroughly in boiled water to clean and remove residual bleach.
d. Sanitise your hands with soap before taking the bottles out and drying them using tissue paper.
e. Clean storage container with bleach and boiled water prior to placing the sample bottles inside prior to field visit.

3. Lab Sampling Preparation

<u>Set-up procedures</u>

a. Make sure there is enough boiled water, sterile water and bleach to conduct the whole procedure.
b. Prepare the three sanitised containers for holding boiled water, sterile water and 5% bleach.
c. Prepare a 1 ml, 50 ml and filter housing (all adequately sanitised).
d. Prepare filter papers.
e. Prepare and sanitise a tweezers for transferring filter papers to the filter housing and onto the re-hydrated plates.
f. Prepare and clean a table with bleach and boil water.
g. Prepare tissue papers for drying/cleaning any sample water on the table.
h. Prepare a bucket or container for storing all unused sample water and wastewater.

<u>1 ml sample preparation</u>

a. Label all 1.ml dry compact plates with sample details (e.g. sample number, team number etc.)

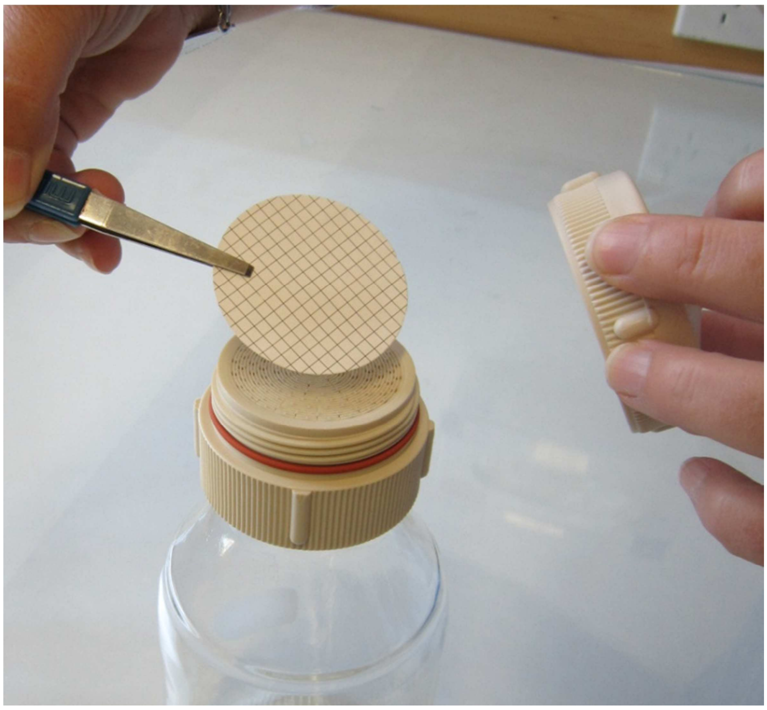
b. Purge 1 ml syringe with boil water before filling and pouring 1 ml sterile water onto the first plate for our 1-ml CONTROL.
c. Rinse the 1 ml syringe thoroughly with boil water (3 times) to clean it before filling it up with sterile water to cool it down.
d. Fill the 1 ml syringe with sample water and the pour the sample into its labelled compact dry plate.
e. Repeat the above, until all samples have been prepared for 1 ml analysis.
f. Store all the rehydrated 1 ml plates in a cooler box and record the incubation start time.

<u>50 ml sample preparation</u>

a. Label all 50 ml dry compact plates with sample details (e.g. sample number, team number etc), including the CONTROL.
b. All plates will need to be rehydrated with 1 ml sterile water prior to placement of sample-rinsed filter papers. (see below)

c. Purge 1 ml syringe with boiled water before filling and pouring 1 ml sterile water onto all labelled dry plates to rehydrate the agar.
d. Fill and rinse the 50 ml syringe with boiled water 3 times. The first rinse should be discharged into the wastewater bucket, while the next two rinses should be run through the filter housing to clean it. Make sure the housing is closed (hand-tight).

e. Rinse the 50 ml syringe now with sterile water and push water through the filter housing to cool both the syringe and filter housing, and at the same time keep filter housing sanitised.
f. Now rinse the 50 ml syringe with the sampled water 3 times. These should dumped in the wastewater bucket.
g. Sanitise the pair of tweezers through 5% bleach and then sterile water. The latter is aimed at removing any residual bleach.
h. Get a filter paper using the sanitised tweezers and place it on the filter housing, place filter (grid side up) on the filter support and close the housing tightly carefully, make sure that the o-ring (orange) is in the correct place (Do not touch the inside of the housing) (See below).



i. Sanitise the tweezers again in bleach and sterile water.
j. Fill the 50 ml syringe with the sample and run this through the filter housing (with the filter paper in). After emptying the syringe, push air through the filter housing (2 or 3 times) to remove any residual water from the filter housing.

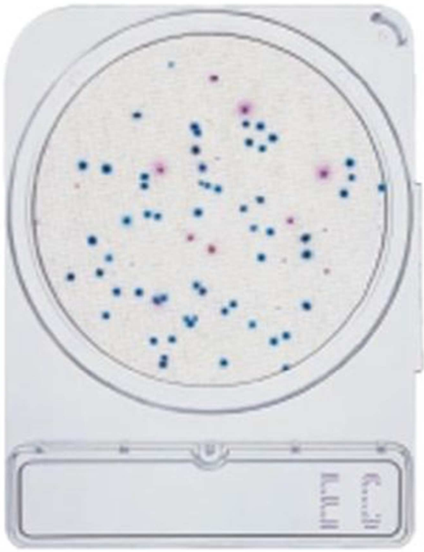
k. Use the sanitised tweezers to transfer the filter paper from the housing to the re-hydrated plate.
l. Repeat steps **d to e** until all samples have been prepared for 50 ml analysis.
m. For the CONTROL, use sterile water, instead of sample water, and subsequent to thoroughly rinsing the syringe and filter housing with boiled and sterile water.
n. Store all the rehydrated 1 ml plates in a cooler box and record the incubation start time.

4. Post sampling procedure

a. Repeat pre-sampling routine to prepare for the next sampling phase

Counting Procedure:

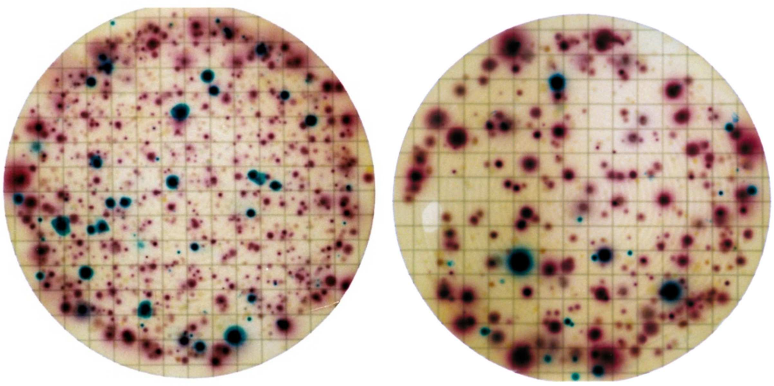
Compact Dry plates: Count the number of red and blue colonies



The number of red and blue colonies = Total Coliforms

The number of blue colonies = *E. coli*

Or the filters on Compact Dry may look like this, again count the number of blue and red colonies.



Note: The left plate would not be counted as there are too many colonies to count (>200).

Count only plates that have between 20-200 colonies on them. If the count is too high count 10 squares randomly on the filter, work out the average per square and multiply by 100 to get a count per filter. This is not a good way of doing it but will give you an estimate from which you can decide what volume you should have filtered. Calculate all your final numbers as bacteria per 100 ml. If you get no growth on 50 ml the result is <1 per 50 ml, you would need to repeat this with 100 ml of new sample as the drinking water standard is 100 ml.

Cleaning of Equipment:

Clean the syringes and filter housing using 5% bleach and then **3** times with boiled water to remove any residual bleach. Then put a large pot of water on the stove to boil. Let this come to the boil and boil it for 10minutes to kill any pathogens in it. Then place the syringes and filter housings in it and boil it for a further 10minutes. Turn of the stove and let the syringes and filter housings cool down in the water with a lid on the pot and remove while they are still warm but as hot as to burn you and place them in a clean plastic container or zip lock bags.

Boiled Water:

Make fresh boiled water each night for the following day of sample processing. Bring a pot of water to the boil and boil continuously for 10 minutes, pour while still hot into a glass bottle, that you have previously cleaned with 5% bleach and rinsed 3 times with boiling water. Let the water cool overnight and use the next day for your sample analysis.

Annex 8

EM34 Geophysics Principles and Kiebu Village Survey Results

Electromagnetic Surveys – EM34 geophysics

1. OBJECTIVE AND BACKGROUND

The use of electromagnetic (EM) geophysical surveys for freshwater lens mapping in atoll environments is well established, being successfully used on Kiribati in recent times Falkland (2004) and GWP (2011a). A Geonics EM34 electromagnetic instrument was used under the current groundwater resource investigations to undertake a rapid assessment of the subsurface ground conductivity, which can be converted to an effective thickness of the freshwater lens.

A good explanation of the EM34 technique is provided by Falkland (2004).

> "The EM34 instrument uses two coils, a transmitter and a receiver, linked by a reference cable. The transmitter and receiver coils, held by two operators, are spaced apart at defined distances of 10 m, 20 m or 40 m using the respective reference cables lengths. The coils can be placed either in a vertical (horizontal dipole) or horizontal (vertical dipole) position. When the transmitter is switched on, it is energised with an alternating current, which generates a primary magnetic field. This time-varying magnetic field induces small currents in the ground that generate a secondary magnetic field. The secondary magnetic field generated depends on the coil spacing, the operating frequency and the ground conductivity. Both magnetic fields are sensed by the receiver coil and a reading of apparent conductivity (or EM conductivity), based on the ratio of the secondary to the primary magnetic fields, is given. The magnitude of the ground conductivity depends on a number of factors (Anthony, 1992). For coral atolls the most important factors are the porosity of unconsolidated sediments and the conductivity of pore-infilling fluids (freshwater or groundwater)".

A guidance note on the use of EM34, including calibration, was thoroughly prepared by GWP, 2011.

2. CALIBRATION

EM34 measurements used to estimate freshwater lens thickness should be calibrated against known freshwater thickness, measured from multi-depth monitoring bores. The relationship between measured EM34 apparent ground conductivity readings and known freshwater lens thicknesses is best represented and interpreted using a logarithmic relationship (Falkland, 2004). Multi-depth groundwater monitoring wells are not available on Makin Island to allow calibration. In the absence of salinity monitoring bores specific to the investigation site, a calibration exercise was conducted at the Bonriki water reserve to approximate the field conditions expected.

One week prior to the survey, field equipment and techniques were tested and reviewed. Salinity readings and water level depths from multi-depth tubes at six (6) selected monitoring bores (BN1, BN2, BN21, BN26, BN27 and BN11) were collected to determine the freshwater lens thickness. EM34 measurements were taken at the boreholes of known salinity, using horizontal dipole (vertical coil alignment) and the 10-m and 20-m coil spacing. The apparent ground conductivity readings are then compared against the measured depth salinity to help determine the relationship between EM apparent conductivity and freshwater lens thickness. The limit of the freshwater lens to which the EM34 readings were calibrated is 2500 µS/cm.

To provide increased confidence in the determination of freshwater lens thickness from the EM34 three (3) calibration datasets were considered to allow comparison between results. These include:

- EM34 readings conducted at boreholes on Abatao, Tabiteuea and Bonriki in October-November during the SAPHE Project 2003 (hereafter referred to as "SAPHE 2003") (Falkland et al., 2003);
- October 2012 results (KIRIWATSAN 2012); and
- The combined KIRIWATSAN & SAPHE.

The resulting logarithmic relationship generated from each set of calibration periods were considered during the analysis to better accommodate the variances in topography, soil, water table depths, hydrogeological conditions and climatic conditions encountered in the Gilbert Island group at the time of the survey.

The three calibration datasets are presented as logarithmic curves and equations which are used to calculate freshwater thickness Figure A8-1 (below).

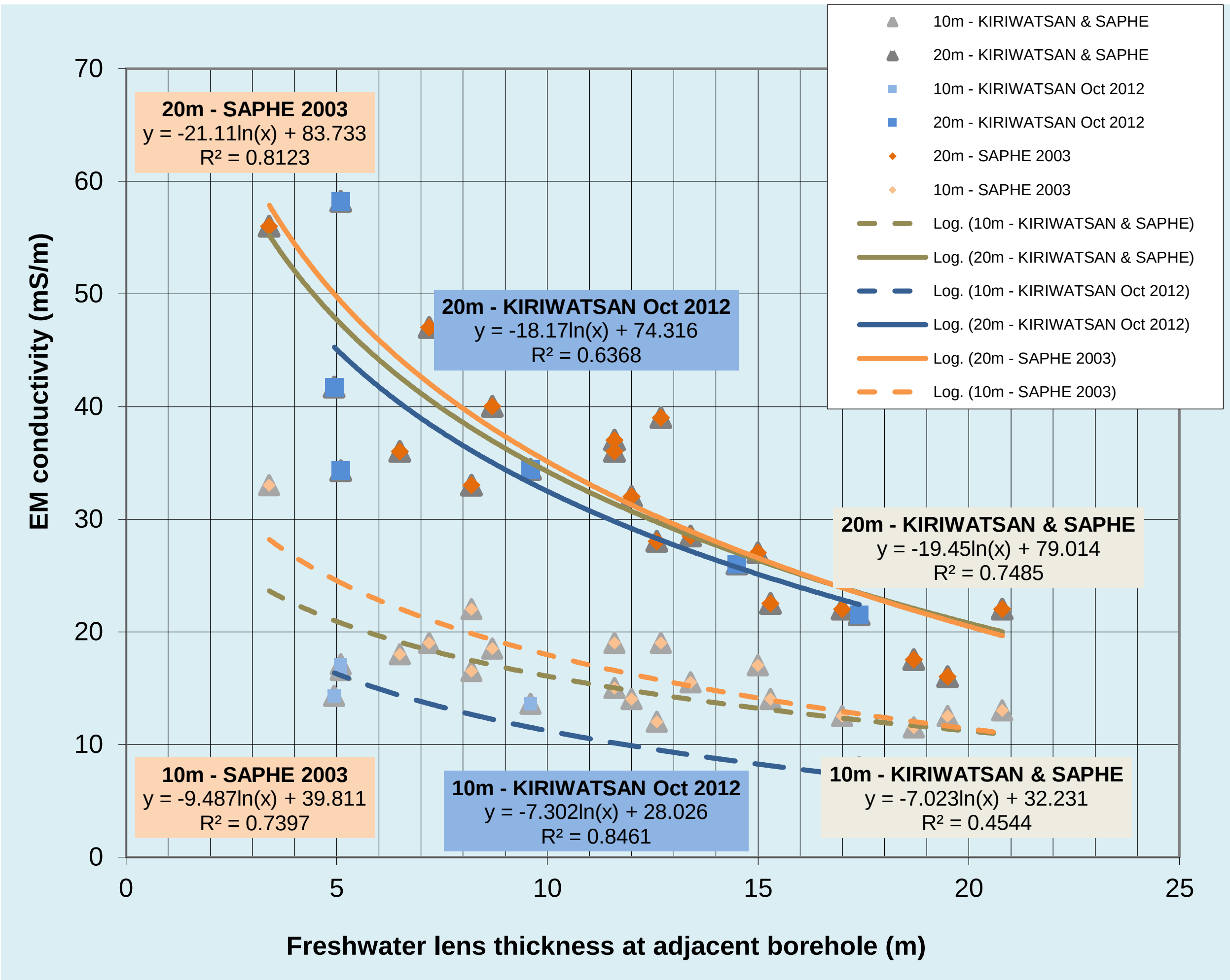


Figure A8-1. Calibration data from (1) SAPHE; (2) KIRIWATSAN; and combined (3) KIRIWATSAN & SAPHE. Note that (3) was used to estimate the freshwater lens thickness for 10-m and 20-m separations.

SAPHE 2003 data shows a good fit for Nov-2003 20-m spacing measurements, expressed by the high coefficient of determination of 0.81 (R^2),whilst the 10-m responses showed slightly more variability and a slightly lower R^2 of 0.74. The 10-m spacing result is effective in exploring areas of shallow depths (< 8 m) whereas the increasing depth of exploration from the 20-m spacing yields minor differences in conductivity measurements, making it more difficult during interpretation (Falkland, 2004 & GWP, 2011a).

KIRIWATSAN data shows a slightly higher trend and slightly more scatter for the 20 m measurements, expressed by a lower slope of -18 and a lower R^2 value of 0.64, in relation to the SAPHE – 20 m. Hence, the 2003 20-m trend appears to be a reasonable fit due to its slightly higher R^2 value. The KIRIWATSAN 10 m, mostly plotted below the 10 m - SAPHE, and shows a slightly lower slope of -7.3 with a slightly higher R^2 value of 0.85. This overall low EM response is attributed to the saturated subsurface condition, which better represents the climatic and ground conditions prevalent during the Makin Island field assessment.

The combined SAPHE-KIRIWATSAN readings provided an average of both the datasets, which generated reasonable trend and R^2 value.

Additional "rules of thumb" or practical guidance notes, used to interpret the freshwater lens thickness at each measurement point include:

- If both the 10-m and 20-m EM34 apparent conductivities estimate the lens to be less than 8 m, the 10-m estimate will be adopted; and
- If both the 10-m and 20-m EM34 apparent conductivities estimate the lens to be more than 8 m the 20-m estimate will be adopted.

3. INTERPRETATION OF RESULTS

The combined SAPHE-KIRIWATSAN logarithmic relationships, shown on Figure A8-1, was used on all 10-m and 20-m field measurements to estimate the freshwater lens thickness, whilst the adopted lens thickness at each survey point was guided by the specific conditions and "rules of thumb". Summary of all the survey lines in the different target villages and the maximum freshwater lens thickness is presented in Table A8-1.

Freshwater lens thicknesses were produced using a 2.5-m contour interval of the ground conductivity indicating groundwater salinity less than 2500 µS/cm, to show the spatial extent and depth variability of freshwater across the target villages. This inferred fresh groundwater resource, can be utilised for resource estimation, planning, development, and management purposes.

Further analysis was conducted to delineate the optimal freshwater zone underneath the target village. This was based on the predicted freshwater lens thickness reduction of 5.5 m using the 1998-2000 drought data of the Tarawa water reserve (Falkland & White, 2009). Consequently, field readings with an estimated lens thickness of 6 m, or more, were classified as optimal and resilient resource, and represent ideal options for sustainable groundwater use and management.

4. SUMMARY OF FINDINGS

In Table A8-1 (below), EM34 provides a useful and rapid assessment on estimates of freshwater lens thickness based on salinity during the time of the survey. For Kiebu Village, it is clear that the fresh groundwater potential of the underlying geological formation is extremely limited and hence, the likelihood of saline intrusion will be moderate to high during extreme climatic conditions. Further, the resulting freshwater lens estimates do not make any inference on the potability of the groundwater or its risk from contamination. Water quality testing is required to determine the likelihood of contamination of the groundwater from faecal sources in any specific area.

The location of EM34 survey lines and the mapped freshwater body are presented in Annex 6.

Table A8-1. Survey results from around Kiebu Village.

Survey location		Field readings		Estimated FW lens thickness			GPS readings		Additional Information	
Waypoint	(m)	10 m reading	20 m reading	10 m estimated lens thickness	20 m estimated lens thickness	Adopted freshwater lens thickness	N degrees	E degrees	Trend	Comments
MTK1X1	0	64.6	132.2	0.0	0.1	0.0	3.325883	172.9752	103	western beach
MTK1X2	30	69.1	130.9	0.0	0.1	0.0	3.325717	172.9754	104	
MTK1X3	60	67.9	127.1	0.0	0.1	0.0	3.3256	172.9757	98	
MTK1X4	90	71.4	131.8	0.0	0.1	0.0	3.325583	172.976	98	
MTK1X5	120	70.9	134.4	0.0	0.1	0.0	3.32545	172.9762	88	start of coconut grove
MTK1X6	150	73.1	137.7	0.0	0.0	0.0	3.325317	172.9764	92	
MTK1X7	180	81.7	144.5	0.0	0.0	0.0	3.325283	172.9768	96	coconut grove
MTK1X8	210	94.3	158.6	0.0	0.0	0.0	3.325067	172.977	92	centre of coconut grove
MTK1X9	240	111.8	170.7	0.0	0.0	0.0	3.325267	172.9772	98	
MTK1X10	270	136.8	189.8	0.0	0.0	0.0	3.325	172.9775	92	
MTK1X11	300	154.1	206.0	0.0	0.0	0.0	3.324883	172.9776	98	coconut grove
MTK1X12	330	91.5	164.1	0.0	0.0	0.0	3.32485	172.9784	92	
MTK1X13	360	70.7	147.0	0.0	0.0	0.0	3.324783	172.9783	92	
MTK1X14	390	123.0	167.6	0.0	0.0	0.0	3.3247	172.9785	96	end, about 10 m away from beach
MTK2X1	0	72.7	146.1	0.0	0.0	0.0	3.324533	172.9745	94	western beach
MTK2X2	30	77.8	143.1	0.0	0.0	0.0	3.324283	172.9747	94	
MTK2X3	60	79.1	145.5	0.0	0.0	0.0	3.324417	172.975	92	
MTK2X4	90	81.8	144.7	0.0	0.0	0.0	3.324283	172.9752	94	
MTK2X5	120	87.3	152.5	0.0	0.0	0.0	3.324233	172.9755	92	start of coconut grove
MTK2X6	150	89.8	153.6	0.0	0.0	0.0	3.324183	172.9757	94	
MTK2X7	180	93.6	156.5	0.0	0.0	0.0	3.324067	172.9761	92	under the pandanus tree
MTK2X8	210	96.2	163.8	0.0	0.0	0.0	3.324017	172.9763	92	
MTK2X9	240	107.4	176.1	0.0	0.0	0.0	3.324	172.9766	90	into the coconut grove
MTK2X10	270	121.5	178.3	0.0	0.0	0.0	3.32365	172.9767	96	about 20 m away from *bwabwai* pit
MTK2X11	300	111.2	175.2	0.0	0.0	0.0	3.323833	172.9771	96	coconut grove

Survey location		Field readings		Estimated FW lens thickness			GPS readings			Additional Information
Waypoint	(m)	10 m reading	20 m reading	10 m estimated lens thickness	20 m estimated lens thickness	Adopted freshwater lens thickness	N degrees	E degrees	Trend	Comments
MTK2X12	330	142.0	191.8	0.0	0.0	0.0	3.323733	172.9777	92	about 20 m away from *bwabwai* pit
MTK2X13	360	123.2	183.4	0.0	0.0	0.0	3.3237	172.9779	88	
MTK2X14	390	123.2	183.4	0.0	0.0	0.0	3.3237	172.9779	88	*bwabwai* pit end, about 20 m away
MTK2X15	420	124.7	184.2	0.0	0.0	0.0	3.323717	172.9781	90	stopped at about 40 m away from the beach
MTK3X1	0	75.6	148.7	0.0	0.0	0.0	3.32205	172.9735	102	western beach
MTK3X2	30	81.2	151.7	0.0	0.0	0.0	3.321933	172.9737	104	
MTK3X3	60	86.0	152.5	0.0	0.0	0.0	3.321817	172.974	102	
MTK3X4	90	83.4	149.0	0.0	0.0	0.0	3.3217	172.9742	98	start, 15 m away from the beach
MTK3X5	120	82.4	150.8	0.0	0.0	0.0	3.321617	172.9745	98	
MTK3X6	150	87.3	155.2	0.0	0.0	0.0	3.3215	172.9747	102	
MTK3X7	180	88.1	156.4	0.0	0.0	0.0	3.321333	172.975	96	
MTK3X8	210	98.5	171.2	0.0	0.0	0.0	3.32125	172.9752	94	
MTK3X9	240	143.8	196.3	0.0	0.0	0.0	3.321133	172.9821	98	stopped 15 m away from the *bwabwai* pit
MTK4X1	0	61.4	135.1	0.0	0.1	0.0	3.319167	172.9725	100	start from the end of the village
MTK4X2	30	67.0	133.2	0.0	0.1	0.0	3.31915	172.9729	104	
MTK4X3	60	68.5	135.5	0.0	0.1	0.0	3.319017	172.973	1O4	
MTK4X4	90	74.1	139.8	0.0	0.0	0.0	3.318733	172.9732	106	
MTK4X5	120	72.1	140.2	0.0	0.0	0.0	3.318717	172.9735	102	stopped about 30 m away from the *bwabwai* pit
MTK5X1	0	74.3	144.3	0.0	0.0	0.0	3.308017	172.9721	92	start about 20 m from the beach
MTK5X2	30	84.2	148.8	0.0	0.0	0.0	3.316267	172.9723	94	
MTK5X3	60	78.8	142.4	0.0	0.0	0.0	3.316183	172.9726	92	
MTK5X4	90	71.0	139.9	0.0	0.0	0.0	3.316017	172.9729	94	
MTK5X5	120	71.4	142.4	0.0	0.0	0.0	3.316083	172.973	92	
MTK5X6	150	78.2	148.6	0.0	0.0	0.0	3.316	172.9732	92	
MTK5X7	180	88.2	160.1	0.0	0.0	0.0	3.31585	172.9736	92	
MTK5X8	210	113.3	174.4	0.0	0.0	0.0	3.315783	172.9739	92	start about 20 m from the beach

Survey location		Field readings		Estimated FW lens thickness			GPS readings		Additional Information	
Waypoint	(m)	10 m reading	20 m reading	10 m estimated lens thickness	20 m estimated lens thickness	Adopted freshwater lens thickness	N degrees	E degrees	Trend	Comments
MTK6X1	0	62.8	130.8	0.0	0.1	0.0	3.319483	172.9726	92	start about 20 m from the beach
MTK6X2	30	65.3	130.6	0.0	0.1	0.0	3.319417	172.9727	92	
MTK6X3	60	67.6	133.0	0.0	0.1	0.0	3.3193	172.9731	92	
MTK6X4	90	68.6	137.2	0.0	0.1	0.0	3.319233	172.9734	96	
MTK6X5	120	77.3	140.3	0.0	0.0	0.0	3.31905	172.9736	104	
MTK6X6	150	78.4	146.1	0.0	0.0	0.0	3.319	172.9738	104	
MTK6X7	180	69.5	141.5	0.0	0.0	0.0	3.318767	172.9741	98	
MTK6X8	210	68.2	137.2	0.0	0.1	0.0	3.318717	172.9742	100	
MTK6X9	240	67.8	139.5	0.0	0.0	0.0	3.318517	172.9745	98	
MTK6X10	270	66.7	139.6	0.0	0.0	0.0	3.318367	172.9747	98	
MTK6X11	300	75.6	149.8	0.0	0.0	0.0	3.3182	172.975	98	*bwabwai* pit 10 m away
MTK6X12	330	96.7	163.0	0.0	0.0	0.0	3.318233	172.9753	100	stopped 25 m from the beach

Annex 8

EM34 Geophysics Principles and Kiebu Village Survey Results

Electromagnetic Surveys – EM34 geophysics

1. OBJECTIVE AND BACKGROUND

The use of electromagnetic (EM) geophysical surveys for freshwater lens mapping in atoll environments is well established, being successfully used on Kiribati in recent times Falkland (2004) and GWP (2011a). A Geonics EM34 electromagnetic instrument was used under the current groundwater resource investigations to undertake a rapid assessment of the subsurface ground conductivity, which can be converted to an effective thickness of the freshwater lens.

A good explanation of the EM34 technique is provided by Falkland (2004).

> “The EM34 instrument uses two coils, a transmitter and a receiver, linked by a reference cable. The transmitter and receiver coils, held by two operators, are spaced apart at defined distances of 10 m, 20 m or 40 m using the respective reference cables lengths. The coils can be placed either in a vertical (horizontal dipole) or horizontal (vertical dipole) position. When the transmitter is switched on, it is energised with an alternating current, which generates a primary magnetic field. This time-varying magnetic field induces small currents in the ground that generate a secondary magnetic field. The secondary magnetic field generated depends on the coil spacing, the operating frequency and the ground conductivity. Both magnetic fields are sensed by the receiver coil and a reading of apparent conductivity (or EM conductivity), based on the ratio of the secondary to the primary magnetic fields, is given. The magnitude of the ground conductivity depends on a number of factors (Anthony, 1992). For coral atolls the most important factors are the porosity of unconsolidated sediments and the conductivity of pore-infilling fluids (freshwater or groundwater)”.

A guidance note on the use of EM34, including calibration, was thoroughly prepared by GWP, 2011.

2. CALIBRATION

EM34 measurements used to estimate freshwater lens thickness should be calibrated against known freshwater thickness, measured from multi-depth monitoring bores. The relationship between measured EM34 apparent ground conductivity readings and known freshwater lens thicknesses is best represented and interpreted using a logarithmic relationship (Falkland, 2004). Multi-depth groundwater monitoring wells are not available on Makin Island to allow calibration. In the absence of salinity monitoring bores specific to the investigation site, a calibration exercise was conducted at the Bonriki water reserve to approximate the field conditions expected.

One week prior to the survey, field equipment and techniques were tested and reviewed. Salinity readings and water level depths from multi-depth tubes at six (6) selected monitoring bores (BN1, BN2, BN21, BN26, BN27 and BN11) were collected to determine the freshwater lens thickness. EM34 measurements were taken at the boreholes of known salinity, using horizontal dipole (vertical coil alignment) and the 10-m and 20-m coil spacing. The apparent ground conductivity readings are then compared against the measured depth salinity to help determine the relationship between EM apparent conductivity and freshwater lens thickness. The limit of the freshwater lens to which the EM34 readings were calibrated is 2500 µS/cm.

To provide increased confidence in the determination of freshwater lens thickness from the EM34 three (3) calibration datasets were considered to allow comparison between results. These include:

- EM34 readings conducted at boreholes on Abatao, Tabiteuea and Bonriki in October-November during the SAPHE Project 2003 (hereafter referred to as "SAPHE 2003") (Falkland et al., 2003);
- October 2012 results (KIRIWATSAN 2012); and
- The combined KIRIWATSAN & SAPHE.

The resulting logarithmic relationship generated from each set of calibration periods were considered during the analysis to better accommodate the variances in topography, soil, water table depths, hydrogeological conditions and climatic conditions encountered in the Gilbert Island group at the time of the survey.

The three calibration datasets are presented as logarithmic curves and equations which are used to calculate freshwater thickness Figure A8-1 (below).

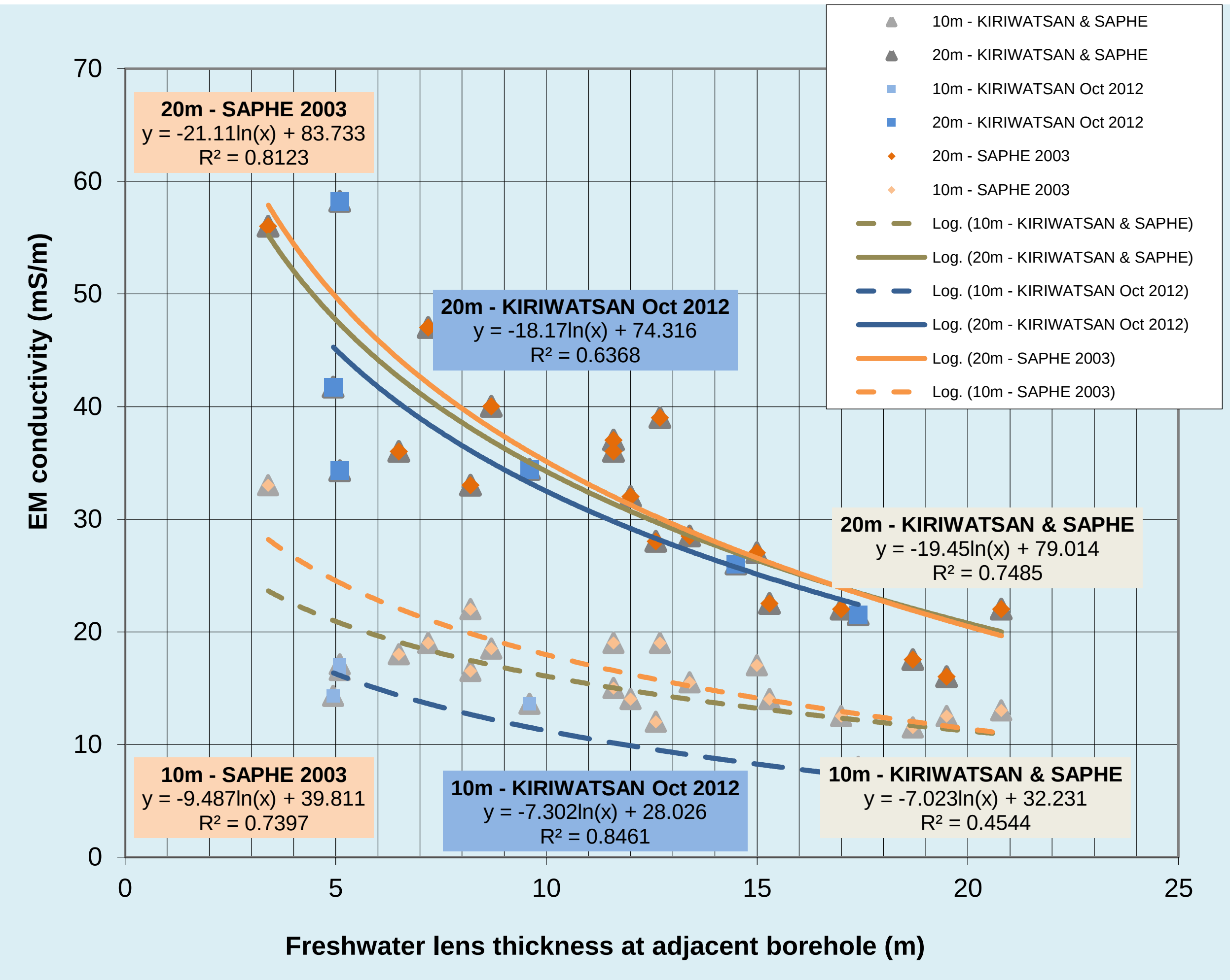


Figure A8-1. Calibration data from (1) SAPHE; (2) KIRIWATSAN; and combined (3) KIRIWATSAN & SAPHE. Note that (3) was used to estimate the freshwater lens thickness for 10-m and 20-m separations.

SAPHE 2003 data shows a good fit for Nov-2003 20-m spacing measurements, expressed by the high coefficient of determination of 0.81 (R^2),whilst the 10-m responses showed slightly more variability and a slightly lower R^2 of 0.74. The 10-m spacing result is effective in exploring areas of shallow depths (< 8 m) whereas the increasing depth of exploration from the 20-m spacing yields minor differences in conductivity measurements, making it more difficult during interpretation (Falkland, 2004 & GWP, 2011a).

KIRIWATSAN data shows a slightly higher trend and slightly more scatter for the 20 m measurements, expressed by a lower slope of -18 and a lower R^2 value of 0.64, in relation to the SAPHE – 20 m. Hence, the 2003 20-m trend appears to be a reasonable fit due to its slightly higher R^2 value. The KIRIWATSAN 10 m, mostly plotted below the 10 m - SAPHE, and shows a slightly lower slope of -7.3 with a slightly higher R^2 value of 0.85. This overall low EM response is attributed to the saturated subsurface condition, which better represents the climatic and ground conditions prevalent during the Makin Island field assessment.

The combined SAPHE-KIRIWATSAN readings provided an average of both the datasets, which generated reasonable trend and R^2 value.

Additional "rules of thumb" or practical guidance notes, used to interpret the freshwater lens thickness at each measurement point include:

- If both the 10-m and 20-m EM34 apparent conductivities estimate the lens to be less than 8 m, the 10-m estimate will be adopted; and
- If both the 10-m and 20-m EM34 apparent conductivities estimate the lens to be more than 8 m the 20-m estimate will be adopted.

3. INTERPRETATION OF RESULTS

The combined SAPHE-KIRIWATSAN logarithmic relationships, shown on Figure A8-1, was used on all 10-m and 20-m field measurements to estimate the freshwater lens thickness, whilst the adopted lens thickness at each survey point was guided by the specific conditions and "rules of thumb". Summary of all the survey lines in the different target villages and the maximum freshwater lens thickness is presented in Table A8-1.

Freshwater lens thicknesses were produced using a 2.5-m contour interval of the ground conductivity indicating groundwater salinity less than 2500 µS/cm, to show the spatial extent and depth variability of freshwater across the target villages. This inferred fresh groundwater resource, can be utilised for resource estimation, planning, development, and management purposes.

Further analysis was conducted to delineate the optimal freshwater zone underneath the target village. This was based on the predicted freshwater lens thickness reduction of 5.5 m using the 1998-2000 drought data of the Tarawa water reserve (Falkland & White, 2009). Consequently, field readings with an estimated lens thickness of 6 m, or more, were classified as optimal and resilient resource, and represent ideal options for sustainable groundwater use and management.

4. SUMMARY OF FINDINGS

In Table A8-1 (below), EM34 provides a useful and rapid assessment on estimates of freshwater lens thickness based on salinity during the time of the survey. For Kiebu Village, it is clear that the fresh groundwater potential of the underlying geological formation is extremely limited and hence, the likelihood of saline intrusion will be moderate to high during extreme climatic conditions. Further, the resulting freshwater lens estimates do not make any inference on the potability of the groundwater or its risk from contamination. Water quality testing is required to determine the likelihood of contamination of the groundwater from faecal sources in any specific area.

The location of EM34 survey lines and the mapped freshwater body are presented in Annex 6.

Table A8-1. Survey results from around Kiebu Village.

Survey location		Field readings		Estimated FW lens thickness			GPS readings		Additional Information	
Waypoint	(m)	10 m reading	20 m reading	10 m estimated lens thickness	20 m estimated lens thickness	Adopted freshwater lens thickness	N degrees	E degrees	Trend	Comments
MTK1X1	0	64.6	132.2	0.0	0.1	0.0	3.325883	172.9752	103	western beach
MTK1X2	30	69.1	130.9	0.0	0.1	0.0	3.325717	172.9754	104	
MTK1X3	60	67.9	127.1	0.0	0.1	0.0	3.3256	172.9757	98	
MTK1X4	90	71.4	131.8	0.0	0.1	0.0	3.325583	172.976	98	
MTK1X5	120	70.9	134.4	0.0	0.1	0.0	3.32545	172.9762	88	start of coconut grove
MTK1X6	150	73.1	137.7	0.0	0.0	0.0	3.325317	172.9764	92	
MTK1X7	180	81.7	144.5	0.0	0.0	0.0	3.325283	172.9768	96	coconut grove
MTK1X8	210	94.3	158.6	0.0	0.0	0.0	3.325067	172.977	92	centre of coconut grove
MTK1X9	240	111.8	170.7	0.0	0.0	0.0	3.325267	172.9772	98	
MTK1X10	270	136.8	189.8	0.0	0.0	0.0	3.325	172.9775	92	
MTK1X11	300	154.1	206.0	0.0	0.0	0.0	3.324883	172.9776	98	coconut grove
MTK1X12	330	91.5	164.1	0.0	0.0	0.0	3.32485	172.9784	92	
MTK1X13	360	70.7	147.0	0.0	0.0	0.0	3.324783	172.9783	92	
MTK1X14	390	123.0	167.6	0.0	0.0	0.0	3.3247	172.9785	96	end, about 10 m away from beach
MTK2X1	0	72.7	146.1	0.0	0.0	0.0	3.324533	172.9745	94	western beach
MTK2X2	30	77.8	143.1	0.0	0.0	0.0	3.324283	172.9747	94	
MTK2X3	60	79.1	145.5	0.0	0.0	0.0	3.324417	172.975	92	
MTK2X4	90	81.8	144.7	0.0	0.0	0.0	3.324283	172.9752	94	
MTK2X5	120	87.3	152.5	0.0	0.0	0.0	3.324233	172.9755	92	start of coconut grove
MTK2X6	150	89.8	153.6	0.0	0.0	0.0	3.324183	172.9757	94	
MTK2X7	180	93.6	156.5	0.0	0.0	0.0	3.324067	172.9761	92	under the pandanus tree
MTK2X8	210	96.2	163.8	0.0	0.0	0.0	3.324017	172.9763	92	
MTK2X9	240	107.4	176.1	0.0	0.0	0.0	3.324	172.9766	90	into the coconut grove
MTK2X10	270	121.5	178.3	0.0	0.0	0.0	3.32365	172.9767	96	about 20 m away from *bwabwai* pit
MTK2X11	300	111.2	175.2	0.0	0.0	0.0	3.323833	172.9771	96	coconut grove

Survey location		Field readings		Estimated FW lens thickness			GPS readings			Additional Information
Waypoint	(m)	10 m reading	20 m reading	10 m estimated lens thickness	20 m estimated lens thickness	Adopted freshwater lens thickness	N degrees	E degrees	Trend	Comments
MTK2X12	330	142.0	191.8	0.0	0.0	0.0	3.323733	172.9777	92	about 20 m away from *bwabwai* pit
MTK2X13	360	123.2	183.4	0.0	0.0	0.0	3.3237	172.9779	88	
MTK2X14	390	123.2	183.4	0.0	0.0	0.0	3.3237	172.9779	88	*bwabwai* pit end, about 20 m away
MTK2X15	420	124.7	184.2	0.0	0.0	0.0	3.323717	172.9781	90	stopped at about 40 m away from the beach
MTK3X1	0	75.6	148.7	0.0	0.0	0.0	3.32205	172.9735	102	western beach
MTK3X2	30	81.2	151.7	0.0	0.0	0.0	3.321933	172.9737	104	
MTK3X3	60	86.0	152.5	0.0	0.0	0.0	3.321817	172.974	102	
MTK3X4	90	83.4	149.0	0.0	0.0	0.0	3.3217	172.9742	98	start, 15 m away from the beach
MTK3X5	120	82.4	150.8	0.0	0.0	0.0	3.321617	172.9745	98	
MTK3X6	150	87.3	155.2	0.0	0.0	0.0	3.3215	172.9747	102	
MTK3X7	180	88.1	156.4	0.0	0.0	0.0	3.321333	172.975	96	
MTK3X8	210	98.5	171.2	0.0	0.0	0.0	3.32125	172.9752	94	
MTK3X9	240	143.8	196.3	0.0	0.0	0.0	3.321133	172.9821	98	stopped 15 m away from the *bwabwai* pit
MTK4X1	0	61.4	135.1	0.0	0.1	0.0	3.319167	172.9725	100	start from the end of the village
MTK4X2	30	67.0	133.2	0.0	0.1	0.0	3.31915	172.9729	104	
MTK4X3	60	68.5	135.5	0.0	0.1	0.0	3.319017	172.973	1O4	
MTK4X4	90	74.1	139.8	0.0	0.0	0.0	3.318733	172.9732	106	
MTK4X5	120	72.1	140.2	0.0	0.0	0.0	3.318717	172.9735	102	stopped about 30 m away from the *bwabwai* pit
MTK5X1	0	74.3	144.3	0.0	0.0	0.0	3.308017	172.9721	92	start about 20 m from the beach
MTK5X2	30	84.2	148.8	0.0	0.0	0.0	3.316267	172.9723	94	
MTK5X3	60	78.8	142.4	0.0	0.0	0.0	3.316183	172.9726	92	
MTK5X4	90	71.0	139.9	0.0	0.0	0.0	3.316017	172.9729	94	
MTK5X5	120	71.4	142.4	0.0	0.0	0.0	3.316083	172.973	92	
MTK5X6	150	78.2	148.6	0.0	0.0	0.0	3.316	172.9732	92	
MTK5X7	180	88.2	160.1	0.0	0.0	0.0	3.31585	172.9736	92	
MTK5X8	210	113.3	174.4	0.0	0.0	0.0	3.315783	172.9739	92	start about 20 m from the beach

Survey location		Field readings		Estimated FW lens thickness			GPS readings			Additional Information
Waypoint	(m)	10 m reading	20 m reading	10 m estimated lens thickness	20 m estimated lens thickness	Adopted freshwater lens thickness	N degrees	E degrees	Trend	Comments
MTK6X1	0	62.8	130.8	0.0	0.1	0.0	3.319483	172.9726	92	start about 20 m from the beach
MTK6X2	30	65.3	130.6	0.0	0.1	0.0	3.319417	172.9727	92	
MTK6X3	60	67.6	133.0	0.0	0.1	0.0	3.3193	172.9731	92	
MTK6X4	90	68.6	137.2	0.0	0.1	0.0	3.319233	172.9734	96	
MTK6X5	120	77.3	140.3	0.0	0.0	0.0	3.31905	172.9736	104	
MTK6X6	150	78.4	146.1	0.0	0.0	0.0	3.319	172.9738	104	
MTK6X7	180	69.5	141.5	0.0	0.0	0.0	3.318767	172.9741	98	
MTK6X8	210	68.2	137.2	0.0	0.1	0.0	3.318717	172.9742	100	
MTK6X9	240	67.8	139.5	0.0	0.0	0.0	3.318517	172.9745	98	
MTK6X10	270	66.7	139.6	0.0	0.0	0.0	3.318367	172.9747	98	
MTK6X11	300	75.6	149.8	0.0	0.0	0.0	3.3182	172.975	98	*bwabwai* pit 10 m away
MTK6X12	330	96.7	163.0	0.0	0.0	0.0	3.318233	172.9753	100	stopped 25 m from the beach

Annex 9

Village CTD Diver Data

This annex presents the salinity and water level records and graphs obtained from selected wells in Kiebu Village using the Schlumberger CTD logging device.

Table A9-1. A summary of the logger data records and calculated tidal lags and efficiencies for Kiebu.

Village	Well Owner	Diver number	Distance from closest water body, ocean or lagoon	Start Date and time	End date and time	Length of record (hrs)	Tidal lag	Tidal efficiency
Kiebu	Health Clinic	K6813		26/10/2012 18:00	27/10/2012 17:00	28	8.42	5%
	Communal well	K6818		26/10/2012 18:45	27/10/2012 15:30	20.75	9.38	8%
Average						24.38	8.90	7%

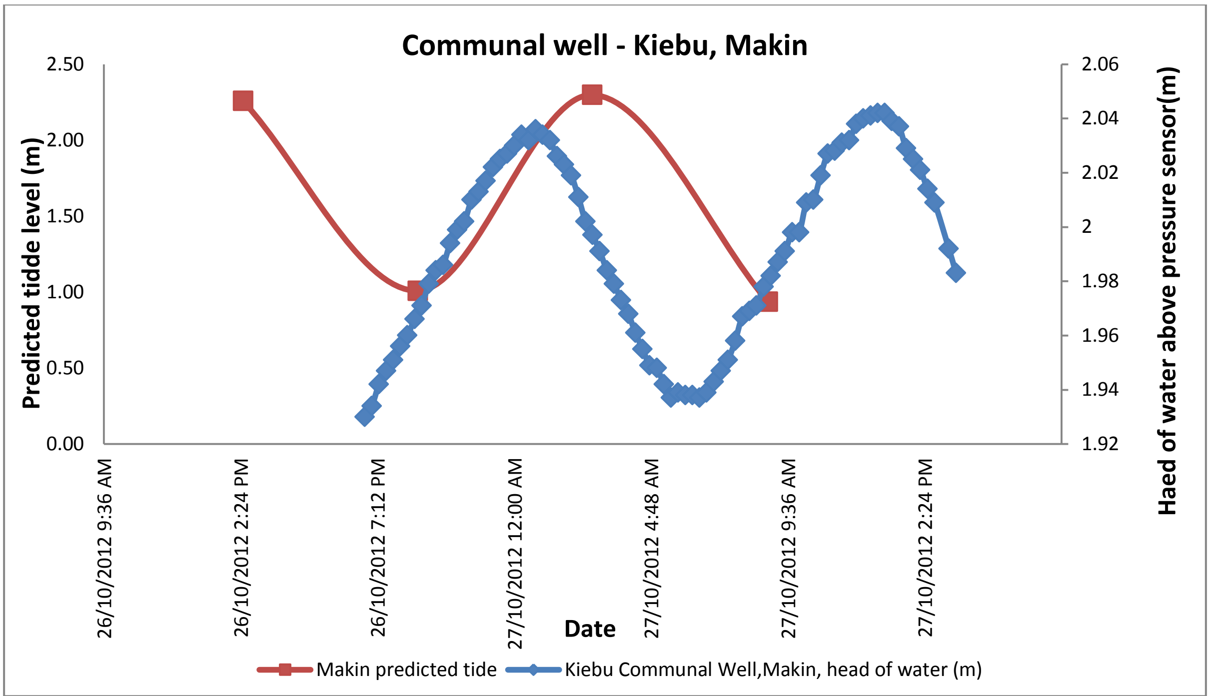


Figure A9-1. Predicted tidal height and measured groundwater level at the community well, at Kiebu Village.

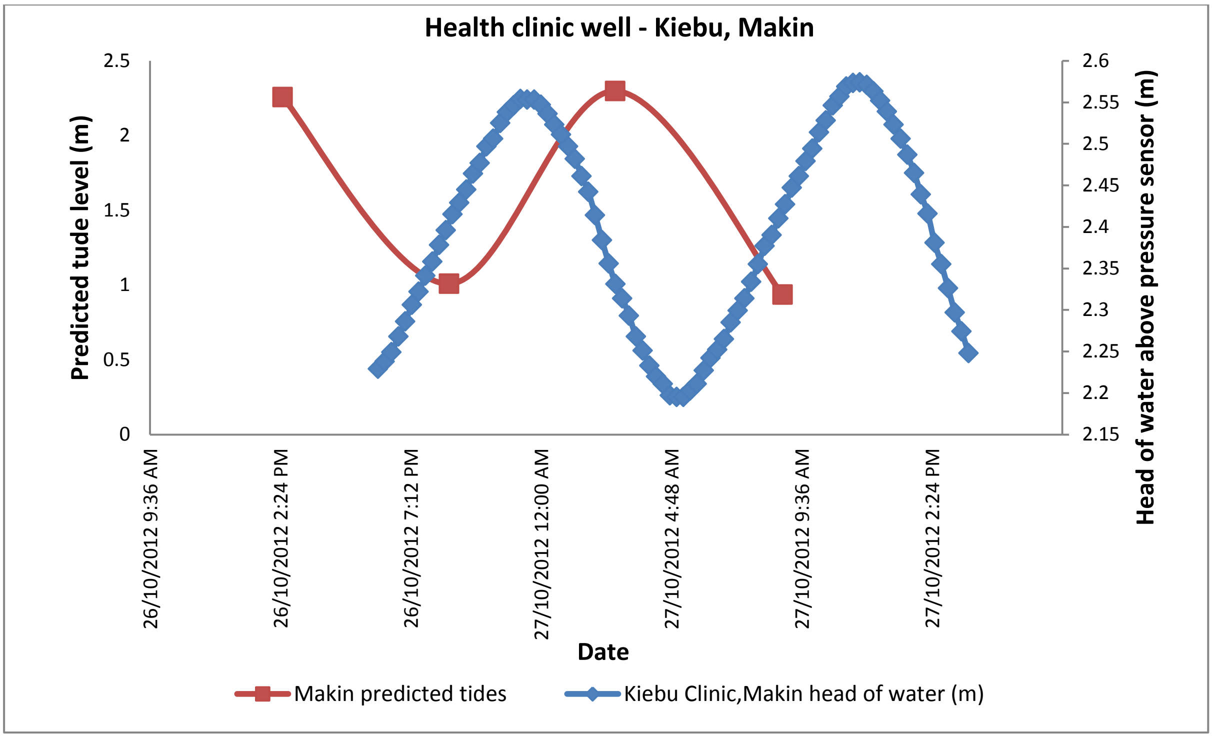


Figure A9-2. Predicted tidal height and measured groundwater level at the Health Clinic well at Kiebu Village.

Annex 10

Rainwater Harvesting Analysis Calculator and Kiebu Village Results

This annex presents the analysis of potential rainwater harvesting centres in Kiebu Village on Makin atoll. The analysis uses White's (2010) rainfall calculator spreadsheet (Table A10-2) and the historical monthly rainfall for Makin Island from January 1955 to May 2014.

Data on roof areas, guttering coverage and condition, and existing storage volumes of all target communal buildings were collected during the KIRIWATSAN field survey.

An effective roof area for each target communal building was calculated based on the approach by White (2010) (see Table A10-1), which considers the collecting roof area and guttering condition to determine the capture efficiency for each building.

Table A10-1. Rainwater harvesting parameters suggested by White (2014)

Attribute	Explanation
Building ID Number	Unique number identifying building
Type of building	Commercial, Community, Government, Other, Residential
Rain Tank Capacity (L)	S = Tank Capacity/1000 (L)
Roof Area (m^2)	A
% Guttering	Percentage of roof edge bordered by guttering
Collecting Roof Area (m^2)	A_{col} = (%Guttering) x A/100
Guttering Condition (Capture Efficiency, C, where ($0 \le C \le 1$))	Good (C = 0.75) Adequate (C = 0.55) Repair (C = 0.35) Replace (C = 0.15)
Effective Roof Area (m^2)	A_{eff} = C x A_{col}

Furthermore, the rainfall calculator (White, 2010) was used to generate estimates of the available water for each selected building based on the following assumptions:

- No change to current roof area.
- Available water per person per day for each scenario considers an equal distribution of calculated available water amongst the entire current and predicted 2030 populations.
- Effective roof area calculated incorporates guttering losses and runoff coefficient, with an input runoff parameter C equal to 1.
- An 84% satisfaction limit was assumed, whereby the rainwater harvesting system would be able to provide the calculated volume of water per person per day for 10 out of 12 months.

The available water for each selected building was calculated for the three scenarios outlined below:

1. Existing building under current catchment and storage conditions with no improvements made.

2. Existing building with fully improved roof catchment infrastructure, i.e. guttering and down pipes are in good condition with a capture efficiency of 0.75 under the existing roof area and storage volume.
3. Existing building with fully improved roof catchment infrastructure, i.e. guttering and down pipes are in good condition with a capture efficiency of 0.75 under existing roof area and each building is supplied with an additional 20,000 L of storage volume.

For each scenario the combined available water that could be supplied for the identified population by all the target buildings was then aggregated to give an estimate of the total available water for both the 2010 and the projected 2030 populations.

It should be noted that in using these rainwater harvesting projections, one needs to be aware of the following basic assumptions by White (2010):

1. Demand is constant irrespective of the remaining volume in the tank.
2. All the interception, evaporation and leakage losses are constant irrespective of rainfall intensity.
3. The capture efficiency is independent of instantaneous rainfall rate.
4. Monthly rainfall is used but the spread of rain over the month is not considered.

Table A10-2. Rainwater calculator created by White (2010) and utilises Makin long-term and discontinuous monthly rainfall from January 1955 to May 2014.

INPUTS

Catchment area	A	500	m2
runoff C	C	1	0.95-0.7
tank vol	S	30000	litres
demand	D	36.5	l/p/d
users	N	100	
month days	dt	30.4333	
initial tank volume		0	

RESULTS

length of record

months	447
years	37

Overflow

average monthly overflow 37,688 litres

Reliability (at end of month t)

% (months) empty	38.7%
% of months demand met	61.3%
% tank full	46.5%

Satisfaction

	84%	of monthly demand met on average
longest	10	months in a row where less than 100% demand is met
dry spell	7	months in a row where less than 60% of demand is met

NB Enter inputs into yellow boxes only. Results displayed depend on catchment area, runoff coefficient, tank volume, demand per person, and number of users

Makin rainfall, Jan-1955 – May-2014 (with gaps)					surplus/deficit	**Storage**							
month-yr	rain	**Runoff (I)**	I + Vt-1	**Total D (O)**	I + Vt - O	0	**overflow**	**% of D**	100%met	run	60%met	run	
Jan-55	35	17500	17500	111082	-93582	0	0	16%	0	0	0	0	
Feb-55	89	44500	44500	111082	-66582	0	0	40%	0	1	0	1	
Mar-55	118	59000	59000	111082	-52082	0	0	53%	0	2	0	2	
Apr-55	247	123500	123500	111082	12418	12418	0	100%	1	0	1	0	
May-55	166	83000	95418	111082	-15663	0	0	86%	0	1	1	0	
Jun-55	65	32500	32500	111082	-78582	0	0	29%	0	2	0	1	
Jul-55	105	52500	52500	111082	-58582	0	0	47%	0	3	0	2	
Aug-55	201	100500	100500	111082	-10582	0	0	90%	0	4	1	0	
Sep-55	170	85000	85000	111082	-26082	0	0	77%	0	5	1	0	
Oct-55	67	33500	33500	111082	-77582	0	0	30%	0	6	0	1	
Nov-55	137	68500	68500	111082	-42582	0	0	62%	0	7	1	0	
Dec-55	5	2500	2500	111082	-108582	0	0	2%	0	8	0	1	
Jan-56	67	33500	33500	111082	-77582	0	0	30%	0	9	0	2	
Feb-56	103	51500	51500	111082	-59582	0	0	46%	0	10	0	3	
Mar-56	242	121000	121000	111082	9918	9918	0	100%	1	0	1	0	
Apr-56	695	347500	357418	111082	246337	30000	216337	100%	1	0	1	0	
May-56	264	132000	162000	111082	50918	30000	20918	100%	1	0	1	0	

Jun-56	203	101500	131500	111082	20418	20418	0	100%	1	0	1	0	
Jul-56	331	165500	185918	111082	74837	30000	44837	100%	1	0	1	0	
Aug-56	137	68500	98500	111082	-12582	0	0	89%	0	1	1	0	
Sep-56	245	122500	122500	111082	11418	11418	0	100%	1	0	1	0	
Oct-56	240	120000	131418	111082	20337	20337	0	100%	1	0	1	0	
Nov-56	56	28000	48337	111082	-62745	0	0	44%	0	1	0	1	
Dec-56	132	66000	66000	111082	-45082	0	0	59%	0	2	0	2	
Jan-57	269	134500	134500	111082	23418	23418	0	100%	1	0	1	0	
Feb-57	135	67500	90918	111082	-20163	0	0	82%	0	1	1	0	
Mar-57	511	255500	255500	111082	144418	30000	114418	100%	1	0	1	0	
Apr-57	537	268500	298500	111082	187418	30000	157418	100%	1	0	1	0	
May-57	563	281500	311500	111082	200418	30000	170418	100%	1	0	1	0	
Jun-57	599	299500	329500	111082	218418	30000	188418	100%	1	0	1	0	
Jul-57	385	192500	222500	111082	111418	30000	81418	100%	1	0	1	0	
Aug-57	168	84000	114000	111082	2918	2918	0	100%	1	0	1	0	
Sep-57	216	108000	110918	111082	-163	0	0	100%	1	0	1	0	
Oct-57	97	48500	48500	111082	-62582	0	0	44%	0	1	0	1	
Nov-57	399	199500	199500	111082	88418	30000	58418	100%	1	0	1	0	
Dec-57	309	154500	184500	111082	73418	30000	43418	100%	1	0	1	0	
Jan-58	208	104000	134000	111082	22918	22918	0	100%	1	0	1	0	
Feb-58	334	167000	189918	111082	78837	30000	48837	100%	1	0	1	0	
Mar-58	276	138000	168000	111082	56918	30000	26918	100%	1	0	1	0	
Apr-58	629	314500	344500	111082	233418	30000	203418	100%	1	0	1	0	
May-58	647	323500	353500	111082	242418	30000	212418	100%	1	0	1	0	
Jun-58	370	185000	215000	111082	103918	30000	73918	100%	1	0	1	0	
Jul-58	303	151500	181500	111082	70418	30000	40418	100%	1	0	1	0	
Aug-58	290	145000	175000	111082	63918	30000	33918	100%	1	0	1	0	
Dec-58	395	197500	227500	111082	116418	30000	86418	100%	1	0	1	0	
Jan-59	35	17500	47500	111082	-63582	0	0	43%	0	1	0	1	
Feb-59	532	266000	266000	111082	154918	30000	124918	100%	1	0	1	0	
Mar-59	907	453500	483500	111082	372418	30000	342418	100%	1	0	1	0	
Apr-59	388	194000	224000	111082	112918	30000	82918	100%	1	0	1	0	
May-59	386	193000	223000	111082	111918	30000	81918	100%	1	0	1	0	
Jun-59	141	70500	100500	111082	-10582	0	0	90%	0	1	1	0	
Jul-59	342	171000	171000	111082	59918	30000	29918	100%	1	0	1	0	
Aug-59	148	74000	104000	111082	-7082	0	0	94%	0	1	1	0	
Sep-59	86	43000	43000	111082	-68082	0	0	39%	0	2	0	1	
Oct-59	226	113000	113000	111082	1918	1918	0	100%	1	0	1	0	

Nov-59	233	116500	118418	111082	7337	7337	0	100%	1	0	1	0	
Dec-59	337	168500	175837	111082	64755	30000	34755	100%	1	0	1	0	
Jan-60	1072	536000	566000	111082	454918	30000	424918	100%	1	0	1	0	
Feb-60	257	128500	158500	111082	47418	30000	17418	100%	1	0	1	0	
Mar-60	274	137000	167000	111082	55918	30000	25918	100%	1	0	1	0	
Apr-60	378	189000	219000	111082	107918	30000	77918	100%	1	0	1	0	
May-60	173	86500	116500	111082	5418	5418	0	100%	1	0	1	0	
Jun-60	180	90000	95418	111082	-15663	0	0	86%	0	1	1	0	
Jul-60	334	167000	167000	111082	55918	30000	25918	100%	1	0	1	0	
Aug-60	89	44500	74500	111082	-36582	0	0	67%	0	1	1	0	
Sep-60	64	32000	32000	111082	-79082	0	0	29%	0	2	0	1	
Oct-60	151	75500	75500	111082	-35582	0	0	68%	0	3	1	0	
Nov-60	90	45000	45000	111082	-66082	0	0	41%	0	4	0	1	
Dec-60	353	176500	176500	111082	65418	30000	35418	100%	1	0	1	0	
Jan-61	237	118500	148500	111082	37418	30000	7418	100%	1	0	1	0	
Feb-61	421	210500	240500	111082	129418	30000	99418	100%	1	0	1	0	
Mar-61	116	58000	88000	111082	-23082	0	0	79%	0	1	1	0	
Apr-61	109	54500	54500	111082	-56582	0	0	49%	0	2	0	1	
May-61	129	64500	64500	111082	-46582	0	0	58%	0	3	0	2	
Jun-61	99	49500	49500	111082	-61582	0	0	45%	0	4	0	3	
Jul-61	129	64500	64500	111082	-46582	0	0	58%	0	5	0	4	
Aug-61	199	99500	99500	111082	-11582	0	0	90%	0	6	1	0	
Sep-61	74	37000	37000	111082	-74082	0	0	33%	0	7	0	1	
Oct-61	23	11500	11500	111082	-99582	0	0	10%	0	8	0	2	
Nov-61	229	114500	114500	111082	3418	3418	0	100%	1	0	1	0	
Dec-61	253	126500	129918	111082	18837	18837	0	100%	1	0	1	0	
Jan-62	409	204500	223337	111082	112255	30000	82255	100%	1	0	1	0	
Feb-62	295	147500	177500	111082	66418	30000	36418	100%	1	0	1	0	
Mar-62	240	120000	150000	111082	38918	30000	8918	100%	1	0	1	0	
Apr-62	348	174000	204000	111082	92918	30000	62918	100%	1	0	1	0	
May-62	221	110500	140500	111082	29418	29418	0	100%	1	0	1	0	
Jun-62	322	161000	190418	111082	79337	30000	49337	100%	1	0	1	0	
Jul-62	487	243500	273500	111082	162418	30000	132418	100%	1	0	1	0	
Aug-62	257	128500	158500	111082	47418	30000	17418	100%	1	0	1	0	
Sep-62	239	119500	149500	111082	38418	30000	8418	100%	1	0	1	0	
Oct-62	93	46500	76500	111082	-34582	0	0	69%	0	1	1	0	
Nov-62	66	33000	33000	111082	-78082	0	0	30%	0	2	0	1	
Dec-62	187	93500	93500	111082	-17582	0	0	84%	0	3	1	0	

Jan-63	365	182500	182500	111082	71418	30000	41418	100%	1	0	1	0	
Feb-63	161	80500	110500	111082	-582	0	0	99%	1	0	1	0	
Mar-63	34	17000	17000	111082	-94082	0	0	15%	0	1	0	1	
Apr-63	44	22000	22000	111082	-89082	0	0	20%	0	2	0	2	
May-63	131	65500	65500	111082	-45582	0	0	59%	0	3	0	3	
Jun-63	217	108500	108500	111082	-2582	0	0	98%	0	4	1	0	
Jul-63	340	170000	170000	111082	58918	30000	28918	100%	1	0	1	0	
Aug-63	388	194000	224000	111082	112918	30000	82918	100%	1	0	1	0	
Sep-63	320	160000	190000	111082	78918	30000	48918	100%	1	0	1	0	
Oct-63	312	156000	186000	111082	74918	30000	44918	100%	1	0	1	0	
Nov-63	508	254000	284000	111082	172918	30000	142918	100%	1	0	1	0	
Dec-63	724	362000	392000	111082	280918	30000	250918	100%	1	0	1	0	
Jan-64	370	185000	215000	111082	103918	30000	73918	100%	1	0	1	0	
Feb-64	427	213500	243500	111082	132418	30000	102418	100%	1	0	1	0	
Mar-64	293	146500	176500	111082	65418	30000	35418	100%	1	0	1	0	
Apr-64	133	66500	96500	111082	-14582	0	0	87%	0	1	1	0	
May-64	66	33000	33000	111082	-78082	0	0	30%	0	2	0	1	
Jun-64	149	74500	74500	111082	-36582	0	0	67%	0	3	1	0	
Jul-64	171	85500	85500	111082	-25582	0	0	77%	0	4	1	0	
Aug-64	121	60500	60500	111082	-50582	0	0	54%	0	5	0	1	
Sep-64	101	50500	50500	111082	-60582	0	0	45%	0	6	0	2	
Oct-64	34	17000	17000	111082	-94082	0	0	15%	0	7	0	3	
Nov-64	145	72500	72500	111082	-38582	0	0	65%	0	8	1	0	
Dec-64	66	33000	33000	111082	-78082	0	0	30%	0	9	0	1	
Jan-65	307	153500	153500	111082	42418	30000	12418	100%	1	0	1	0	
Feb-65	593	296500	326500	111082	215418	30000	185418	100%	1	0	1	0	
Mar-65	401	200500	230500	111082	119418	30000	89418	100%	1	0	1	0	
Apr-65	583	291500	321500	111082	210418	30000	180418	100%	1	0	1	0	
May-65	376	188000	218000	111082	106918	30000	76918	100%	1	0	1	0	
Jun-65	326	163000	193000	111082	81918	30000	51918	100%	1	0	1	0	
Jul-65	265	132500	162500	111082	51418	30000	21418	100%	1	0	1	0	
Aug-65	220	110000	140000	111082	28918	28918	0	100%	1	0	1	0	
Sep-65	329	164500	193418	111082	82337	30000	52337	100%	1	0	1	0	
Oct-65	203	101500	131500	111082	20418	20418	0	100%	1	0	1	0	
Nov-65	129	64500	84918	111082	-26163	0	0	76%	0	1	1	0	
Dec-65	371	185500	185500	111082	74418	30000	44418	100%	1	0	1	0	
Jan-66	208	104000	134000	111082	22918	22918	0	100%	1	0	1	0	
Feb-66	224	112000	134918	111082	23837	23837	0	100%	1	0	1	0	

Mar-66	1216	608000	631837	111082	520755	30000	490755	100%	1	0	1	0	
Apr-66	1240	620000	650000	111082	538918	30000	508918	100%	1	0	1	0	
May-66	455	227500	257500	111082	146418	30000	116418	100%	1	0	1	0	
Jun-66	139	69500	99500	111082	-11582	0	0	90%	0	1	1	0	
Jul-66	776	388000	388000	111082	276918	30000	246918	100%	1	0	1	0	
Aug-66	227	113500	143500	111082	32418	30000	2418	100%	1	0	1	0	
Sep-66	226	113000	143000	111082	31918	30000	1918	100%	1	0	1	0	
Oct-66	346	173000	203000	111082	91918	30000	61918	100%	1	0	1	0	
Nov-66	81	40500	70500	111082	-40582	0	0	63%	0	1	1	0	
Dec-66	422	211000	211000	111082	99918	30000	69918	100%	1	0	1	0	
Jan-67	606	303000	333000	111082	221918	30000	191918	100%	1	0	1	0	
Feb-67	388	194000	224000	111082	112918	30000	82918	100%	1	0	1	0	
Mar-67	208	104000	134000	111082	22918	22918	0	100%	1	0	1	0	
Apr-67	318	159000	181918	111082	70837	30000	40837	100%	1	0	1	0	
May-67	154	77000	107000	111082	-4082	0	0	96%	0	1	1	0	
Jun-67	456	228000	228000	111082	116918	30000	86918	100%	1	0	1	0	
Jul-67	368	184000	214000	111082	102918	30000	72918	100%	1	0	1	0	
Aug-67	170	85000	115000	111082	3918	3918	0	100%	1	0	1	0	
Sep-67	150	75000	78918	111082	-32163	0	0	71%	0	1	1	0	
Oct-67	86	43000	43000	111082	-68082	0	0	39%	0	2	0	1	
Nov-67	177	88500	88500	111082	-22582	0	0	80%	0	3	1	0	
Dec-67	326	163000	163000	111082	51918	30000	21918	100%	1	0	1	0	
Jan-68	184	92000	122000	111082	10918	10918	0	100%	1	0	1	0	
Feb-68	328	164000	174918	111082	63837	30000	33837	100%	1	0	1	0	
Mar-68	74	37000	67000	111082	-44082	0	0	60%	0	1	1	0	
Apr-68	69	34500	34500	111082	-76582	0	0	31%	0	2	0	1	
May-68	110	55000	55000	111082	-56082	0	0	50%	0	3	0	2	
Jun-68	86	43000	43000	111082	-68082	0	0	39%	0	4	0	3	
Jul-68	257	128500	128500	111082	17418	17418	0	100%	1	0	1	0	
Aug-68	93	46500	63918	111082	-47163	0	0	58%	0	1	0	1	
Sep-68	220	110000	110000	111082	-1082	0	0	99%	1	0	1	0	
Oct-68	68	34000	34000	111082	-77082	0	0	31%	0	1	0	1	
Nov-68	464	232000	232000	111082	120918	30000	90918	100%	1	0	1	0	
Dec-68	200	100000	130000	111082	18918	18918	0	100%	1	0	1	0	
Jan-69	467	233500	252418	111082	141337	30000	111337	100%	1	0	1	0	
Feb-69	561	280500	310500	111082	199418	30000	169418	100%	1	0	1	0	
Mar-69	304	152000	182000	111082	70918	30000	40918	100%	1	0	1	0	
Apr-69	745	372500	402500	111082	291418	30000	261418	100%	1	0	1	0	

May-69	334	167000	197000	111082	85918	30000	55918	100%	1	0	1	0	
Jun-69	363	181500	211500	111082	100418	30000	70418	100%	1	0	1	0	
Jul-69	386	193000	223000	111082	111918	30000	81918	100%	1	0	1	0	
Aug-69	215	107500	137500	111082	26418	26418	0	100%	1	0	1	0	
Sep-69	267	133500	159918	111082	48837	30000	18837	100%	1	0	1	0	
Oct-69	154	77000	107000	111082	-4082	0	0	96%	0	1	1	0	
Nov-69	181	90500	90500	111082	-20582	0	0	81%	0	2	1	0	
Dec-69	415	207500	207500	111082	96418	30000	66418	100%	1	0	1	0	
Jan-70	161	80500	110500	111082	-582	0	0	99%	1	0	1	0	
Feb-70	477	238500	238500	111082	127418	30000	97418	100%	1	0	1	0	
Mar-70	276	138000	168000	111082	56918	30000	26918	100%	1	0	1	0	
Apr-70	467	233500	263500	111082	152418	30000	122418	100%	1	0	1	0	
May-70	290	145000	175000	111082	63918	30000	33918	100%	1	0	1	0	
Jun-70	299	149500	179500	111082	68418	30000	38418	100%	1	0	1	0	
Jul-70	218	109000	139000	111082	27918	27918	0	100%	1	0	1	0	
Aug-70	126	63000	90918	111082	-20163	0	0	82%	0	1	1	0	
Sep-70	47	23500	23500	111082	-87582	0	0	21%	0	2	0	1	
Oct-70	18	9000	9000	111082	-102082	0	0	8%	0	3	0	2	
Nov-70	0	0	0	111082	-111082	0	0	0%	0	4	0	3	
Dec-70	45	22500	22500	111082	-88582	0	0	20%	0	5	0	4	
Jan-71	82	41000	41000	111082	-70082	0	0	37%	0	6	0	5	
Feb-71	240	120000	120000	111082	8918	8918	0	100%	1	0	1	0	
Mar-71	243	121500	130418	111082	19337	19337	0	100%	1	0	1	0	
Apr-71	132	66000	85337	111082	-25745	0	0	77%	0	1	1	0	
May-71	274	137000	137000	111082	25918	25918	0	100%	1	0	1	0	
Jun-71	252	126000	151918	111082	40837	30000	10837	100%	1	0	1	0	
Jul-71	321	160500	190500	111082	79418	30000	49418	100%	1	0	1	0	
Aug-71	192	96000	126000	111082	14918	14918	0	100%	1	0	1	0	
Sep-71	118	59000	73918	111082	-37163	0	0	67%	0	1	1	0	
Oct-71	134	67000	67000	111082	-44082	0	0	60%	0	2	1	0	
Nov-71	151	75500	75500	111082	-35582	0	0	68%	0	3	1	0	
Dec-71	589	294500	294500	111082	183418	30000	153418	100%	1	0	1	0	
Jan-72	168	84000	114000	111082	2918	2918	0	100%	1	0	1	0	
Feb-72	201	100500	103418	111082	-7663	0	0	93%	0	1	1	0	
Mar-72	153	76500	76500	111082	-34582	0	0	69%	0	2	1	0	
Apr-72	153	76500	76500	111082	-34582	0	0	69%	0	3	1	0	
May-72	385	192500	192500	111082	81418	30000	51418	100%	1	0	1	0	
Jun-72	202	101000	131000	111082	19918	19918	0	100%	1	0	1	0	

Jul-72	404	202000	221918	111082	110837	30000	80837	100%	1	0	1	0	
Aug-72	183	91500	121500	111082	10418	10418	0	100%	1	0	1	0	
Sep-72	441	220500	230918	111082	119837	30000	89837	100%	1	0	1	0	
Oct-72	498	249000	279000	111082	167918	30000	137918	100%	1	0	1	0	
Nov-72	234	117000	147000	111082	35918	30000	5918	100%	1	0	1	0	
Dec-72	953	476500	506500	111082	395418	30000	365418	100%	1	0	1	0	
Jan-73	451	225500	255500	111082	144418	30000	114418	100%	1	0	1	0	
Feb-73	500	250000	280000	111082	168918	30000	138918	100%	1	0	1	0	
Mar-73	391	195500	225500	111082	114418	30000	84418	100%	1	0	1	0	
Apr-73	550	275000	305000	111082	193918	30000	163918	100%	1	0	1	0	
May-73	485	242500	272500	111082	161418	30000	131418	100%	1	0	1	0	
Jun-73	160	80000	110000	111082	-1082	0	0	99%	1	0	1	0	
Jul-73	50	25000	25000	111082	-86082	0	0	23%	0	1	0	1	
Aug-73	0	0	0	111082	-111082	0	0	0%	0	2	0	2	
Sep-73	0	0	0	111082	-111082	0	0	0%	0	3	0	3	
Oct-73	17	8500	8500	111082	-102582	0	0	8%	0	4	0	4	
Nov-73	40	20000	20000	111082	-91082	0	0	18%	0	5	0	5	
Dec-73	0	0	0	111082	-111082	0	0	0%	0	6	0	6	
Jan-74	0	0	0	111082	-111082	0	0	0%	0	7	0	7	
Feb-74	207	103500	103500	111082	-7582	0	0	93%	0	8	1	0	
Mar-74	520	260000	260000	111082	148918	30000	118918	100%	1	0	1	0	
Apr-74	239	119500	149500	111082	38418	30000	8418	100%	1	0	1	0	
May-74	277	138500	168500	111082	57418	30000	27418	100%	1	0	1	0	
Jun-74	75	37500	67500	111082	-43582	0	0	61%	0	1	1	0	
Jul-74	223	111500	111500	111082	418	418	0	100%	1	0	1	0	
Aug-74	62	31000	31418	111082	-79663	0	0	28%	0	1	0	1	
Sep-74	189	94500	94500	111082	-16582	0	0	85%	0	2	1	0	
Oct-74	64	32000	32000	111082	-79082	0	0	29%	0	3	0	1	
Nov-74	79	39500	39500	111082	-71582	0	0	36%	0	4	0	2	
Dec-74	239	119500	119500	111082	8418	8418	0	100%	1	0	1	0	
Jan-75	169	84500	92918	111082	-18163	0	0	84%	0	1	1	0	
Feb-75	200	100000	100000	111082	-11082	0	0	90%	0	2	1	0	
Mar-75	180	90000	90000	111082	-21082	0	0	81%	0	3	1	0	
Apr-75	314	157000	157000	111082	45918	30000	15918	100%	1	0	1	0	
Jun-75	273	136500	166500	111082	55418	30000	25418	100%	1	0	1	0	
Nov-75	75	37500	67500	111082	-43582	0	0	61%	0	1	1	0	
Dec-75	158	79000	79000	111082	-32082	0	0	71%	0	2	1	0	
Jan-76	15	7500	7500	111082	-103582	0	0	7%	0	3	0	1	

Feb-76	6	3000	3000	111082	-108082	0	0	3%	0	4	0	2	
Dec-76	515	257500	257500	111082	146418	30000	116418	100%	1	0	1	0	
Jan-77	302	151000	181000	111082	69918	30000	39918	100%	1	0	1	0	
Jun-77	168	84000	114000	111082	2918	2918	0	100%	1	0	1	0	
Jul-77	183	91500	94418	111082	-16663	0	0	85%	0	1	1	0	
Aug-77	110	55000	55000	111082	-56082	0	0	50%	0	2	0	1	
Oct-77	389	194500	194500	111082	83418	30000	53418	100%	1	0	1	0	
Nov-77	294	147000	177000	111082	65918	30000	35918	100%	1	0	1	0	
Mar-78	212	106000	136000	111082	24918	24918	0	100%	1	0	1	0	
Apr-78	464	232000	256918	111082	145837	30000	115837	100%	1	0	1	0	
May-78	268	134000	164000	111082	52918	30000	22918	100%	1	0	1	0	
Jun-78	165	82500	112500	111082	1418	1418	0	100%	1	0	1	0	
Jul-78	97	48500	49918	111082	-61163	0	0	45%	0	1	0	1	
Aug-78	179	89500	89500	111082	-21582	0	0	81%	0	2	1	0	
Sep-78	88	44000	44000	111082	-67082	0	0	40%	0	3	0	1	
Oct-78	81	40500	40500	111082	-70582	0	0	36%	0	4	0	2	
Nov-78	268	134000	134000	111082	22918	22918	0	100%	1	0	1	0	
Dec-78	292	146000	168918	111082	57837	30000	27837	100%	1	0	1	0	
Jan-79	237	118500	148500	111082	37418	30000	7418	100%	1	0	1	0	
Feb-79	186	93000	123000	111082	11918	11918	0	100%	1	0	1	0	
Mar-79	770	385000	396918	111082	285837	30000	255837	100%	1	0	1	0	
Apr-79	175	87500	117500	111082	6418	6418	0	100%	1	0	1	0	
May-79	438	219000	225418	111082	114337	30000	84337	100%	1	0	1	0	
Jun-79	401	200500	230500	111082	119418	30000	89418	100%	1	0	1	0	
Jul-79	108	54000	84000	111082	-27082	0	0	76%	0	1	1	0	
Aug-79	346	173000	173000	111082	61918	30000	31918	100%	1	0	1	0	
Sep-79	230	115000	145000	111082	33918	30000	3918	100%	1	0	1	0	
Oct-79	249	124500	154500	111082	43418	30000	13418	100%	1	0	1	0	
Nov-79	308	154000	184000	111082	72918	30000	42918	100%	1	0	1	0	
Dec-79	353	176500	206500	111082	95418	30000	65418	100%	1	0	1	0	
Jan-80	590	295000	325000	111082	213918	30000	183918	100%	1	0	1	0	
Feb-80	385	192500	222500	111082	111418	30000	81418	100%	1	0	1	0	
Mar-80	754	377000	407000	111082	295918	30000	265918	100%	1	0	1	0	
Apr-80	242	121000	151000	111082	39918	30000	9918	100%	1	0	1	0	
May-80	321	160500	190500	111082	79418	30000	49418	100%	1	0	1	0	
Jun-80	187	93500	123500	111082	12418	12418	0	100%	1	0	1	0	
Jul-80	331	165500	177918	111082	66837	30000	36837	100%	1	0	1	0	
Aug-80	274	137000	167000	111082	55918	30000	25918	100%	1	0	1	0	

Sep-80	62	31000	61000	111082	-50082	0	0	55%	0	1	0	1	
Oct-80	301	150500	150500	111082	39418	30000	9418	100%	1	0	1	0	
Nov-80	249	124500	154500	111082	43418	30000	13418	100%	1	0	1	0	
Dec-80	304	152000	182000	111082	70918	30000	40918	100%	1	0	1	0	
Jan-81	504	252000	282000	111082	170918	30000	140918	100%	1	0	1	0	
Feb-81	471	235500	265500	111082	154418	30000	124418	100%	1	0	1	0	
Mar-81	415	207500	237500	111082	126418	30000	96418	100%	1	0	1	0	
Apr-81	727	363500	393500	111082	282418	30000	252418	100%	1	0	1	0	
May-81	308	154000	184000	111082	72918	30000	42918	100%	1	0	1	0	
Jun-81	235	117500	147500	111082	36418	30000	6418	100%	1	0	1	0	
Jul-81	306	153000	183000	111082	71918	30000	41918	100%	1	0	1	0	
Aug-81	198	99000	129000	111082	17918	17918	0	100%	1	0	1	0	
Sep-81	86	43000	60918	111082	-50163	0	0	55%	0	1	0	1	
Oct-81	134	67000	67000	111082	-44082	0	0	60%	0	2	1	0	
Nov-81	136	68000	68000	111082	-43082	0	0	61%	0	3	1	0	
Dec-81	240	120000	120000	111082	8918	8918	0	100%	1	0	1	0	
Jan-82	227	113500	122418	111082	11337	11337	0	100%	1	0	1	0	
Feb-82	135	67500	78837	111082	-32245	0	0	71%	0	1	1	0	
Mar-82	177	88500	88500	111082	-22582	0	0	80%	0	2	1	0	
Apr-82	111	55500	55500	111082	-55582	0	0	50%	0	3	0	1	
May-82	233	116500	116500	111082	5418	5418	0	100%	1	0	1	0	
Jun-82	207	103500	108918	111082	-2163	0	0	98%	0	1	1	0	
Jul-82	314	157000	157000	111082	45918	30000	15918	100%	1	0	1	0	
Aug-82	243	121500	151500	111082	40418	30000	10418	100%	1	0	1	0	
Sep-82	108	54000	84000	111082	-27082	0	0	76%	0	1	1	0	
Oct-82	309	154500	154500	111082	43418	30000	13418	100%	1	0	1	0	
Nov-82	153	76500	106500	111082	-4582	0	0	96%	0	1	1	0	
Dec-82	196	98000	98000	111082	-13082	0	0	88%	0	2	1	0	
Jan-83	20	10000	10000	111082	-101082	0	0	9%	0	3	0	1	
Feb-83	39	19500	19500	111082	-91582	0	0	18%	0	4	0	2	
Mar-83	31	15500	15500	111082	-95582	0	0	14%	0	5	0	3	
Apr-83	42	21000	21000	111082	-90082	0	0	19%	0	6	0	4	
May-83	228	114000	114000	111082	2918	2918	0	100%	1	0	1	0	
Jun-83	310	155000	157918	111082	46837	30000	16837	100%	1	0	1	0	
Jul-83	464	232000	262000	111082	150918	30000	120918	100%	1	0	1	0	
Aug-83	274	137000	167000	111082	55918	30000	25918	100%	1	0	1	0	
Sep-83	69	34500	64500	111082	-46582	0	0	58%	0	1	0	1	
Oct-83	45	22500	22500	111082	-88582	0	0	20%	0	2	0	2	

Nov-83	216	108000	108000	111082	-3082	0	0	97%	0	3	1	0	
Dec-83	153	76500	76500	111082	-34582	0	0	69%	0	4	1	0	
Jan-84	365	182500	182500	111082	71418	30000	41418	100%	1	0	1	0	
Feb-84	187	93500	123500	111082	12418	12418	0	100%	1	0	1	0	
Mar-84	221	110500	122918	111082	11837	11837	0	100%	1	0	1	0	
Apr-84	77	38500	50337	111082	-60745	0	0	45%	0	1	0	1	
May-84	232	116000	116000	111082	4918	4918	0	100%	1	0	1	0	
Jun-84	177	88500	93418	111082	-17663	0	0	84%	0	1	1	0	
Jul-84	156	78000	78000	111082	-33082	0	0	70%	0	2	1	0	
Aug-84	280	140000	140000	111082	28918	28918	0	100%	1	0	1	0	
Sep-84	165	82500	111418	111082	337	337	0	100%	1	0	1	0	
Oct-84	75	37500	37837	111082	-73245	0	0	34%	0	1	0	1	
Nov-84	204	102000	102000	111082	-9082	0	0	92%	0	2	1	0	
Dec-84	111	55500	55500	111082	-55582	0	0	50%	0	3	0	1	
Jan-85	277	138500	138500	111082	27418	27418	0	100%	1	0	1	0	
Feb-85	297	148500	175918	111082	64837	30000	34837	100%	1	0	1	0	
Mar-85	302	151000	181000	111082	69918	30000	39918	100%	1	0	1	0	
Apr-85	155	77500	107500	111082	-3582	0	0	97%	0	1	1	0	
May-85	177	88500	88500	111082	-22582	0	0	80%	0	2	1	0	
Jun-85	357	178500	178500	111082	67418	30000	37418	100%	1	0	1	0	
Jul-85	172	86000	116000	111082	4918	4918	0	100%	1	0	1	0	
Aug-85	214	107000	111918	111082	837	837	0	100%	1	0	1	0	
Oct-85	61	30500	31337	111082	-79745	0	0	28%	0	1	0	1	
Nov-85	100	50000	50000	111082	-61082	0	0	45%	0	2	0	2	
Dec-85	318	159000	159000	111082	47918	30000	17918	100%	1	0	1	0	
Jan-86	392	196000	226000	111082	114918	30000	84918	100%	1	0	1	0	
Feb-86	132	66000	96000	111082	-15082	0	0	86%	0	1	1	0	
Mar-86	202	101000	101000	111082	-10082	0	0	91%	0	2	1	0	
Apr-86	253	126500	126500	111082	15418	15418	0	100%	1	0	1	0	
May-86	135	67500	82918	111082	-28163	0	0	75%	0	1	1	0	
Jun-86	191	95500	95500	111082	-15582	0	0	86%	0	2	1	0	
Jul-86	279	139500	139500	111082	28418	28418	0	100%	1	0	1	0	
Aug-86	227	113500	141918	111082	30837	30000	837	100%	1	0	1	0	
Sep-86	244	122000	152000	111082	40918	30000	10918	100%	1	0	1	0	
Oct-86	251	125500	155500	111082	44418	30000	14418	100%	1	0	1	0	
Nov-86	453	226500	256500	111082	145418	30000	115418	100%	1	0	1	0	
Dec-86	664	332000	362000	111082	250918	30000	220918	100%	1	0	1	0	
Jan-87	246	123000	153000	111082	41918	30000	11918	100%	1	0	1	0	

Feb-87	343	171500	201500	111082	90418	30000	60418	100%	1	0	1	0	
Mar-87	273	136500	166500	111082	55418	30000	25418	100%	1	0	1	0	
Apr-87	264	132000	162000	111082	50918	30000	20918	100%	1	0	1	0	
May-87	157	78500	108500	111082	-2582	0	0	98%	0	1	1	0	
Jun-87	396	198000	198000	111082	86918	30000	56918	100%	1	0	1	0	
Jul-87	118	59000	89000	111082	-22082	0	0	80%	0	1	1	0	
Aug-87	352	176000	176000	111082	64918	30000	34918	100%	1	0	1	0	
Sep-87	82	41000	71000	111082	-40082	0	0	64%	0	1	1	0	
Oct-87	134	67000	67000	111082	-44082	0	0	60%	0	2	1	0	
Nov-87	376	188000	188000	111082	76918	30000	46918	100%	1	0	1	0	
Dec-87	491	245500	275500	111082	164418	30000	134418	100%	1	0	1	0	
Jan-88	316	158000	188000	111082	76918	30000	46918	100%	1	0	1	0	
Feb-88	501	250500	280500	111082	169418	30000	139418	100%	1	0	1	0	
Mar-88	647	323500	353500	111082	242418	30000	212418	100%	1	0	1	0	
Apr-88	433	216500	246500	111082	135418	30000	105418	100%	1	0	1	0	
Dec-89	129	64500	94500	111082	-16582	0	0	85%	0	1	1	0	
Jan-90	705	352500	352500	111082	241418	30000	211418	100%	1	0	1	0	
Jun-90	290	145000	175000	111082	63918	30000	33918	100%	1	0	1	0	
Jul-90	247	123500	153500	111082	42418	30000	12418	100%	1	0	1	0	
Aug-90	336	168000	198000	111082	86918	30000	56918	100%	1	0	1	0	
Sep-90	463	231500	261500	111082	150418	30000	120418	100%	1	0	1	0	
Oct-90	194	97000	127000	111082	15918	15918	0	100%	1	0	1	0	
Dec-90	28	14000	29918	111082	-81163	0	0	27%	0	1	0	1	
Jan-91	29	14500	14500	111082	-96582	0	0	13%	0	2	0	2	
Feb-91	123	61500	61500	111082	-49582	0	0	55%	0	3	0	3	
Mar-91	300	150000	150000	111082	38918	30000	8918	100%	1	0	1	0	
Apr-91	127	63500	93500	111082	-17582	0	0	84%	0	1	1	0	
Mar-99	250	125000	125000	111082	13918	13918	0	100%	1	0	1	0	
Apr-99	213	106500	120418	111082	9337	9337	0	100%	1	0	1	0	
May-99	214	107000	116337	111082	5255	5255	0	100%	1	0	1	0	
Jun-99	211	105500	110755	111082	-326	0	0	100%	1	0	1	0	
Oct-99	102	51000	51000	111082	-60082	0	0	46%	0	1	0	1	
Nov-99	57	28500	28500	111082	-82582	0	0	26%	0	2	0	2	
May-00	245	122500	122500	111082	11418	11418	0	100%	1	0	1	0	
Jun-00	170	85000	96418	111082	-14663	0	0	87%	0	1	1	0	
Jul-00	120	60000	60000	111082	-51082	0	0	54%	0	2	0	1	
Aug-00	316	158000	158000	111082	46918	30000	16918	100%	1	0	1	0	
Sep-00	103	51500	81500	111082	-29582	0	0	73%	0	1	1	0	

Oct-00	152	76000	76000	111082	-35082	0	0	68%	0	2	1	0	
Nov-00	95	47500	47500	111082	-63582	0	0	43%	0	3	0	1	
Mar-01	306	153000	153000	111082	41918	30000	11918	100%	1	0	1	0	
May-01	273	136500	166500	111082	55418	30000	25418	100%	1	0	1	0	
Jul-01	379	189500	219500	111082	108418	30000	78418	100%	1	0	1	0	
Sep-01	165	82500	112500	111082	1418	1418	0	100%	1	0	1	0	
Oct-01	179	89500	90918	111082	-20163	0	0	82%	0	1	1	0	
Mar-02	737	368500	368500	111082	257418	30000	227418	100%	1	0	1	0	
Apr-02	191	95500	125500	111082	14418	14418	0	100%	1	0	1	0	
May-02	278	139000	153418	111082	42337	30000	12337	100%	1	0	1	0	
Jun-02	433	216500	246500	111082	135418	30000	105418	100%	1	0	1	0	
Aug-02	306	153000	183000	111082	71918	30000	41918	100%	1	0	1	0	
Feb-03	298	149000	179000	111082	67918	30000	37918	100%	1	0	1	0	
Jan-11	71.7	35850	65850	111082	-45232	0	0	59%	0	1	0	1	
Feb-11	22.6	11300	11300	111082	-99782	0	0	10%	0	2	0	2	
Mar-11	195.3	97650	97650	111082	-13432	0	0	88%	0	3	1	0	
Apr-11	273.3	136650	136650	111082	25568	25568	0	100%	1	0	1	0	
May-11	336.5	168250	193818	111082	82737	30000	52737	100%	1	0	1	0	
Jun-11	475.7	237850	267850	111082	156768	30000	126768	100%	1	0	1	0	
Jul-11	481.3	240650	270650	111082	159568	30000	129568	100%	1	0	1	0	
Aug-11	93.5	46750	76750	111082	-34332	0	0	69%	0	1	1	0	
Sep-11	363.3	181650	181650	111082	70568	30000	40568	100%	1	0	1	0	
Dec-11	147.8	73900	103900	111082	-7182	0	0	94%	0	1	1	0	
Jan-12	331.0	165500	165500	111082	54418	30000	24418	100%	1	0	1	0	
Feb-12	115.3	57650	87650	111082	-23432	0	0	79%	0	1	1	0	
Mar-12	310.4	155200	155200	111082	44118	30000	14118	100%	1	0	1	0	
Apr-12	350.8	175400	205400	111082	94318	30000	64318	100%	1	0	1	0	
May-12	299.4	149700	179700	111082	68618	30000	38618	100%	1	0	1	0	
Jun-12	317.6	158800	188800	111082	77718	30000	47718	100%	1	0	1	0	
Jul-12	566.6	283300	313300	111082	202218	30000	172218	100%	1	0	1	0	
Aug-12	229.6	114800	144800	111082	33718	30000	3718	100%	1	0	1	0	
Sep-12	384.3	192150	222150	111082	111068	30000	81068	100%	1	0	1	0	
Oct-12	275.0	137500	167500	111082	56418	30000	26418	100%	1	0	1	0	
Nov-12	379.4	189700	219700	111082	108618	30000	78618	100%	1	0	1	0	
Dec-12	381.2	190600	220600	111082	109518	30000	79518	100%	1	0	1	0	
Jan-13	289.6	144800	174800	111082	63718	30000	33718	100%	1	0	1	0	
Feb-13	151.6	75800	105800	111082	-5282	0	0	95%	0	1	1	0	
Apr-13	292.5	146250	146250	111082	35168	30000	5168	100%	1	0	1	0	

May-13	206.0	103000	133000	111082	21918	21918	0	100%	1	0	1	0	
Jun-13	224.6	112300	134218	111082	23137	23137	0	100%	1	0	1	0	
Jul-13	265.1	132550	155687	111082	44605	30000	14605	100%	1	0	1	0	
Aug-13	141.1	70550	100550	111082	-10532	0	0	91%	0	1	1	0	
Sep-13	199.4	99700	99700	111082	-11382	0	0	90%	0	2	1	0	
Oct-13	188.6	94300	94300	111082	-16782	0	0	85%	0	3	1	0	
Nov-13	409.3	204650	204650	111082	93568	30000	63568	100%	1	0	1	0	
Jan-14	242.6	121300	151300	111082	40218	30000	10218	100%	1	0	1	0	
Feb-14	120.5	60250	90250	111082	-20832	0	0	81%	0	1	1	0	
Mar-14	434.3	217150	217150	111082	106068	30000	76068	100%	1	0	1	0	
Apr-14	542.4	271200	301200	111082	190118	30000	160118	100%	1	0	1	0	
May-14	348.4	174200	204200	111082	93118	30000	63118	100%	1	0	1	0	

Table A10-3. RWH potential of surveyed communal buildings in relation to meeting current and future village drinking water demands.

Village	Building Type	Owner	Roof area (m^2)	Building ID	Percentage of roof margin covered by guttering	Collecting Roof Area (m^2)	Guttering Condition	Guttering Efficiency	Effective Roof Area (m^2)	Improved Roof Area (m^2)	Rain Tank Capacity (L)	Building ID	Population	RWH capacity under current catchment conditions (L/p/d)	RWH capacity under current and improved catchment conditions	RWH capacity with roof improvements and increased storage 20,000 L
Kiebu	Church	Catholic church	470	Ki1	100%	470	Adequate	0.55	259	352.5	110,000	Ki1	2010 (434)	4.2	5.6	7.4
													2030 (483)	3.8	5	6.7
Kiebu	*Maneaba*	Catholic church	400	Ki2	75%	300	Adequate	0.55	165	300	8500	Ki2	2010 (434)	2.7	4.7	5.1
													2030 (483)	2.45	4.2	4.6
Kiebu	*Maneaba*	Saint Arobati	409	Ki3	50%	204.5	Good	0.75	153	306.75	13,500	Ki3	2010 (434)	2.7	4.9	5.2
													2030 (483)	2.4	4.4	4.6
Kiebu	Church	KPC	112	Ki4	100%	112	Adequate	0.55	62	84	20,000	Ki4	2010 (434)	1.25	1.65	1.65
													2030 (483)	1.13	1.4	1.4
Village Total													2010 (434)	11	17	18
													2030 (483)	10	15.5	16

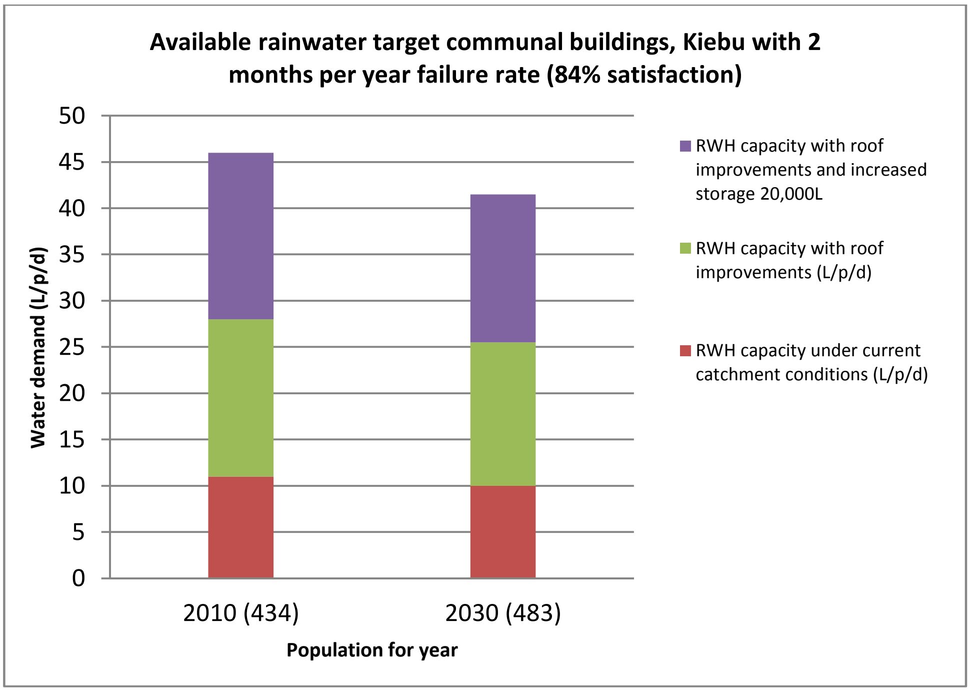


Figure A10-1. Analysis of all target communal buildings in Kiebu Village.

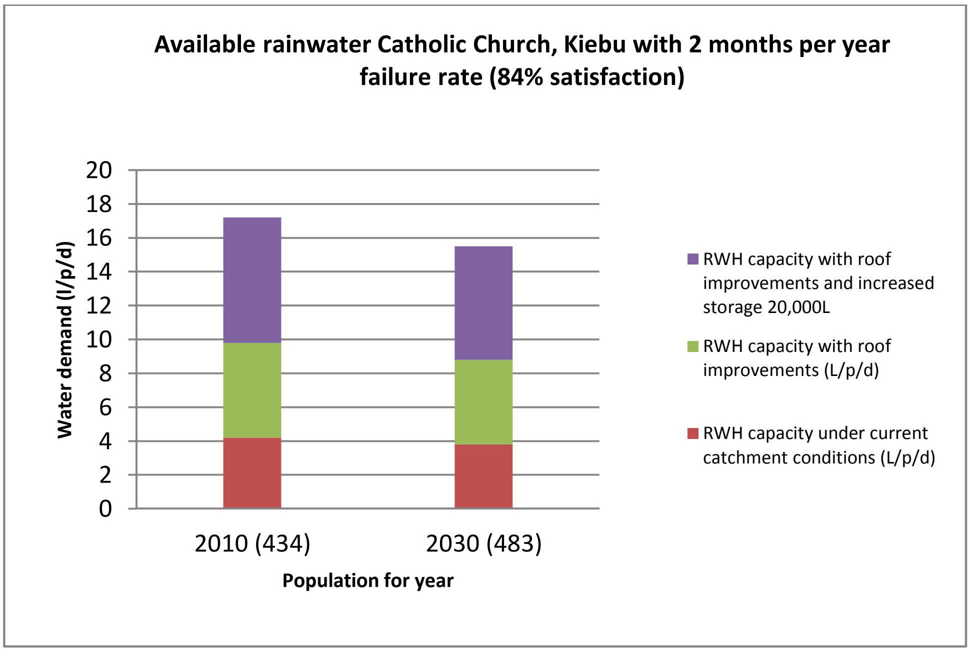


Figure A10-2. Analysis of Catholic Church in Kiebu Village.

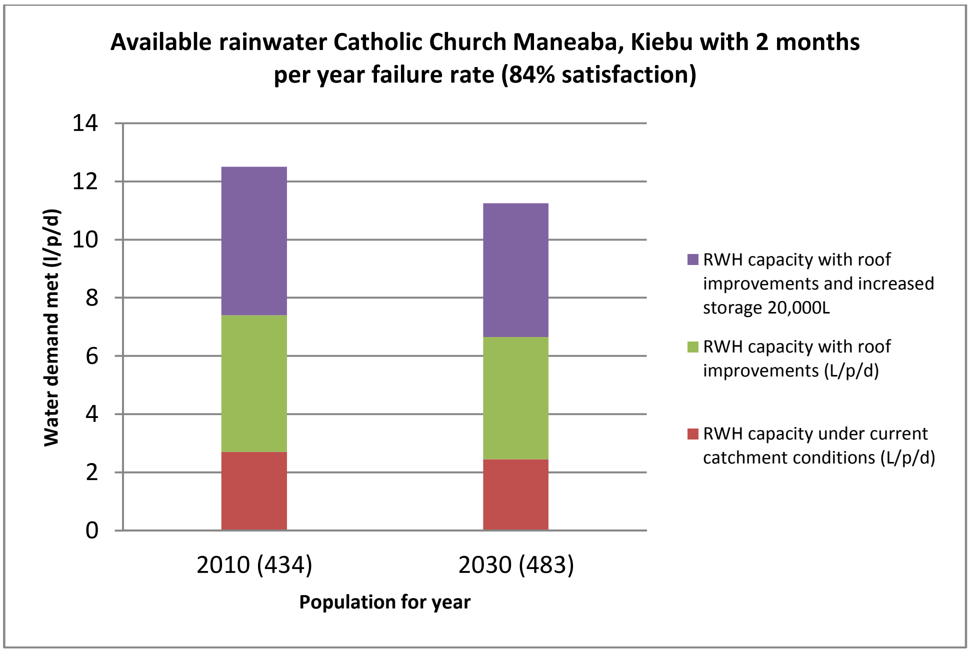


Figure A10-3. Analysis of the Catholic Maneaba In Kiebu Village.

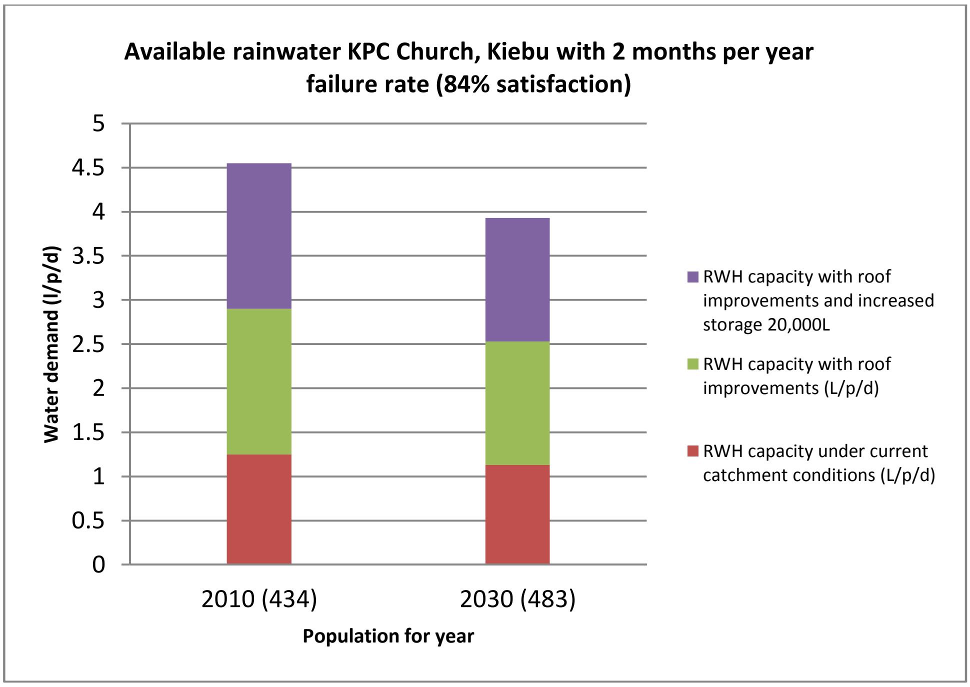


Figure A10-4. Analysis of the KPC Church for Kiebu Village.

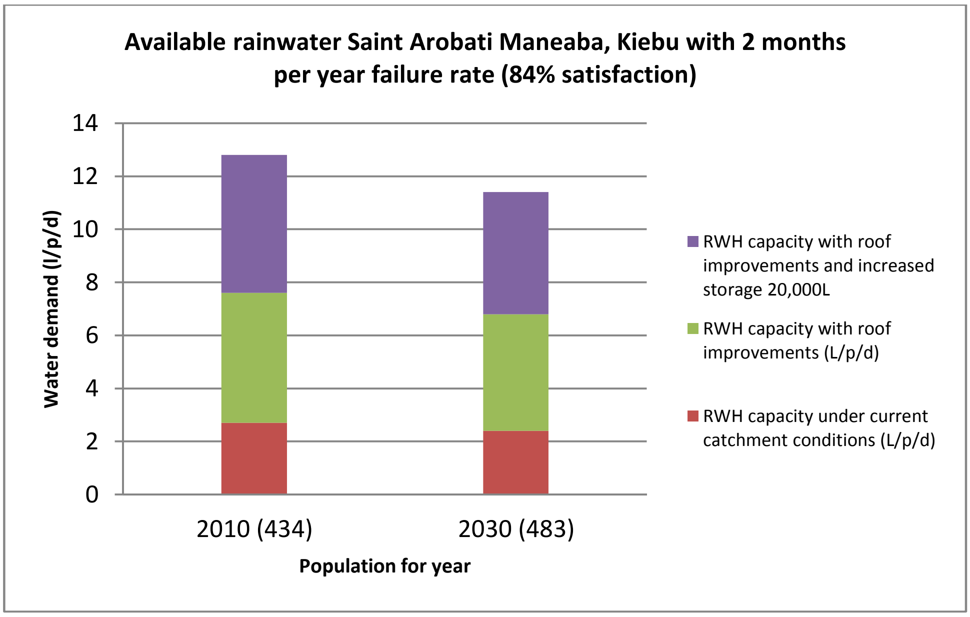


Figure A10-5. Analysis of the Arobati **Maneaba** ***for Kiebu Village.***

Table A10-4. Summary of water available L/p/d for 100 people assuming 84% satisfaction or 2 months per year failure rate under varying roof area and storage.

Roof Catchment Projected Demand	5000	10,000	15,000	20,000	25,000	30,000
50 meter squared catchment	3.8	4.2	4.35	4.45	4.55	4.65
100 meter squared catchment	7.1	7.6	8.1	8.4	8.5	8.6
150 meter squared catchment	10.5	11	11.4	11.8	12.2	12.6
200 meter squared catchment	13.5	14.5	15.1	15.6	16	16.3
250 meter squared catchment	16.5	17.5	18	18.5	19	19.6
300 meter squared catchment	20	21	21.5	22	22.5	23
350 meter squared catchment	23	24	25	25	26	26.5
400 meter squared catchment	26	27	28	28.5	29	29.5
450 meter squared catchment	29	30	31	31.5	32	33
500 meter squared catchment	32	33	34	34.5	36	36.5

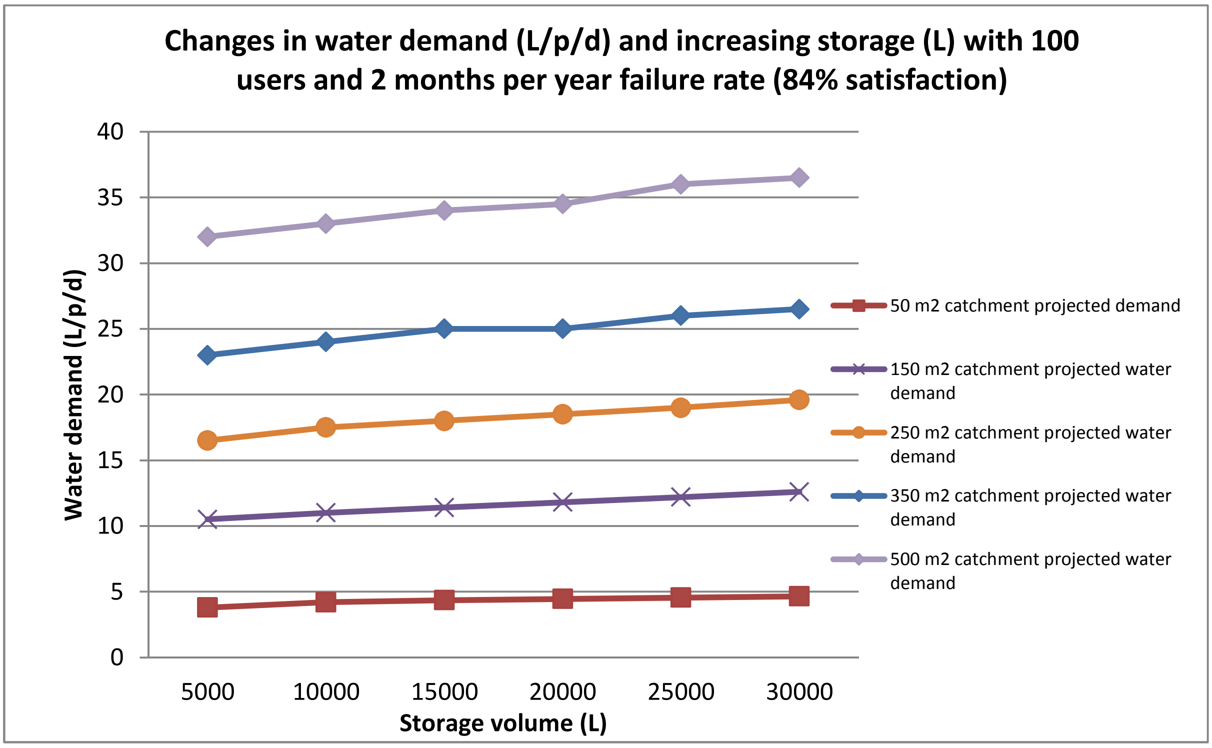


Figure A10-6. Analysis of changing water demand on varying roof catchment area based on a fixed number of users and 84% satisfaction.

Annex 11

Village Meeting Notes from Kiebu Village, Makin

This annex presents the issues and challenges raised by various communities during the village consultation meetings in Kiebu Village, Makin.

Table A11-1. Summary of the Kiebu Village meeting notes.

Date	Issues raised	WRA team's response
26/10/2012 **Number of villagers present:** Estimated to be ten men associated with the main Catholic Church	Meetings were held in Catholic Church *maneaba*, *Unimwane* present. Kamango was the head *Unimwane* that we met with Well water is normally brackish, reliance on rainwater Advised that for one month a year they often experience a shortage of rainwater Rainwater collected from the *maneaba* and churches is collected and accessed by the community There are three sectors with the community with separate water supplies; (south, north, and central), and they are responsible for looking after their own water needs People in the central district have more water because to access to rainwater tanks attached to the Catholic church and the *maneaba* People walk to nearest tank or distributed tank to access water People boil their water for drinking During dry periods people turn to *bwabwai* and dig small pits and skim the freshwater from these. They often have to dig many pits. Last time that they resorted to this was July/August 2010 Some people have toilets that they use at night – pour-flush systems are less than 10 Generally people use the beach, it being taboo to use the bush, although people do **Community preferences** More water catchments, guttering and storages Consider existing RWH efficient but are concerned about the overflow of tanks when it rains, 'lost water' **Requested improvements** Cisterns that they can bail and bucket water from More catchments to be built Improved distribution of water. Catholic Church to provide improved distributed rainwater system but retain some water for community functions There is a preference for cisterns as they are seen to be more robust than plastic tanks, many of which have failed Guttering made from half pipes considered to be more durable – will not capture as much rain	Groundwater is very limited, recommend efforts into RWH The churches provide a distributed RWH system and improvements can be made to this. However agreements for access and maintenance will be required prior to investment *Maneaba* continue to provide centralised water distribution for each sector. These would be the highest priority Improve catchment/transmission, storage, abstraction required School RWH collection and building identified for renewal Plastic tanks which have failed are the 5000 L stackable tanks, some of these could be repaired with the right equipment – recommend that this equipment be purchased under the project if feasible. Plastic tanks which are one piece are expected to be more durable Improved storage and standpipes and protection of standpipes Access and maintenance agreements required

Annex 12

Selection of Kiebu Village Survey Photos

This annex presents selected photos captured during the water resources assessment (WRA) and is intended to show the status and/or condition of water supply infrastructure in Kiebu Village, Makin at the time of the assessment from 25th to 28th October 2012.

Figure A12-1. Survey team arriving on Makin Island airstrip.

Figure A12-2. Team preparing for a boat-trip to Kiebu islet.

Figure A12-3. Villager in Kiebu using rainwater for bathing.

Figure A12-4. EM34 survey across Kiebu islet.

Figure A12-5. Church building representing a target communal building for rainwater harvesting.

Figure A12-6. Inadequate RWH facility showing the use of an additional gutter as downpipe.

Figure A12-7. Rainwater tank mounted on a raised tank stand.

Figure A12-8. Split PVC pipes used as guttering on a* maneaba *roof catchment – the pipes allow splash losses from the rainwater collection system.

Figure A12-9. Split PVC pipe used as guttering and covering some parts of the roof edge.

Figure A12-10. Women using rainwater for washing – this proves the poor fresh groundwater potential.

Figure A12-11. Survey team assessing the communal well.

Figure A12-12.Team taking salinity measurements at the village Health Clinic well.

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