Government of the Republic of Kiribati

Tarawa Water Master Plan:

Te Ran, Groundwater

Coordinated by the National Adaptation Steering Committee

under Office Te Beretitenti

and the National Water and Sanitation Coordination Committee

through the Ministry of Public Works and Utilities

Kiribati Adaptation Programme Phase II Water Component 3.2.1, World Bank, AusAID, NZaid

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This Water Master Plan is a response to widespread public concerns over freshwater voiced during wide spread public consultations conducted during the National Adaptation Program of Action, Kiribati Adaptation Project Phase I (KAP I). It was developed under the Kiribati Adaptation Project Phase II Water Component Project 3.2.1 and was overseen by the National Water and Sanitation Coordination Committee under the chair of the Ministry of Public Works and Utilities and by the National Adaptation Steering Committee under the chair of the Office Te Beretitenti. This plan has been drafted by Professor Ian White, Australian National University with the valuable assistance of Tony Falkland of Island Hydrology Services, a tireless and long-standing friend of Kiribati, and Marella Rebgetz, KAPII Water Specialist. This plan is based on the National Water Resources Policy and its accompanying National Water Resources Implementation Plan. This plan has involved help, critical inputs and helpful comments from:

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Scope:

The scope of this Technical Assistance activity is to produce a Water Master Plan for water development, management, protection and monitoring in Tarawa taking account of all available water resources (primarily groundwater and rainwater) and possible additional sources.

Terms of Reference

The original terms of reference (ToR) for this Water Master Plan for Tarawa are:

1. Review relevant parts of existing documents related to water master planning including the following: Draft Water Master Plan of 1992 (Shalev, 2002) and subsequent revisions (WEU, 2000); PUB Business Plan, 2004-2006 (PUB, 2004) (and updated documents if available); Project reports from the water component of the SAPHE project including the Review of Groundwater Resources Management for Tarawa (Falkland, 2003a); Draft National Water Policy (EU-SOPAC, 2007a); Revised Draft National 10-Year Water Plan (EU-SOPAC, 2007b).
2. Consult with relevant GoK agencies and individuals (refer list above) about water planning and management issues in relation to both groundwater and rainwater.
3. Consult with other organisations including local NGOs and private companies, as appropriate.
4. Estimate future demands for water based on most current population data, growth trends, per capita consumption and estimates water use for commercial, community and industrial activities. Use planning horizons of 10 and 20 years.
5. Develop a logical sequence of water resources development based on technical assessments, cost estimates, and land ownership/management issues and environmental factors.
6. Review current water management, protection and monitoring procedures and recommend, as appropriate, additional mechanisms to ensure that the groundwater resources are usable by present and future generations.
7. Prepare a draft Water Master Plan for Tarawa, ensure that it is consistent with the draft National Water Policy and 10-Year Water Plan and present to the NWSCC and key KAPII consultants.
8. After feedback from the NWSCC and KAPII personnel, assess the comments received, undertake additional analysis as required and prepare a final draft Water Master Plan for Tarawa.

On 27 February 2009 it was agreed to alter ToR point 8 and include an additional point 9:

8. After feedback from the NWSCC, NASC and KAPII personnel at initial and final Workshops, assess the comments received, undertake additional analysis as required and prepare a final draft Water Master Plan for Tarawa
9. The consultant will compile a brief final report which records activities undertaken and documents produced in fulfilment of both Parts 1 and 2 of the consultancy. The purpose of the report is to demonstrate fulfilment of TOR, provide a list of final draft documents submitted clearly indicating versions and dates, and electronic file names of documents submitted.

Process

After review of all relevant documents, consultations with all relevant Ministries, private companies and NGOs were carried out in the course of this work. Draft reports were circulated to Ministries for comment in August and September 2009. Workshops on the TWMP were held with key government agencies on 9 and 14 December 2010. Presentations of material in this plan were also given to the NWSCC, chaired by Secretary MPWU, on 4 August 2008, 23 June 2009 and 13 December 2010 and to the NASC, chaired by Secretary OB, on 5 August 2008 and 15 December 2010. Plan documents were revised in light of the comments received prior to finalising them.

Acronyms

ADB	Asian Development Bank
AusAID	Australian Agency for International Development
℃	degrees Celsius
cm	centimeter (one hundredth of a metre)
CO_2	carbon dioxide
CV	coefficient of variation
d	day
EC	electrical conductivity
EM	electromagnetic
EPA	Environmental Protection Agency (US)
EU	European Union
ENSO	El Niño- Southern Oscillation Index
GCM	Global Climate Model
GOK	Government of Kiribati
GWP	GWP Consultants LLP (UK) Water Resource Consultants for KAPII
ha	hectare (= 10,000 m^2)
IHP	International Hydrological Programme (of UNESCO)
IPCC	Intergovernmental Panel on Climate Change
KAP	Kiribati Adaptation Program (Phases I, II & III)
KHC	Kiribati Housing Corporation
KMS	Kiribati Meteorology Service (within MCTTD)
km	kilometre
km^2	square kilometre (= 100 ha)
k	Thousand
KL	kilolitre (= 1000 L = 1 m^3)
L	litre
L/day	litres per day
L/pers/day	litres per person per day (water use)
m	metre
mm	millimetre (one thousandth of a metre)
m^2	square metre
m^3	cubic metre
M	million
ML	mega litre (one million litres = 1,000 KL = 1,000 m^3)
ML/day	mega litre per day
ML/y	
MLPID	Ministry of Line and Phoenix Island Development
MPWU	Ministry of Public Works and Utilities
mth	month
NAPA	National Adaptation Plan of Action
NASC	National Adaptation Steering Committee
NCAR	National Center for Atmospheric Research (US)
NGO	non-government organisation
NSO	National Statistics Office
NSPRAU	National Strategic Policy and Risk Assessment Unit (within OB)
NWSCC	National Water and Sanitation Coordination Committee
NWRIP	National Water Resources Implementation Plan
NWRP	National Water Resources Policy
NZAID	New Zealand International Aid and Development Agency
OB	Office Te Beretitenti (the President)
pers	person
pers/km^2	people per square kilometre
PUB	Public Utilities Board (within MPWU)
SAPHE	Sanitation, Public Health and Environment Improvement Project
SCOPIC	seasonal climate outlook for Pacific island countries
SOI	Southern Oscillation Index
SOPAC	Pacific Islands Applied Geoscience Commission
SRES	Special Report on Emission Scenarios
SST	sea surface temperature
ToR	terms of reference
UNESCO	United Nations Educational, Scientific and Cultural Organization
WB	World Bank
WEU	Water Engineering Unit (within MPWU)
μS/cm	micro Siemens per centimetre, a measure of electrical conductivity or salinity

Summary

This Tarawa Water Master Plan, TWMP, is a direct response to the Government of Kiribati's National Water Resources Policy and its accompanying Implementation Plan. This component focuses on the ability of groundwater sources, the traditional source of the majority of water used in Tarawa, to meet expected future demands. This focus is necessary because there are a number of knowledge gaps and difficult issues which need to be addressed by the government, its Ministries and agencies as well as the community. The issues faced in groundwater management in Tarawa are already critical and future population growth will severely challenge the Government's ability to provide adequate supplies of safe, good quality water.

Water sources, groundwater, drought and climate change

The 2005 Census shows that predominant source of drinking water in Tarawa is water sourced from local household wells. In South Tarawa, only about 2/3 of households use water supplied by the PUB piped water system sourced from water reserves in Bonriki and Buota with about an equal amount coming from local wells. Fresh, shallow groundwater in Tarawa is contained in thin groundwater lenses floating over and mixing with underlying seawater in the aquifer. These groundwater lenses are fragile and delicately balanced between inputs from rainfall recharge and outputs from evapotranspiration, discharge to the sea, tidal-mixing with the underlying seawater in the aquifer and pumping or extraction of groundwater. Because annual rainfall in Tarawa is characterised by large year-to-year variability, with frequent severe droughts strongly coupled to ENSO events and sea surface temperatures, the thickness and salinity of these lenses also varies. During these droughts, which occur on average every 7 years and last on average for 2 years, groundwater lenses in narrow islands become brackish or saline. Only groundwater in larger islands, such as Bonriki and Buota, can survive severe droughts.

Predictions of the impacts of climate change on future rainfall, drought frequency and groundwater recharge in Tarawa are problematic. The large scale of global circulation models used in predictions, relative to the size of small islands, their failure to simulate ENSO events and their general failure to predict past rainfall histories, mean that rainfall, drought and groundwater recharge predictions are unreliable. The predicted sealevel rises as a result of climate change suggest that Tarawa may have up to 20% less groundwater available by 2030. The sustainable yields of groundwater, which are estimated to permit pumping at the specified rate throughout the longest drought on record, have only been determined for four islands in Tarawa: Bonriki, Buota, Abatao and Tabiteuea. A review is given of previous estimates of safe yield in Tarawa. Ranges of first order estimates have been made for the other major water lenses in North Tarawa but their accuracy is doubtful. It is strongly recommended that the sustainable or safe yield of these be accurately assessed as soon as possible. The combined safe yield of Bonriki, Buota, Abatao and Tabiteuea is 2.23 ML/d. It is estimated that the sustainable yield of all major groundwater lenses in Tarawa lies between 4.2 and 6.9 ML/d, close to the estimated demand by 2030.

Safety of local groundwater in South Tarawa

About 65% of households in South Tarawa and 95% of households in North Tarawa rely on local household for some of their drinking water requirements. The high permeability of coral sands in atolls and their lack of absorptive capacity means that local shallow groundwater wells, whether closed or open are at risk of contamination. The principal pollution threat to household wells, whether closed or open, and human health is from faecal contamination. There are two sources of faecal contamination in Tarawa, humans and animals (including birds). An analysis here on the risk of contamination by pit latrines, septic tanks, people using the bush and free ranging domestic animals shows that, in South Tarawa, the density of these pollution sources is over 16 times the US EPA recommended safety limit. North Tarawa, with its lower population density, has about one tenth of the density than in South Tarawa. It is suspected that many household water wells in higher density areas Tarawa are too polluted for use, except perhaps for toilet flushing. It is strongly recommended that intensive monitoring of household water wells in Tarawa be commenced.

Future options for groundwater supply

Seven progressive options for using available groundwater sources to supply future needs have been considered, together with their consequences, for increasing the water supply rate in Tarawa. They range from "do nothing", reducing leakage to 25%, refurbishing Bonriki reserve, using other groundwater sources in South Tarawa, sourcing water from Abatao and Tabiteuea, sourcing water from Buariki, and connecting all major groundwater systems in North Tarawa into the reticulation system. Development of North Tarawa groundwater systems and feeding that water into the South Tarawa reticulation system comes at a considerable penalty to residents of North Tarawa who have sufficient water themselves until 2030. The wisdom of sourcing groundwater from North Tarawa for South Tarawa needs to be considered carefully since North Tarawa at present seems a *de facto* growth centre, supplying South Tarawa with fresh produce produced by irrigation. With these options, and assuming that the rate of water loss has been reduced to 25%, the range of water available per person der day in South and North Tarawa expected to 2030 is

summarised below. By 2030, South Tarawa water availability is less than design demand of 60 L/pers/day.

Year	Option	Average Per Capita Water Availability South Tarawa (L/pers/day)			Average Per Capita Water Availability North Tarawa (L/pers/day)		
		2010	2020	2030	2010	2020	2030
Option 1	Do Nothing	22-23	18-21	12-15	250-680	145-390	68-220
Option 2	Leakage reduction South Tarawa	33-34	27-31	17-23	250-681	145-391	68-221
Option 3	Refurbish Bonriki	41-43	33-39	22-29	250-682	145-392	68-222
Option 4	Extra Sources South Tarawa	43-46	35-42	23-31	250-683	145-393	68-223
Option 5*	Abatao & Tabiteuea	45-49	37-45	24-33	275-774	170-431	84-246
Option 6†	Buariki	49-67	38-58	24-39	49-67	38-58	24-39
Option 7†	All remaining North Tarawa	58-97	46-83	29-56	58-97	46-83	29-56

*Includes Abatao and Tabiteuea with South Tarawa
† Includes all of North Tarawa with South Tarawa

Approximate costs of these options have also been estimated by amortizing costs over 20 years. Operational and maintenance costs have not been included. They are summarised below. Land rental for water reserves represents a substantial fraction of costs

	Option	Estimated Total Cost* Including Land Rental $million	Rental Costs 20 years $million	Extra Water Produced in 20 years (ML)	Cost/KL ($/KL)
1	Do Nothing	8.24	8.24	0	3.80†
2	Decrease Losses	11.5	0	3,700	3.11?‡
3a	Bonriki Remove Trees	0.07	0	1,370	0.06
3b	Bonriki Fill Ponds	2.08	0.38	1,370	1.52
4	South Tarawa Sources	0.47	0	550-1,100	0.43-0.86
5	Abatao & Tabiteuea	2.32	0.56	1,205	1.93
6	Buariki & Taratai	17.35	5.95	2800-8,300	2.08-6.23
7	All North Tarawa	36.45	17.3	7,900-21,200	1.72-4.63
	Total (1-5&7)	61.13	26.48	14,900-28,740	2.13-4.11

* Excludes maintenance and operations costs
† Includes current operational, maintenance and land rental costs.
‡ Price/KL on water saved in this option. Cost decreases as more sources used as per Table 29. Price depends on severity of problem which has yet to be assessed

Priority tasks

A number of priority tasks have been identified in this plan:

1. The urgent reduction of leakage from the domestic reticulation system.
2. An assessment of the current per capita water use in Tarawa from different sources.
3. Accurate assessment of operational, maintenance and depreciation costs of water supply system
4. Extensive monitoring of water quality in household water wells.
5. Detailed assessment of possible additional groundwater sources in South Tarawa.
6. Develop a drought contingency plan for South Tarawa involving conjunctive use of groundwater and rainwater.
7. The establishment of a community-government water reserve management committee to oversee the management, protection, conservation and development of the existing Bonriki and Buota water reserves.
8. Start negotiations over the possible removal of trees vegetation, the infilling of babwai and mining pits from the centre of Bonriki and possibly Buota water reserves. This will involve use of local landowners and could employ local landowners as custodians and managers of the reserve (tied to compensation payments). It also could involve establishment of sports fields on the reserve.
9. Commence negotiations with landowners and the local community over the possible infilling of the brackish water ponds at the western end of the Bonriki water reserve. A plan for cleaning organic matter the bottom of the ponds and using dredging to infill the ponds will need to be developed and cost/benefit studies conducted.

10. Finalise and report accurate assessments of the groundwater resources in North Tarawa. Since these have been surveyed in a very wet period, it is essential that all groundwater resources in North Tarawa be monitored to ensure that the safe yields are appropriate and that the water quality is acceptable.
11. Commence broadly-based discussions and debate about the possible, ethical, cultural and social and economic implications of transferring more water from North Tarawa to South Tarawa.
12. Start negotiations with communities in North Tarawa over the monitoring and development of all major groundwater sources in North Tarawa.
13. Start negotiations with MELAD over the information necessary for EISs for groundwater development in North Tarawa.
14. Examine the legal basis for proclaiming, managing and protecting water reserves in North Tarawa and the possible transfer of water from North Tarawa to South Tarawa.
15. Develop staff training and succession plans to ensure that PUB and MPWU staff have the necessary skills to carry out the complex tasks required in the future to use wisely, manage well and protect freshwater resources in Tarawa.

Information Gaps

This component of the plan has attempted to determine if the known and estimated groundwater sources in South and North Tarawa are able to supply the projected demand to the year 2030. The estimates here have been hampered by a lack of knowledge.

1. There is no information on the current average household use of water from various sources in Tarawa.
2. There is very little information on the quality of water from local household groundwater wells in Tarawa.
3. There is no accurate information on unaccounted for water losses in the domestic reticulation systems in South Tarawa.
4. Apart from Buota, Abatao and Tabiteuea, the safe groundwater yields of the remaining islands in North Tarawa have just been assessed in only a wet period and the lenses need to be monitored to ensure they are robust.
5. The impact of future sealevel rise on fresh groundwater availability and of climate change on groundwater recharge, demand for water and population density is uncertain.
6. The statutory basis for MPWU and PUB sourcing water from North Tarawa, declaring water reserves in North Tarawa, protecting and managing water reserves in North Tarawa is unclear.

This lack of information complicates the development of a soundly-based Tarawa Master Plan.

Assumptions

The main assumptions underpinning this plan are discussed below:

Groundwater from groundwater reserves will be the main source of water supply in Tarawa
Groundwater contained in thin freshwater lenses, floating over seawater have traditional been the main source of drinking water in Tarawa. Projects since the 1960s have developed reticulation systems to supply communities in South Tarawa with disinfected water. It has been assumed here that fresh groundwater lenses will continue to be the main source of freshwater to communities up to at least 2030.

Rainwater, household wells, rainwater and seawater will supplement piped groundwater use.
Currently many households in South Tarawa and most in North Tarawa rely on household groundwater wells to supplement their water supply. It has been assumed here that in South Tarawa local household wells in 50% of households will be too polluted to use. In South Tarawa, a substantial number of households and in North Tarawa a lesser number also use rainwater tanks to supplement water supply. It has been assumed here that that will continue into the future.

Populations in Tarawa will continue to grow at the estimated rates
Two population growth models have been assumed here in order to estimate future water demand in Tarawa. In the first, an upper estimate, the exponential growth model has been used together with the growth rates given by the NSO for North and South Tarawa, 4.8 and 1.9% per year respectively, for the period 2000 to 2005. These growth rates are assumed to hold until 2030. In the second, a lower estimate, it is assumed that South Tarawa is full so the population of South Tarawa will only reach

50,000 by 2030. In North Tarawa a linear fit of the percentage of the total Kiribati population living in North Tarawa from 2000 to 2005 is assumed to hold until 2030. These percentages are then applied to the NSO's total Kiribati 'most probable' population projection growing at an exponential rate of 1.8% per year from 2005 until 2030. The lower and upper population estimates span the expected population increases. Population growth projections have not taken into account any impacts of climate change on population growth.

The amount of per capita water needed in Tarawa is between 50 to 80 L/pers/day.

The SAPHE project used a design consumption figure for South Tarawa of 40L/pers/day. This is less than the current average supply rate. Here, a brief survey from Nonouti and a more detailed survey from all villages in Kiritimati suggest that with institutional, commercial and industrial use and increasing temperatures due to climate change the amount of water needed is assumed to be 50 L/pers/day for rural areas, 68 L/pers/day in urban areas where local groundwater is fit for non-consumptive use and 80 l/pers/day, for areas where local groundwater is too polluted for use. It has been assumed that water for toilet flushing will either be sourced from seawater or from local well water. It has also been assumed that 50% of the household wells are too polluted for use.

Leakage rates will decrease to 25%

The current rate of leakage in South Tarawa from the main reticulation pipeline is around 22%. The amount of leakage from the domestic reticulation system to households is unknown but is estimated to be at least 50%. This is enormously wasteful and means that it is not possible to supply sufficient treated water to meet current demand. NSO data shows that this forces many households in South Tarawa to rely on probably polluted household well water for consumption. This plan has assumed that in the future total leakage rates will be reduced to 25%, one of the target values in the PUB business plan.

Climate change impacts on sealevel

As global temperatures continue to increase it is expected that sealevel will continue to rise. This plan has used the results of a NIWA (2008b) study of sealevel rise in Tarawa and has assumed that the sustainable groundwater yield will decrease by 20% in 2030.

Climate change impacts on rainfall will be within the historic variation

The predicted impacts of climate change on rainfall, droughts and groundwater recharge are equivocal because the current GCMs do not predict historic tropical rainfall or ENSO events well. The relatively short records of historic rainfall, drought and groundwater recharge show very large variations and no significant trends with increasing global warming over the 60 year records. For that reason we have used the historic record to estimate sustainable groundwater yields in order to estimate the adequacy of supply.

Groundwater reserves will continue to be protected

A major assumption here is that the current water reserves at Bonriki and Buota will continue to be viable until 2030. Past groundwater reserves in South Tarawa have had to be abandoned due to the encroachment of settlements on the reserves. Maintaining the water reserves at Bonriki and Buota will require a commitment by government and the involvement of local communities.

Statutory basis

It is assumed here that both MPWU and PUB have the legal basis for sourcing water from North Tarawa, for declaring water reserves in North Tarawa and for protecting groundwater resources. It is also assumed that the Lands Division of MELAD has the legal basis for paying rentals to land owners in areas declared water reserves.

Table of Contents

List of Tables

List of Figures

1 Introduction

I-Kiribati have always recognised that freshwater is a vital and limited resource. *Te ran*, shallow groundwater, traditionally has been the main source of freshwater in the scattered atolls and islands that make up Kiribati. In former times water management from local groundwater wells was the responsibility of *kaainga*, a group of extended families sharing a piece of land. While this social organisation remains fundamentally important, particularly in rural, outer island areas, it is less so in high-density, urban areas, such as South Tarawa, which have developed over the past 50 years. There, traditional means of managing water supplies are not suited to managing and protecting treated piped water supplies sourced from groundwater reserves.

Geographical, hydrologic, climatic, demographic, cultural and socio-economic factors all combine to make water issues in Kiribati amongst the most complex in the world. Island communities experience the extremes of climate variability. Droughts related to La Niña events are common and safe freshwater is often scarce so water resources have to be protected and used carefully. Increasing impacts of human settlement, the vulnerability of freshwater sources in low, small islands to climate change, climate variability, and storm surges coupled to the links between development, poverty alleviation, health and safe water availability require continued leadership by the government and commitment by the community to protect, conserve and use wisely the nation's water resources.

At the inaugural Asia Pacific Water Summit in Beppu, Japan, in December 2007, Te Beretitenti, His Excellency Anote Tong, reaffirmed his government's commitment to protecting, conserving and using wisely the nation's water resources. Consequently, Cabinet of the Government of Kiribati on 14 January 2009 provided clear leadership by approving the National Water Resources Policy (NWRP) and the accompanying National Water Resources Implementation Plan (NWRIP). These built on previous government policies, decisions, national development strategies and development plans, and are timely responses to public concerns over the availability and quality of fresh water identified during wide community consultations under the World Bank (WB) National Adaptation Program of Action, Kiribati Adaptation Project Phase I (KAP I).

From the 2005 Census, approximately 43.5% of the national population of Kiribati lives in the capital on urban South Tarawa, with population densities as high as 12,500 people per square kilometre (pers/km^2). Altogether, Tarawa atoll has nearly 50% of the national population. Currently, estimates of the demand for sate water in South Tarawa exceed the sustainable yield from treated groundwater sources for South Tarawa (White and Falkland, 2009a). The limited land area of 31 km^2 in Tarawa, coupled with the population growth rate there, increases the difficulties of providing safe water for communities in the islands that make up North and South Tarawa (see Figure 1).

This Water Master Plan for Tarawa is a direct response to the National Water Resources Policy and the accompanying Implementation Plan. To construct the Interim Plan, analyses were undertaken of expected future demand for freshwater (White and Falkland, 2009a), sources of freshwater including rainwater (White and Falkland, 2009b), groundwater (this report and White and Falkland, 2009c), other sources (White and Falkland, 2009d) protection and management of water reserves (White and Falkland, 2009e, and partly covered in White *et al*, 2008). It is aimed at providing a strategic plan for the development of groundwater resources in Tarawa over the next 20 years. This component of the interim plan concentrates on the ability to supply future demand from groundwater sources in Tarawa.

1.1. Uncertainty in the Master Plan

The scope of this Plan is the development, management, protection and monitoring of fresh water resources in Tarawa taking account of all available water resources (primarily groundwater and rainwater) and possible additional sources. When the Water Component projects of KAP II were planned, it was envisaged that a companion project within KAPII on assessment of available water resources throughout Tarawa would have been completed prior to commencement of this Plan. The water resources of the islands of Bonriki, Buota, Abatao and Tabiteuea (Figure 1) were reassessed under the Asian Development Bank (ADB) Sanitation, Public Health and Environment Improvement Project (SAPHE), completed in 2005 (Falkland, 2005) but the remaining islands in North Tarawa are only now being assessed under KAPII. The quantities of groundwater water available for use in Tarawa are therefore only partly known, which is a significant impediment to the development of a Master Plan for the next 10 to 20 years. For this reason we acknowledge that this version Water Master Plan is based on uncertain estimates. This component of the plan covers only potential strategies for meeting demand from groundwater sources. Other issues will be considered in other components of the plan. It is recommended that when detailed information is provided on the water resources of North Tarawa and on the magnitude of water losses in South Tarawa that this plan be updated.

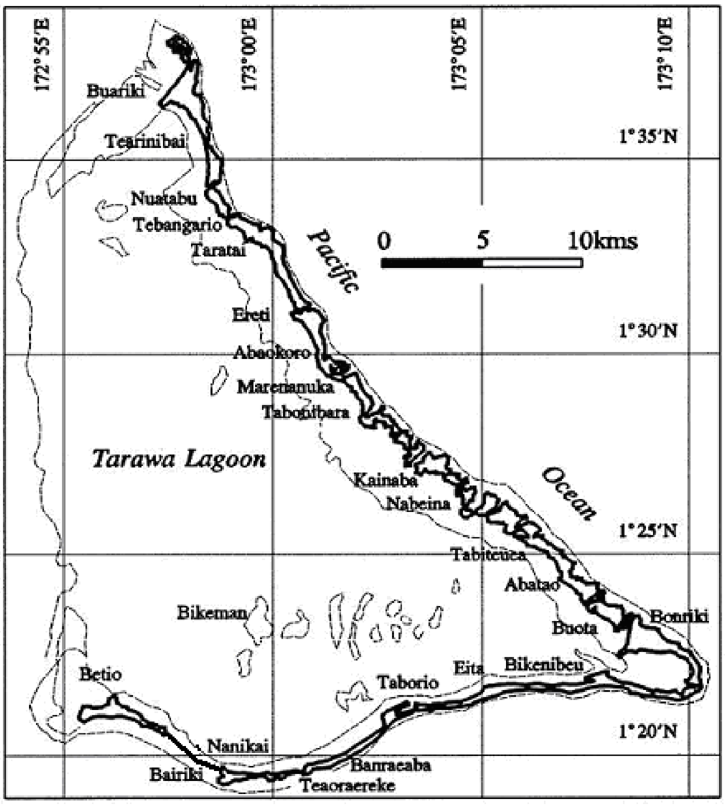


Figure 1. The islands of Tarawa Atoll, Republic of Kiribati. South Tarawa extends from Betio to Bonriki and North Tarawa from Buota to Buariki.

This Water Master Plan for Tarawa builds on previous plans and information contained in the Draft Water Master Plan of 1992 (Shalev, 1992) and subsequent revisions (WEU, 2000), the Public Utilities Board (PUB) Business Plan, 2004-2006 (PUB, 2004), the PUB Business Operation Plan 2008-11 (PUB, 2009), the 20 year roadmap plan for water resources (ADB, 2004), and project reports from the water component of the SAPHE project including the Review of Groundwater Resources Management for Tarawa (Falkland, 2003a). It is also a direct outcome of the both the 2009 Kiribati National Water Resources Policy and its Implementation Plan, which are used as a framework for this Interim Master Plan.

1.2 Consistency with National Water Resources Policy and Implementation Plan

The NWRP and the NWRIP, approved by Cabinet in January 2009, were developed using the Draft Water Master Plan of 1992 (Shalev, 1992) and its subsequent revisions (WEU, 2000), the ADB roadmap (ADB, 2004) and reports from the water component of the SAPHE project were used in the development of the National Water Resources Policy and Implementation Plan and based on previous Government of Kiribati (GoK) policies and statements. These earlier documents together with other reports clearly identified the following national priority issues in freshwater resources:

1. The high rate of preventable deaths and illnesses due to water-borne diseases;
2. Contamination of fresh groundwater sources by human settlements and sanitation;
3. Impacts of climate variability and change on the availability of fresh water;
4. Difficulties in protecting, conserving and managing freshwater sources;
5. Growth in demand for water especially in urban areas;
6. Inequities in provision of services to schools, hospitals, clinics, rural, outer island and urban communities;
7. Limited collection and use of rainwater;
8. Large unaccounted for losses and leakages in water reticulation systems;
9. Financially and hydrologically unsustainable water supply systems;
10. Constraints on development due to limited water supplies;
11. Inadequate knowledge and monitoring of the nation's freshwater resources;
12. Decrease in the number of trained water specialists and technicians;
13. Limited community participation in freshwater management and conservation;
14. Limited community understanding of responsible water use and protection; and
15. A need for enhanced water education in schools.

Many of the above issues apply directly to Tarawa. The NWRP and NWRIP were specifically designed to address the national priorities above through the following policy goals, policy objectives and activities:

Policy Goal 1. Provide safe, socially equitable, financially, technically and environmentally sustainable water supplies to enhance the welfare and livelihood of I-Kiribati.

1. Increase access to safe and reliable water supplies

- 1.1. Identify priority villages and islands for urgent attention.
- 1.2. Decrease the incidence of water-borne diseases by improving the safety of freshwater supplied from groundwater and rainwater systems.
- 1.3. Improve water supplies for schools, hospitals and clinics.
- 1.4. Improve outer island and rural water supplies.
- 1.5. Improve reliability of urban water supplies.
- 1.6. Increase the use of improved rainwater harvesting.
- 1.7. Increase access to safe, basic sanitation removed from water source areas.

2. Achieve sustainable water resource management

- 2.1. Develop policies, instruments, regulations and procedures to help manage demand, allocation and conjunctive use of water sources.
- 2.2. Determine sustainable groundwater extraction rates for all inhabited islands.
- 2.3. Identify acceptable land use practices for water source areas.
- 2.4. Examine the impacts of groundwater extraction on the environment.
- 2.5. Undertake timely maintenance and repairs of water supply systems, and improve operation of such supplies.

Policy Goal 2. Protect and conserve freshwater sources for public water supplies

3. Improve understanding and monitoring of water resources and their use

- 3.1. Improve knowledge of the quality and quantity of the nation's freshwater resources.
- 3.2. Improve understanding of water demand in urban, rural and outer island situations and the capacity to pay for water.
- 3.3. Improve knowledge and management of water resources under climatic extremes and the impacts of climate change.
- 3.4. Improve monitoring, data collection, storage, analysis and reporting of information on water resources.

4. Improve protection of public freshwater sources

4.1. Identify areas that have the potential to be used as water sources for public water supplies.
4.2. Review the regulations regarding Declaration of Water Reserves and their application to all public groundwater sources, and ensure their implementation.
4.3. Find ways of involving local communities in protecting water sources for public water supply systems.
4.4. Identify acceptable land uses for water source areas.
4.5. Improve educational and community awareness programs on protecting water sources
4.6. Develop a National Sanitation Policy.
4.7. Support regional and international projects with an aim to protect and conserve ground water resources and improve sanitation systems.

5. Increase community awareness of and participation in the protection, management and conservation of water

5.1. Improve understanding of the most effective ways of increasing community participation in the water and sanitation sector.
5.2. Increase community awareness and understanding of water resource issues, including protection and conservation.
5.3. Establish and resource water and sanitation committees at the island and/or village level.
5.4. Develop mechanisms for minimising conflicts over water resources.
5.5. Include community representation at the national level in water and sanitation planning.
5.6. Develop education programs for schools on protecting and conserving water supplies and wise water use.

Policy Goal 3. Deliver freshwater efficiently and effectively.

6. Improve governance in the water sector

6.1. Review, revise and make recommendations on water and sanitation policy.
6.2. Review, recommend and enact procedures for implementing policy and monitoring the effectiveness of policy.
6.3. Review, revise, and where necessary enact legislation, regulations and codes relevant to water and sanitation and to the declaration and protection of water reserves.
6.4. Improve coordination and cooperation between agencies with responsibilities in the water and sanitation sector and with relevant community organizations.
6.5. Develop strategic water and sanitation plans for urban South Tarawa and designated growth centres,
6.6. Improve capacity of personnel involved in providing and ensuring safe and sustainable supplies of freshwater.

7. Decrease unaccounted for water losses, improve cost recovery and find alternate sources of water

7.1. Develop effective leak detection, loss reduction and remediation programs for reticulated water supply systems.
7.2. Increase cost recovery for water supply systems.
7.3. Explore alternate sources of freshwater

The above priorities, goals, objectives and activities are directly applicable to Tarawa and are consistent with the Review of Groundwater Resources Management for Tarawa (Falkland, 2003a) and the Kiribati Development Strategy (2008-11). The PUB Business Plan, 2004-2006 (PUB, 2004), the PUB Business Operation Plan 2008-11 (PUB, 2009), and the Kiribati Development Strategy 2008-11, which was developed before the Policy and its Implementation Plan. Its general thrust is, however, consistent with both. Consequently, this Master Plan will use the above goals, objectives and activities as a framework for developing strategic plans to address current and freshwater resource issues in Tarawa.

The current use of freshwater in Tarawa is discussed in the demand component of the TWMP (White and Falkland, 2009a). It shows that the major and most reliable source of freshwater in Tarawa is groundwater. Here we focus on the groundwater resources in Tarawa.

2 Te Ran, Groundwater in Tarawa

Shallow groundwater has been the main source of freshwater since Tarawa was first settled. Fresh through to brackish to saline shallow groundwater is found throughout the islands of Tarawa and in most has been and remains the main source of water for family groups and communities. In the following, the nature of shallow fresh groundwater in atolls is discussed, then a brief survey of past studies of groundwater is given, followed by a review of the amount of water that can be sustainably pumped from these lenses.

2.1 Shallow Fresh Groundwater Lenses

The fresh to brackish groundwater in Tarawa exists as very thin freshwater lenses, mostly less than 25 m thick, floating in the coral and limestone aquifers over a thick brackish saline water transition zone caused by the tidal mixing of the freshwater with the underlying seawater (Figure 2). Fresh groundwater lenses are replenished by groundwater recharge from rainfall which percolates rapidly through the shallow depth of overlying, very permeable coral sands. Most of the groundwater is contained in unconsolidated Holocene sands and gravels which overlie much older Pleistocene karst limestone, which has very large hydraulic transmissivity.

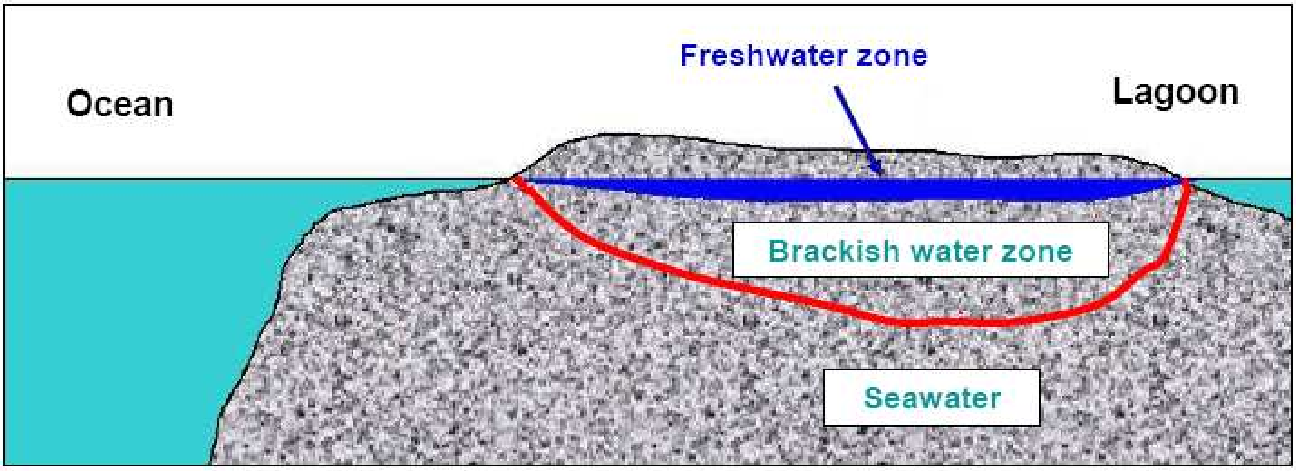


Figure 2 Cross section through a coral atoll showing the thin freshwater lens floating over a brackish transition zone between the lens and underlying seawater in the limestone aquifer

The amount of fresh groundwater available for use is governed by the groundwater recharge rate, the width of the island, the rate of transmission of water through the coral sand and limestone aquifer and the rate of tidally-produced mixing with the underlying seawater in the karst limestone. So the store of available fresh groundwater in an island is a delicate balance between replenishment by rainfall recharge and groundwater being lost through evapotranspiration, discharge into the sea and lagoon at the edge of the island, mixing with underlying seawater and being pumped out for use (Figure 3).

The recharge of groundwater by rainfall is a critical process in the management of water supply systems in low coral islands. It is dependent on rainfall, infiltration of rainfall into the soil, evapotranspiration losses through direct evaporation from the soil and transpiration by plants of stored water back into the atmosphere. The roots of some plants such as coconut trees and pandanus palms are able to tap into the groundwater itself. Removing plants from a groundwater source area decreases transpiration losses and can increase groundwater recharge. The amount of water that can be pumped out of a groundwater system is always less the recharge rate because of the loss of the freshwater through mixing with the underlying seawater or discharge to the sea (Figure 3). In the long term, the mean rate of discharge and mixing with seawater is equal to the mean groundwater recharge rate.

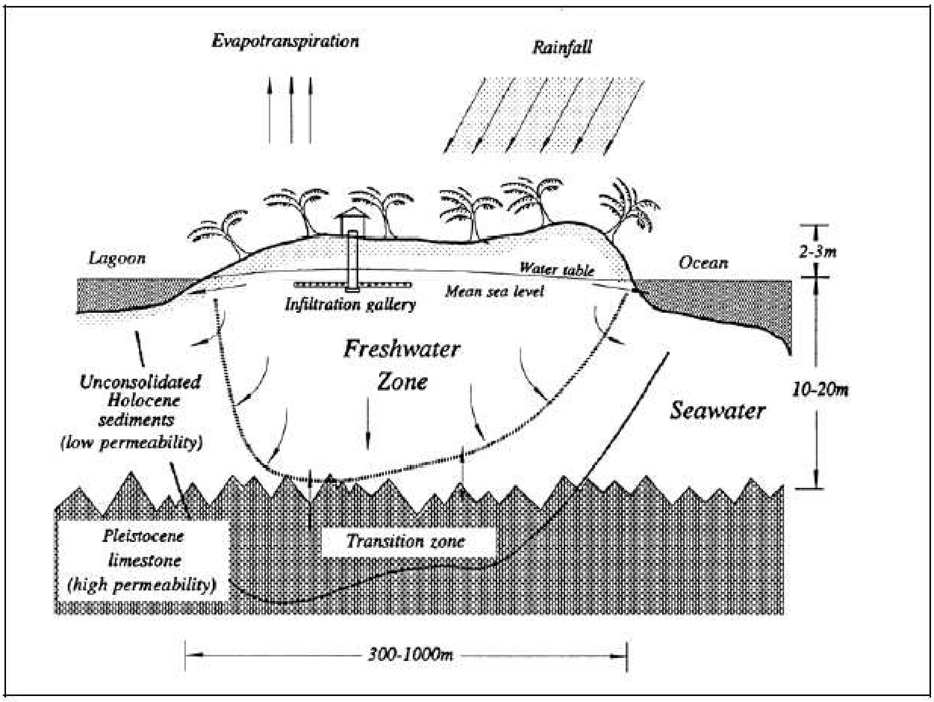


Figure 3 Exaggerated vertical scale cross section through a small coral island showing the main features of a freshwater lens including rainfall recharge, evapotranspiration losses. Discharge to the sea, and tidal mixing creating the transition zone. An infiltration gallery used for groundwater abstraction is also shown.

2.2 Tidal Mixing and Recharge of Groundwater Lenses

On small islands, daily fluctuations in sea level, primarily due to tides, cause movement of the freshwater lens and promote mixing of fresh and seawater, increasing the transition zone thickness. In atoll islands, the amount of tidal mixing is independent of horizontal distance from the shore (e.g. Hunt and Peterson 1980). The reason for this is the rapid transmission of the tidal pressure signal in the underlying high permeability karst Pleistocene limestone. Vertical propagation of tidal signals tends to be dominant in the middle of the island whereas both horizontal and vertical propagation are significant near the seawater margins. This diurnal mixing process erodes freshwater from and injects salinity into the base of the lens.

Recharge of groundwater by heavier rainfalls, usually in excess of 20 mm, occurs rapidly, within an hour or so of the event and causes the groundwater table to rise rapidly. This rapid recharge means that any surface pollutants, or contaminants buried in the shallow coral sands are rapidly transported into the fresh groundwater. Figure 4 shows the response of water table elevation to tidal forcing and to rainfall recharge at Bonriki. The tide can be seen to force the water table elevation to fluctuate daily, while large rainfall recharge events cause rapid rises of the watertable which then decay quite quickly as groundwater is discharged around the shore of the island following rainfall.

2.3 Impacts of Droughts and ENSO Events on Groundwater Lenses

Extended droughts have significant impacts on groundwater lenses in Tarawa (White et al. 1999a). These frequent droughts in Tarawa are strongly correlated with climate variability associated with inter-annual La Niña cycles (Pittock, 1984)and sea surface temperatures (SST). Figure 5 shows the relationship between the depth of the freshwater lens at the edge of Bonriki Island and La Niña and El Niño events identified by the Southern Oscillation Index, SOI. It can be seen that in El Niño events, the depth of freshwater in the lens at the edge of the island thickens due to the increased rainfall while in La Niña events, normally associated with droughts, the lens thickness shrinks as water is lost from the lens and not replaced by rainfall recharge.

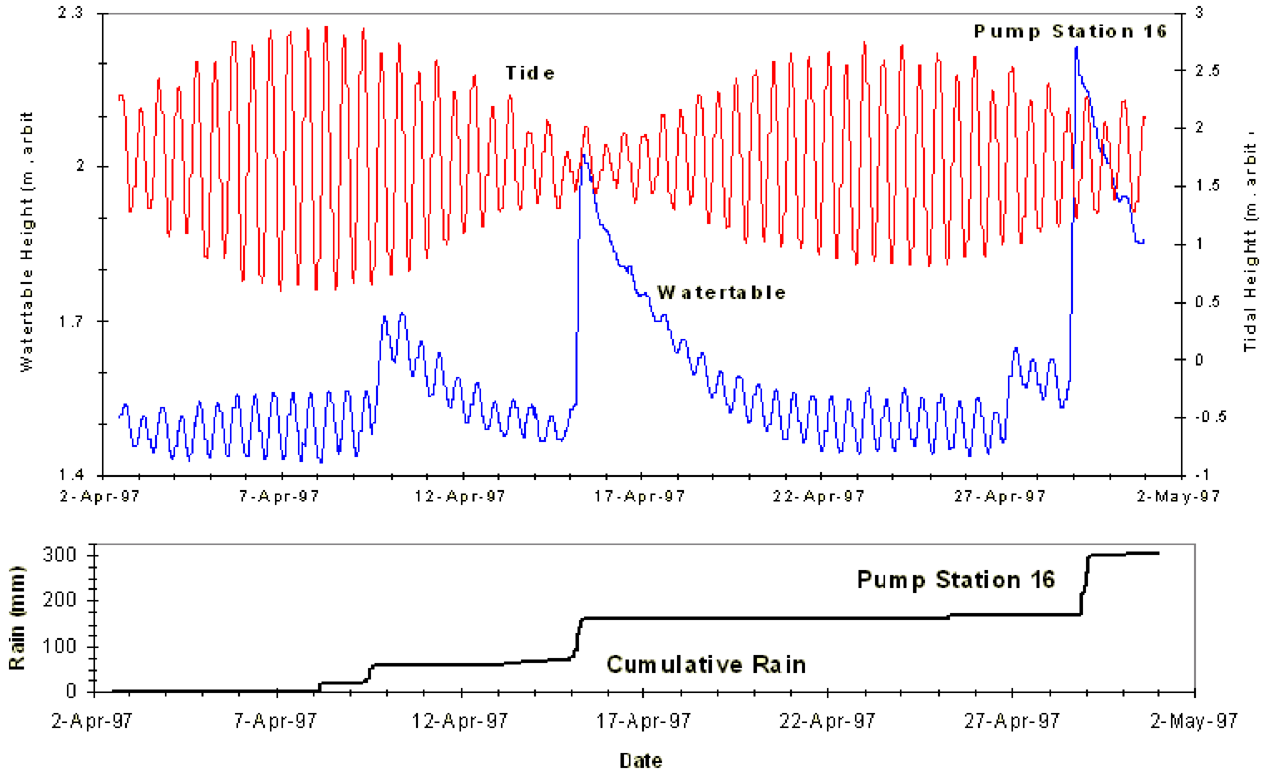


Figure 4 Response of the water table elevation in the pumping well of an infiltration gallery to both tidal forcing and rainfall on 9, 15-16 and 29 April, Bonriki. This well is about 280 m from the ocean (from White et al., 2007b)

In Tarawa, where mean rainfall is appreciable but where annual rainfall has a high coefficient of variability, only large freshwater lenses in wider islands, such as those at Bonriki and Buota, remain viable at the end of major droughts.

2.4 Groundwater Salinity

One way of easily assessing the salinity of the groundwater is to use portable, hand-held electrical conductivity (EC) meters that measure the EC (in µS/cm) of the water, which is related to the water's salinity. As a rule of thumb for small islands, water with EC greater than 2,500 µS/cm is considered too salty for human consumption or watering plants. The EC of the combined pumped groundwater outputs from Bonriki and Buota water reserves since 1996 is shown in Figure 6 where it is compared with annual rainfall at Betio. It can be seen that even in the 1998-2001 and 2008 droughts, the EC was well below the nominal 2,500 µS/cm drinking water limit indicating the significant stores of water in these lenses. The inverse relation between EC of the combined pumped groundwater and annual rainfall is apparent in Figure 6. The anomalous peak in 2005 appears to be due to works carried out during the SAPHE project when pumps were changed to higher pumping rates.

In droughts, with limited or no rainwater recharge of the groundwater store for long periods, the fresh groundwater lens shrinks in thickness, the width of the saline transition zone increases in thickness and the salinity of groundwater increases. On narrow islands, effects of droughts and excess extraction of groundwater are noticed much earlier than on wider islands. Sometimes in these narrower islands, the groundwater can become too saline to use for drinking water. Even in large islands like Bonriki, the effects of saline intrusion can be measured during droughts (Figure 7)

Figure 5 **Relationship between the depth of the freshwater lens below the land surface at the ocean edge of Bonriki and La Niña and El Niño events identified by an average of the SOI over the previous 12 months (White and Falkland, 2009).**

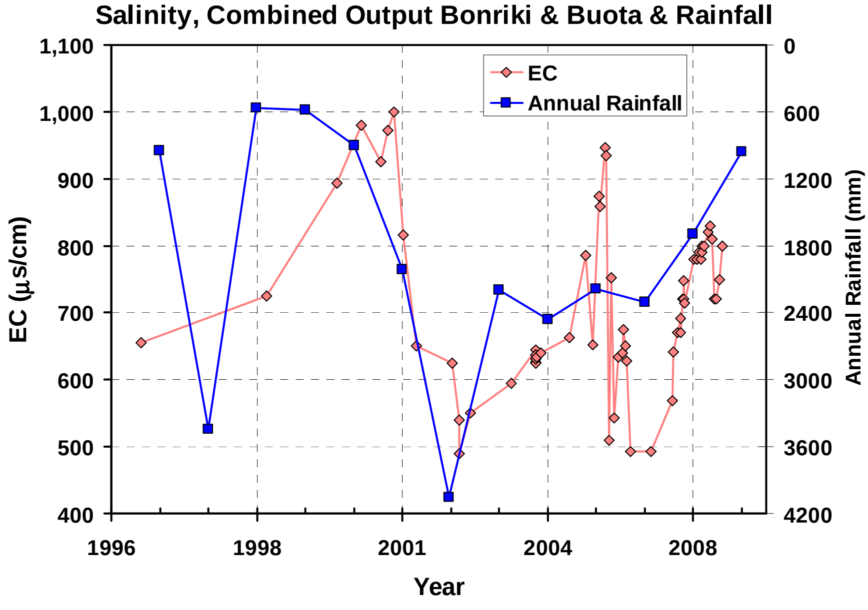
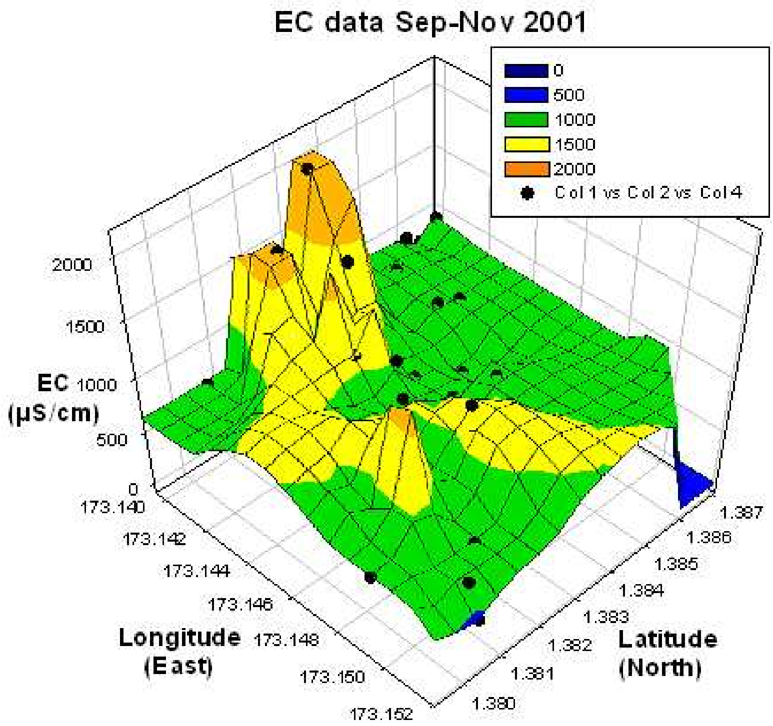


Figure 6 **The salinity (EC) of the combined groundwater pumped from infiltration galleries on Bonriki and Buota compared with annual rainfall. The impact of the 1998 to 2001 and the 2008 droughts and the 1996 and 2002 wet periods are evident.**



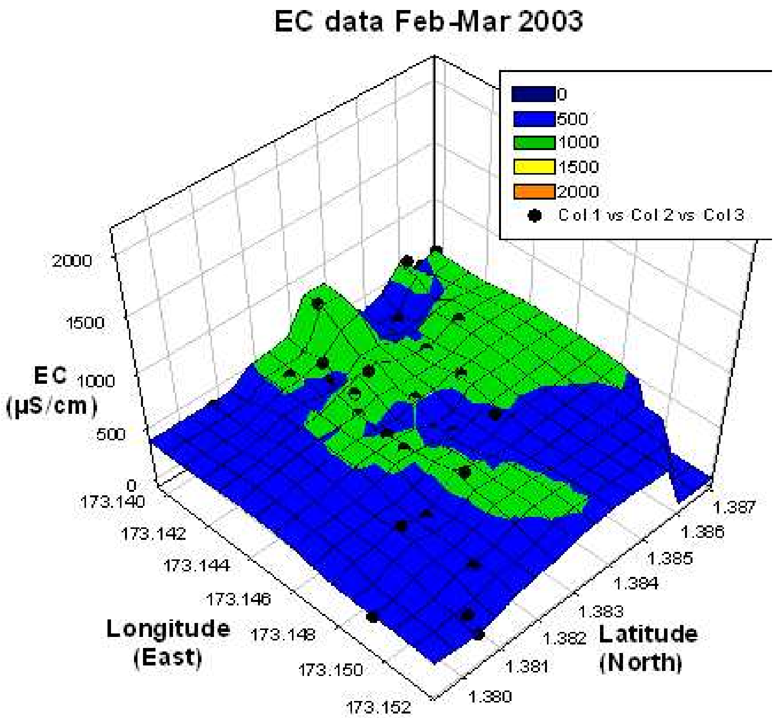


Figure 7 Salinity (EC) distribution in Bonriki water reserve showing seawater intrusion from the lagoon side at the end of the severe ENSO-related 1998-2001 La Niña drought compared with the distribution when the drought had broken (White et al. 2003). The Bonriki freshwater lens was being pumped at a rate of 1,300 m^3/day throughout this period.

2.5 Impact of Abstraction and Pumping on Groundwater Lens

Groundwater was traditionally accessed by households using shallow, open, vertical, hand-dug wells. Almost all households in Tarawa still have these or similar types of vertical wells. If pumps are used in these vertical wells, the salinity of the extracted water can increase dramatically. This is because vertical wells can draw up brackish water zone underlying the fresh groundwater lens (Figure 2).

In South Tarawa, fresh groundwater is pumped from long, horizontal infiltration galleries or skimming wells located in the islands of Bonriki and Buota. These infiltration galleries are designed to skim off the freshwater from the top of the freshwater lens and minimise the draw-up of brackish water. If, however, these are pumped at too high a rate, salinity can also increase. Figure 8 shows the impact of both rainfall and pumping on the local groundwater salinity (EC). In the late 1970s and early 1980s the rate of pumping from this gallery was small, around 30 KL/day, and salinity was low. By 1987 that rate had risen to 55KlL/day but the record rainfall of 1993 kept salinity low. The record-breaking 1998 - 2001 drought combined with pumping caused an increase in salinity of this infiltration gallery which decreased when rains returned in 2002-3. In 2005 the pumping rate was increased significantly from 55 KL/day to 120 KL/day when a new pump was installed under the SAPHE scheme. The salinity increased dramatically in drier periods in 2006 and 2008, despite the droughts in those years being less severe than the 1998 – 2001 drought. This figure again illustrates the importance of regular monitoring in groundwater management.

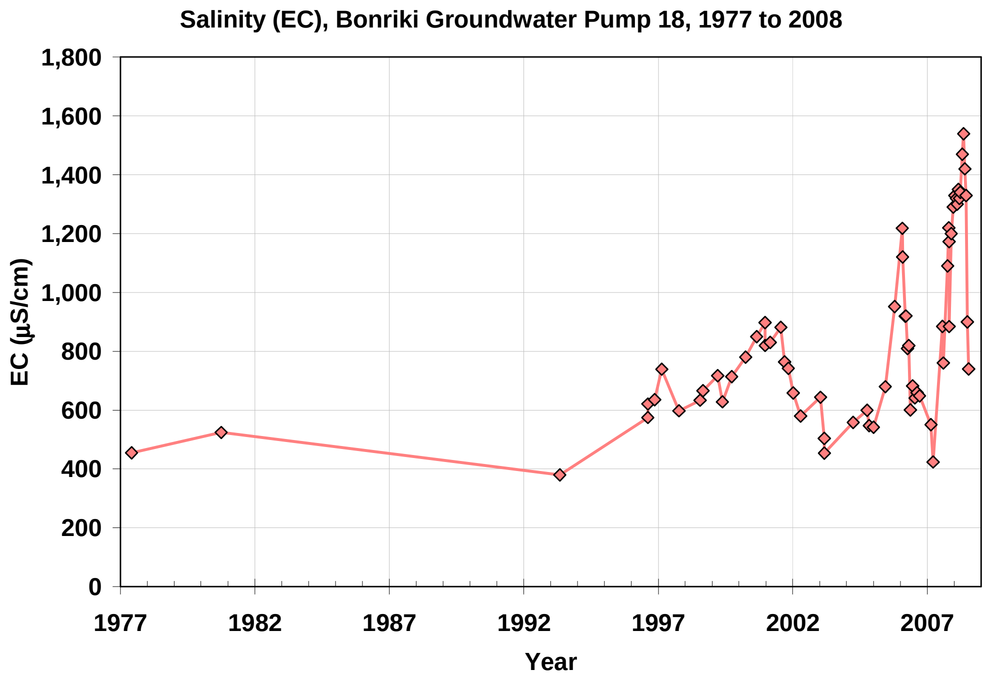


Figure 8 Change in salinity (EC) of water pumped from a short infiltration gallery (PS18) at Bonriki, South Tarawa. From 1996 to 2004, the pumping rate was 55 KL/day. In 2005 it was increased to 120 KL/day

The next section summarises previous estimates of the safe yield from groundwater lenses in Tarawa suitable for pumped water supply.

3 Previous Studies of Groundwater Sources in Tarawa

There are a number of previous water resources studies of freshwater lenses on Tarawa which concentrated on the safe yield of fresh groundwater lenses suitable as sources for reticulated water supply. These are discussed below.

3.1 Early studies

Kirk, Grundy and Partners (1961) studied the groundwater resources of South Tarawa to improve water supplies for Betio, Bairiki and Bikenibeu. Water table fluctuations were measured, water samples were collected for chemical analysis and a preliminary study of the water balance of both groundwater resources and rainwater catchments was carried. The study recommended the installation of short, approximately 61 m long pilot infiltration galleries at Betio, Teaoraereke and Bonriki with pump rates initially of about 109 KL/day. Monitoring procedures including water level and salinity tests were outlined and the pilot galleries were subsequently constructed. Wilton and Bell, Dobbie and Partners (1967) recommended further development of the groundwater resources on Betio, Bairiki and Bikenibeu and the declaration of water reserves at Betio, between Teaoraereke and Antebuka for Bairiki and at Temaiku for Bikenibeu. Increased settlement in Betio forced the abandonment of the gallery there in the 1970's.

Mather (1973) conducted a number of field tests including measurements of water level and water chemistry at wells, an electrical resistivity survey and a limited drilling programme. He concluded that the lens on Betio was very thin and unable to sustain the then pumping rate of about 90 KL/day. The Bairiki lens was found to be even thinner and less sustainable than the Betio lens. Based on salinity observations and a resistivity survey at the Teaoraereke water reserve, Mather concluded that it was non-sustainable for potable water but could be used as a source of brackish water. At the time, one of a proposed five galleries was operational, pumping at a rate of 36 KL/day.

The Bikenibeu area was found by Mather to also be underlain with a thin freshwater lens but was not be considered suitable for a sustainable potable water source. The most extensive investigations were conducted at Bonriki where it was found that the freshwater was greater than 12 m thick over an extensive area. Mather believed the lens was probably more extensive before the ponds at the western, lagoon end of the present airstrip were excavated. He also found an extensive lens at Buota but concluded there were only thin lenses on Abatao and on Tabiteuea.

Mather estimated that the recharge was not more than about 250 mm per year or about 12% of mean annual rainfall and that the safe yield from four infiltration galleries at Bonriki was about 110 KL/day with a similar amount available from the Buota lens. Mather also recommended the declaration of a water reserve at Buota and that the regulations concerning the other water reserves should be better enforced. Following Mather's report, new galleries were installed at Bonriki and Buota and distribution pipes laid from Bonriki to Betio (AGDHC, 1975). The water reserve at Buota was declared on 9th September1974 and Bonriki was declared in the legislation of 1977.

Wagner (1977) summarises some of the previous studies and went further to estimate that the combined yield from the lenses at Teaoraereke, Bonriki and Buota was about 295 KL/day in periods of normal rainfall and about 180 KL/day in drought periods. The actual pumping rate at the time of Wagner's study was about 210 KL/day (40 KL/day from Teaoraereke and 85 KL/day each from Bonriki and Buota). Wagner recommended further monitoring of salinity at galleries and nearby sites including the Bonriki ponds, and the installation of a rain gauge at Bonriki.

Richards and Dumbleton International (1978) investigated water resources for Tarawa including a re-evaluation of groundwater potential. They conducted electrical resistivity surveys at a number of locations on both South and North Tarawa and used a sharp-interface model to analyse four of the known freshwater lenses at Teaoraereke, Bonriki, Buota and Buariki. They concluded that the Bonriki lens, even under very small pump rates was not sustainable in a 1 in 50 year (2%) drought with a duration greater than one year. Their model showed large variations in the freshwater zone of each lens on a year to year basis. They concluded that the potential for further groundwater development was limited and that alternative water sources such as an artificial rainwater catchment and collection system should be considered.

Harrison (1980) in a socio-economic study claimed that Richards and Dumbleton International had incorrectly listed the yield of lenses at the water reserves of Teaoraereke, Bonriki and Buota. Based on Mather (1973) and largely on the relative areas of the three islands he estimated the yields of the water reserves at Teaoraereke, Bonriki and Buota were equivalent to 118 KL/day, 2.35 ML/day and 1.18 ML/day. Subsequent monitoring of freshwater lenses using salinity monitoring boreholes and salinity of the pumped groundwater has shown that Richards and Dumbleton International predictions were incorrect and that the freshwater lenses are more robust and extensive than they predicted but that Harrison's estimates for Bonriki and Buota were too optimistic.

3.2 The Tarawa Water Supply Project, TWSP

Investigations of the groundwater resources of Tarawa (AGDHC, 1982) were carried out as pre-design study for the AIDAB Tarawa Water Supply Project (TWSP). These used the results of geophysical investigations (Jacobson and Taylor, 1981) and a drilling programme (Murphy, 1981) on the thickness and behaviour of the freshwater lenses. Using the results of AGDHC (1982), the TWSP installed 23 of the present galleries at Bonriki and Buota. As part of the study, a recharge model was developed to estimate recharge from monthly rainfall, a relationship between potential evaporation and rainfall and other soil and vegetation parameters. The recharge values were provided as input to a sharp interface model of the Bonriki lens which was used to assess the sustainable yield of the lens using recharge data for the 34 year period from 1947 to 1980. The selected values of sustainable yield for Bonriki and for some of the other freshwater lenses are listed in Table 1.

Table 1. Estimated sustainable yields from islands in Tarawa (AGDHC, 1982)

Island	Sustainable Yield (KL/day)
Bonriki	750
Buota	250
Teaoraereke	150
Abatao	200
Tabiteuea	150
Total	**1500**

The sustainable yields for these lenses is equivalent to about 30% of mean annual recharge, which was estimated to be 34% of mean annual rainfall. This means that the estimated sustainable yield was about 10% of mean annual rainfall. The sustainable yields of other lenses in North Tarawa particularly that at Buariki, were not calculated in AGDHC (1982) although Jacobson and Taylor (1981) commented on the groundwater potential of islands between Tabiteuea and Buariki. DHC (1986) reviewed the design and planning assumptions for the TWSP and accepted the above sustainable yields. The recommendations made in that review on a wide range of water management issues are still relevant.

3.3 Post TWSP Studies

Shalev (1992) used the results of previous studies, primarily DHC (1982), to calculate low and high limits for the sustainable yields of all islands in Kiribati except Banaba. He adopted the combined values for Teaoraereke, Bonriki and Buota in Table 1 of 1,150 KL/day. For North Tarawa, based of island area and recharge estimates, he suggested a safe yield range between 1,240 and 4,100 KL/day.

The Government of Kiribati requested assistance from the Government of Australia to undertake a review of the safe yield of the freshwater lenses (fresh groundwater) on Tarawa in 1991. Falkland (1992) carried out that review and combined an analysis of salinity data from monitoring boreholes and pumping records together with a computer model to simulate the effects of historical rainfall sequences on groundwater recharge. His results for Teaoraereke, Bonriki and Buota are listed in Table 2.

Table 2 Estimated sustainable yields for South Tarawa water supply (Falkland 1992)

Island	Sustainable Yield (KL/day)
Bonriki	1,000
Buota	300
Teaoraereke	100
Total	**1400**

Falkland noted that the estimated long-term recharge to the freshwater lenses from rainfall was about 35% of rainfall (about 700 mm per year) in areas where there is a good cover of coconut trees and other vegetation. He estimated that if trees were cleared, recharge could be increased to nearly 50% of rainfall (close to 1000 mm per year) due to the prevention of direct evapotranspiration losses of groundwater to the atmosphere through tree transpiration.

Falkland also proposed that if the low areas both sides of the Temaiku causeway were infilled with dredged materials, it would be possible eventually to extract an additional safe yield of 4,800 KL/day. By 1993, encroachment on the water reserve at Teaoraereke-Antebuka, declared in April 1968, had forced the return of the water reserve there to landowners so that South Tarawa water supply came from only Bonriki and Buota.

Based on limited data and on the results from the Bonriki, Buota and Teaoraereke lenses, Falkland estimated the sustainable yields for the freshwater lenses on islands in North Tarawa (Table 3), excluding Buota which has long been part of the South Tarawa water supply system. Falkland's total estimate for the combined water yield of North Tarawa was close to the upper limit suggested by Shalev (1992).

Table 3 First order estimates of the sustainable yields for islands in North Tarawa, except Buota (Falkland, 1992; 2003)

Island	Estimated Sustainable Yield (KL/day)	
	Falkland (1992)	Falkland (2003b)
Abatao	250	300
Tabiteuea	300	360
Tabiang	150	180
Marenanuka	250	300
Abaokoro	50	60
Taborio	200	240
Taratai	600	720
Tebangaroi	150	180
Nuatabu	150	180
Tearinibai	250	300
Buariki	1,500	1,800
Total	**3,850**	**4,620**

A UNESCO IHP study of the recharge process at Bonriki which included direct measurements of coconut tree evapotranspiration, found that estimates of evapotranspiration losses using potential evaporation overestimated evaporation losses. Instead equilibrium evaporation seemed to be a better estimate (White *et al.*, 2002). This meant that recharge estimates were 30% too low and yields could be increased.

3.4 The ADB SAPHE Project

A technical assistance project was undertaken as a pre-cursor to the ADB Sanitation, Public Health and Environment (SPAHE) project (Royds, 1996) to prepare a prioritised programme of improvements in water supply, sewage disposal and solid waste management. Royds (1996) adopted Falkland's (1992) estimates of sustainable yield from Bonriki and Buota reserves but suggested that salinity monitoring results indicated a 20% increase in safe yield was feasible. They noted that the pumping rates in February 1996 from Bonriki and Buota were 1,069 and 374 KL/day, respectively, 7% and 24% above the then estimated sustainable yield.

OEC (2000) in a SAPHE project water supply design report adopted the safe yields listed in Table 4. The sources used for those estimates were not provided, except that the estimated yield for Bonriki is 20% greater than that of Falkland (1992), as suggested by Royds (1996), while the yields for Buota, Abatao and Tabiteuea appear to be those of Falkland listed in Table 2 and Table 3. OEC noted that more detailed studies of safe yield were planned as components of the SAPHE project.

Table 4 Estimates of the safe yields adopted by OEC (2000) for the SAPHE project

Island	Sustainable Yield (KL/day)
Bonriki	1,200
Buota	300
Abatao	250
Tabiteuea	300
Total	**2,050**

During the SAPHE project, additional investigations of the safe yields at Bonriki, Buota, Abatao and Tabiteuea were undertaken involving numerical modelling (Alam *et al.*, 2002), further drilling and installation of monitoring boreholes, analysis of salinity profiles and electromagnetic (EM) surveys (Falkland *et al.*, 2003; Falkland, 2004). The estimates from those SAPHE investigations for Bonriki, Buota, Abatao and Tabiteuea are compared in Table 5 with the previous studies discussed above.

Table 5 Successive estimates of the daily sustainable groundwater yield from Bonriki and Buota water reserves, and Abatao and Tabiteuea fresh groundwater lenses, Tarawa Atoll,

	Estimates of Sustainable Yield (KL/day)					
Year	**Bonriki**	**Buota**	**Combined**	**Abatao**	**Tabiteuea**	**Reference**
1973	110	-	-	-	-	Mather (1973)
1978	<85	<85	<170	-	-	Richards and Dumbleton (1978)
1980	2,350	1,180	3,530	-	-	Harrison (1980)
1982	750	250	1,000	200	150	AGDHC (1982)
1992	1,000	300	1,300	250	300	Falkland (1992)
2002	1,350	350	1,700	-	-	Alam *et al.* (2002)
2003	-	-	-	85	135	Falkland *et al*. (2003)
2004	1,660	350	2,010	-	-	Falkland (2004)

Except for the estimate of Harrison (1980), Table 5 shows that there has been a successive increase in the estimated sustainable yield of Bonriki and Buota water reserves. On the basis of these estimated yields, four additional galleries were designed and constructed at Bonriki (Falkland 2004). For Abatao and Tabiteuea, however, the assessed sustainable yields have decreased significantly below the first order estimates. This is partly due to the improved information from the electromagnetic surveys and partly due to the area occupied by settlements, market gardens and babwai pits (Falkland *et al.*, 2003).

3.5 ADB Effective Water Management Policies and Practices

At the same time as the SAPHE project, a strategic ADB technical assistance project, Promotion of Effective Water Management Policies and Practices (ADB, 2004), focussed on outer island water resources. In many ways this was a missed opportunity since South Tarawa was precluded from an otherwise national study because it was supposedly covered by the SAPHE project. As part of that technical assistance, revised estimates were made by Falkland (2003b) of the safe yields of islands in North Tarawa (except Buota). These were based on the results of more detailed groundwater modelling of both the Bonriki and Buota lenses (Alam et al, 2002), where it was found that the safe yield of Buota should be increased by 20% from those in Falkland (1992). The sustainable yield estimates for all the North Tarawa islands with known freshwater lenses were therefore increased by 20%. The sustainable yields estimated in this way (Falkland, 2003b) are compared in Table 3 with earlier estimates from Falkland (1992).

Falkland (2003b) remarked that it was essential to thoroughly investigate each island if future, large-scale pumping systems were to be installed. The reason for this is apparent by observing that the safe combined yield of Abatao and Tabiteuea estimated by Falkland *et al.* (2003b) from filed electromagnetic surveys, 220 KL/day is only 40% of the safe yield estimated by Falkland (1992)(550 KL) and only 33% of the later safe yield of 660 KL/day estimated by Falkland, (2003b). If such a reduction in yield applies to all the lenses in North Tarawa (Table 3), then the total amount of water available there would be 1,540 KL/day. In the absence of actual groundwater survey data from North Tarawa, the safe yield is somewhere between 1,540 and 4,620 KL/day.

3.6 Pacific Regional Consultation 2002

The Kiribati country paper for the Pacific Regional Consultation Meeting on Water in Small Island Countries in Sigatoka, Fiji, 29 July - 3 August 2002 (Metutera, 2002) recognised that the population growth rate in South Tarawa coupled with its limited water sources, means that it will be very difficult to its population with clean and potable water from existing sources. It used the estimates of Falkland (1992) to approximate the groundwater yields potentially available in North Tarawa. The paper, however, recognised that land ownership issues would be a significant impediment to developing groundwater resources in North Tarawa. It would require time consuming and difficult negotiations. The abandonment of the water reserve in Teaoraereke in the early 1990's and the continuing problems in Bonriki and Buota water reserves over landownership were seen a major problems that required government attention if groundwater reserves were to be created in North Tarawa.

3.7 Known Groundwater Resources in Tarawa

In August 2010, the groundwater resources in Tarawa have only been accurately assessed and reported for the islands of Bonriki, Buota, Abatao and Tabiteuea (

Figure 9). Their yields and are listed in Table 6. Assessment includes mapping the extent of useable freshwater lenses and estimating their sustainable or safe yield[1]. Estimation of the sustainable yield is fundamentally important as it determines the maximum rate that water can be abstracted from the groundwater resource without the risk of failure of the resource. This is centrally important in Tarawa because of the frequent major droughts. As information and assessment techniques improved, estimates of the sustainable combined yield for Bonriki and Buota have increased from essentially zero in 1978 to the current estimate of 2.01 ML/day.[2] For the current population of South Tarawa, that is equivalent to less than 43 litres per person per day (L/pers/day) provided there were no leakages in the water supply system.

Table 6 Current, accurately assessed yields of groundwater lenses in Tarawa as of August 2010

Island	Location	Yield (KL/day)	Reference
Bonriki	S.Tarawa	1,660	Falkland (2004)
Buota	N. Tarawa	350	Alam et al. (2002)
Abatao	N. Tarawa	85	Falkland et al. (2003)
Tabiteuea	N. Tarawa	135	Falkland et al. (2003)
	Total	**2,230**	

In some cases, the safe pumping rate may be less than the estimated sustainable yield because of geographic, economic, or social constraints. For example, the combined sustainable yield for the

[1] The sustainable (or safe) yield of a groundwater system is taken here as the amount of water that can be withdrawn in a given time without producing an undesired or adverse effect (such as salinisation of the groundwater).

[2] 2.01 Megalitres per day (ML/d) or 2,010 cubic metres per day (m^3/day) or 2,010 kilolitres per day (KL/d).

islands of Abatao and Tabiteuea was estimated to be 0.43 ML/day (Falkland et al. 2003). In order to position pumping galleries at least 50 m away from houses and other developments, however, the safe combined pumping rate has been reduced to 0.22 ML/day.

3.8 Yields per Land Area and Gallery Design

One way of assessing the yields of groundwater lenses for the design of pumping galleries is to estimate the sustainable yield per unit land area per day. In assessing the yields of Abatao and Tabiteuea, Falkland *et al.* 2003, estimated the daily yield per unit land area for Bonriki and Buota water reserves. It was found for Bonriki that the daily yield per hectare[3] (ha) was equivalent to 13 /ha/day and that for the smaller island of Buota of 11 KL/ha/day. Because both Abatao and Tabiteuea are narrower islands than Buota it was assumed that the safe yield of these for gallery design was 10 KL/ha/day.

For some of the larger islands in North Tarawa, such as Taratai and especially Buariki it is reasonable to assume that their daily yield per ha is similar to Bonriki, 13 KL/ha/day.

Figure 9. The four islands in Tarawa, Bonriki, Buota, Abatao and Tabiteuea where the safe yield and quality of groundwater resources had been accurately assessed in September 2009.

3.9 Range of Possible Yields in North Tarawa

The first order estimates of the sustainable yields of groundwater from major lenses in North Tarawa (Buota excluded) in Table 3 together with the accurately assessed yields in Abatao and Tabiteuea in Table 6 set reasonable bounds on the expected possible range of freshwater resources in Tarawa (Table 7).

It can be seen in Table 7 that the Buariki, on the very northern tip of Tarawa, has the potential to be a major source of groundwater, possibly as productive as Bonriki (Figure 10).

[3] A hectare is an area 100 m x 100 m or 10,000 m^2 which is one hundredth of a square kilometer.

Table 7 Estimated possible range of the sustainable yields of major lenses in North Tarawa, September 2010

Island	Estimated Sustainable Yield (KL/day)	
	Lower Bound*	"Upper" Bound†
Abatao	85‡	85‡
Tabiteuea	135‡	135‡
Tabiang	*60*	*180*
Marenanuka	*100*	*300*
Abaokoro	*20*	*60*
Taborio	*80*	*240*
Taratai	*240*	*720*
Tebangaroi	*60*	*180*
Nuatabu	*60*	*180*
Tearinibai	*100*	*300*
Buariki	*600*	*1,800*
Total	***1,540***	***4,180***

*Estimated assuming yield is ⅓ of the value of Falkland (2003b) as for Abatao & Tabiteuea. Values in *italics* are estimated
† From Falkland (2003b) except for Abatao & Tabiteuea
‡ Assessed from EM surveys and borehole salinity data (Falkland *et al.* (2003).

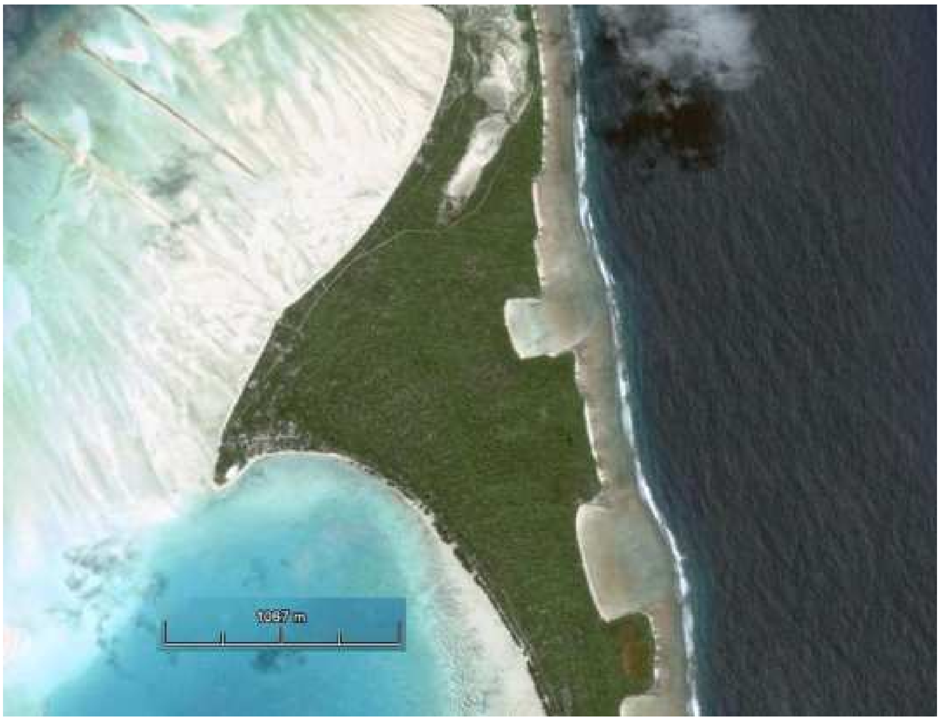


Figure 10 Buariki in the northern tip of Tarawa has the potential to be a major groundwater source (Google Earth, North is at the top centre of the Figure)

3.10 GWP KAPII Survey of North Tarawa 2009-10

As part of the KAPII water component, GWP Consultants LLP have been conducting EM surveys and installing boreholes throughout the islands on North Tarawa (excluding Abatao and Tabiteuea) since December 2010. The results of the EM surveys have just been made available in December 2010 as this report was being finalised[4]. The initial survey results are given in Table 8.

When the results for Abatao and Tabiteuea are added to the total in Table 8, the total possible

[4] We are extremely grateful to Joanna Ellis and Clive Carpenter of GWP Consultants LLP (UK) for supplying this information just prior to the completion of the TWMP (11 December 2010).

water resources in North Tarawa are 3,870ML, smaller than the upper bound estimate in Table 7 but much large than the smaller bound estimate. It is noted that the EM survey estimate for the sustainable yield of the large island of Buariki, with a lens of comparable thickness with Bonriki, is only 48% of the estimated upper yield in Table 7 and is much closer to the lower bound. For Taratai, however, the EM yield is closer to the upper bound estimate in Table 7.

Some caution should be exercised on the yields in Table 8 since the EM surveys were conducted in a wet period when lenses are expected to be at their maximum extent. The true extent of the lenses will only become apparent with repeated monitoring of the salinity boreholes and when a determination is made of what areas of the lenses are acceptable to the local community and landowners for development as water supply sources. In Abatao and Tabiteuea that determination meant that only one third of the lens area was available for development (Falkland *et al.* 2003). Because of this, the results in Table 8 will be considered an upper bound estimate.

Table 8 Sustainable yields of island lenses in North Tarawa from GWP EM surveys, December 2010

Island	Max FW lens thickness based on EM34 survey	Island area (hectare)	Lens area (hectare)	Sustainable yield (m^3/day)
Tabuki	3.4	29.0	22.0	99
Tabiang	22.1	76.5	58.5	263
Nabeina	13.4	39.3	27.7	125
Kainaba	5	23.9	13.7	62
Kairiki	5	29.1	12.7	57
TRZ 19 (Taiti)	6	39.3	21.2	95
Tabonibara	14	94.6	74.9	337
Marenanuka	16.5			
Abaokoro	15	33.3	17.7	80
Notoue	17	100	71.1	320
Taratai	13.6	160.7	146.8	661
Tebangaroi	19.1	60.5	49.5	223
Nuatabu	15.5	65.1	55.6	250
Tearinibai	18.2	97.3	47.9	216
Buariki	>25	242.8	191.7	863
			Total	**3,651**

3.11 Impact of Trees and Ponds on Sustainable Yield

Coconut trees and pandanus palms tap directly into the shallow groundwater in Tarawa and remove groundwater from the lenses by evapotranspiration. Direct measurements have found that each coconut tree can use in excess of 150 L/day (White et al. 2002). Removing trees from the centre of reserves has the potential to increase the sustainable yield and it has long been recognised as a possible option for increasing the water availability in South Tarawa (Falkland, 1992).

Construction of the airport runway in Bonriki led to the excavation of pits which became brackish water ponds at the north western, lagoon end of Bonriki runway (Figure 11). Mather (1973) believed the lens at Bonriki was probably more extensive before excavation of the ponds at the western, lagoon end of the present airstrip were excavated. It has been proposed that if these ponds were cleaned and infilled with clean dredged sand, the sustainable yield of Bonriki could be increased (Falkland 2003b). The estimated total potential increase in sustainable yield from the combined Bonriki and Buota galleries if these options were carried out is shown in

Table 9.

Table 9 Possible increase in potential yield of Bonriki and Buota reserves if management options carried out at Bonriki (after Falkland, 2003b)

Management Option	Estimated Additional Yield (KL/day)	Comments
Selective removal of trees and shrubs from centre of lens	250	Requires approval and cooperation of Bonriki people
Infilling of brackish ponds NW runway	250	Requires an EIS and approval and cooperation of Bonriki people
Combined sustainable yield of Bonriki and Buota reserves	2,010	
Total Potential Yield	**2,510**	

Figure 11 Bonriki island, South Tarawa showing the brackish water ponds at the north western end of the runway and the relatively sparse trees in the centre of the island (Google Earth, North is at the top centre of the Figure)

3.12 Other Possible Groundwater Sources in South Tarawa

In the past groundwater was sourced from other areas in South Tarawa in addition to Bonriki and Buota. Betio, Teaoraereke-Antebuka, Temaiku and Bikenibeu were either used as areas for groundwater sources or were considered to be potential sources of groundwater. Pumping galleries in Betio was abandoned long ago due to pollution by the high density population there. It is important to note that 34 years ago, when Betio only had an estimated population of 8,000. AGDHC (1975, para 4.03) cautioned that *"water from the wells on Betio… is not of good quality and further drinking of it is to be discouraged."* Shalev (1992), seventeen years ago, was even stronger in his remarks "…*the introduction of pit latrines in numerous villages in recent years, their proximity to hand-dug wells is causing many wells to become unsafe for drinking … In high-density housing areas such as South Tarawa, all the remaining old open wells are now a severe health hazard and must be earth filled and abandoned."*

Any contemplated use of pumped groundwater from Betio would require a major study of the groundwater quality in source areas and the efficacy of any proposed treatment. In addition, it would also require rigorous routine monitoring and extremely careful management. It is not a recommended option for potable water for public water supply.

There are two potential locations for galleries in Betio, around the new indoor stadium, and at the MPWU equipment yard, where at least one short gallery is still evident (Figure 12).

Teaoraereke-Antebuka was abandoned as water reserve by 1993[5] due to encroachment of squatters on the reserve. The area is densely populated and the width of the island is relatively narrow making it a far from ideal source for potable water.

Early surveys found a very thin lens at Bairiki and the early strategy was to supply Bairiki from the Teaoraereke-Antebuka reserve. It is possible that there may be a very limited supply of freshwater under the National Sports Stadium at Bairiki (Figure 13) Again, however, this source is surrounded by high density housing and would require a major study of the groundwater quality in the source area and the efficacy of any proposed treatment. In addition, it would also require rigorous routine monitoring and careful management.

Figure 12 Possible locations of infiltration galleries in Betio, around the indoor stadium (left) and at the MPWU equipment yard (right) (Google Earth, North is at the top centre of the Figure)

Early surveys also found limited fresh groundwater at Bikenibeu. There is the possibility of limited water resources in the agricultural research area directly south of the Otintaai Hotel in Bikenibeu (Figure 14). Again, however, this source is surrounded by high density housing and would require a major study of the groundwater quality in the source area and the efficacy of any proposed treatment. In addition, it would also require rigorous routine monitoring and careful management.

Temaiku has been proposed as a possible source of fresh groundwater, however, the coarser sediments on the ocean side and the proximity of the fish ponds and old channel, make this site doubtful as a significant source of freshwater.

[5] Shalev (1992) claims that Teaoraereke was abandoned in 1987.

Figure 13 Possible water source under the National Sports Stadium oval at Bairiki (Google Earth, North is at the top centre of the Figure)

Figure 14 Possible water source in the agricultural research site at Bikenibeu, directly opposite the Otintaai Hotel (Google Earth, North is at the top centre of the Figure)

Table 10 summarises these other possible sources of fresh groundwater in South Tarawa. These potential sources are extremely risky because of the possibility of contamination with human and animal wastes. Expensive treatment plants may therefore be necessary and any exploration of these suggested sites needs to include assessment of their groundwater quality.

Table 10 Possible additional groundwater sources in South Tarawa

Location	Possible Yield (KL/day)	Comments
Betio	50-100	Very risky, requires detailed assessment of water quality and water treatment options
Bairiki	30- 50	Risky, requires detailed assessment of water quality and water treatment options
Bikenibeu	30-50	Risky, requires detailed assessment of water quality and water treatment options
Total	**110-200**	

3.13 Summary of Potential Groundwater Sources in Tarawa

Table 11 summarises the above information.

Table 11 Summary of the estimated groundwater yields of significant, potential sources in Tarawa

South Tarawa			
Location	**Lower Estimate of Yield (KL/day)**	**Upper Estimate of Yield (KL/day)**	**Comments**
Bonriki	1,660	1,660	Existing source, accurately assessed
Buota	350	350	Existing source, accurately assessed
Total Existing Sources	**2,010**	**2,010**	Existing water supply sources, South Tarawa
Bonriki tree removal	*250**	*250*	Estimated value, requires Bonriki approval
Bonriki infilling ponds	*250*	*250*	Estimated value, requires Bonriki approval & EIS
Betio	*50*	*100*	Requires detailed water quality & treatment study
Bairiki	*30*	*50*	Requires detailed water quality & treatment study
Bikenibeu	*30*	*50*	Requires detailed water quality & treatment study
Total South Tarawa	***2,620***	***2,710***	
North Tarawa			
Abatao	85	85	Accurately assessed, Requires island permission & EIS
Tabiteuea	135	135	Accurately assessed, Requires island permission & EIS
Tabuki	33†	99	Requires motoring, island permission & EIS
Tabiang	88	263	Requires motoring, island permission & EIS
Nabeina	42	125	Requires motoring, island permission & EIS
Kainaba	21	62	Requires motoring, island permission & EIS
Kairiki	19	57	Requires motoring, island permission & EIS
Taiti	32	95	Requires motoring, island permission & EIS
Marenanuka/Tabonibara	112	337	Requires motoring, island permission & EIS
Abaokoro	27	80	Requires motoring, island permission & EIS
Taborio/Notoue	107	320	Requires motoring, island permission & EIS
Taratai	220	661	Requires motoring, island permission & EIS
Tebangaroi	74	223	Requires motoring, island permission & EIS
Nuatabu	83	250	Requires motoring, island permission & EIS
Tearinibai	72	216	Requires motoring, island permission & EIS
Buariki	288	863	Requires motoring, island permission & EIS
Total North Tarawa	**1,440**	**3,870**	
Total Tarawa	***4,060***	***6,580***	

* Values in italics are estimated values
† Lower bounds estimated by assumed 1/3 sustainable yield as was found on Abatao and Tabiteuea (Falkland *et al.*, 2003)

Table 11 suggests that the sustainable groundwater yield of Tarawa is somewhere between 4.1 and 6.6 ML/day. It should be cautioned, however, that this includes 0.11 to 0.2 ML/day of doubtful quality water from South Tarawa and water from North Tarawa that is viewed as the property of landowners and communities there and may not be accessible to use by South Tarawa.

3.14 Groundwater Retaining Walls

It has been suggested that construction of a groundwater "dam", essentially a bund retaining wall inserted or excavated to the depth of the karst Pleistocene limestone, would increase groundwater lens storage by lowering discharge of freshwater to the ocean and lagoon. This extremely expensive-to-implement suggestion ignores the totally fact that tidally-induced dispersive mixing of the fresh groundwater with seawater underlying all the island which occurs in the karst limestone aquifer underneath the island, is a major contributor to fresh groundwater loss from the lens. Inserting a retraining wall around the island margins at great cost would do nothing to lessen this loss. In addition, it also ignores the possibility that the very important near shore reef ecology may rely on the groundwater discharge from the island.

4 Impact of Climate Change on Groundwater

Climate change over the next century could have significant impacts on three key factors influencing shallow groundwater in Tarawa. The first is the direct influence on rainfall which recharges groundwater, the second is changes in evapotranspiration which determines how much water is lost to the atmosphere during and following the recharge process and the third is the sealevel rise due to global warming and the partial melting of the polar and Greenland ice caps.

4.1 Impacts on Rainfall, Evapotranspiration, Recharge and Yield

The increase in global temperatures is expected to cause an increase in sea temperatures and lead to an overall increase in rainfall in small islands in the Pacific. This increase, however, may be offset by increases in evapotranspiration with increasing temperature and increasing carbon dioxide (CO_2) levels, despite an increase in cloudiness. Increased CO_2 levels increase plant productivity and evapotranspiration. It is difficult therefore to predict if groundwater recharge will increase, decrease or remain the same with climate change over the next 20 years.

Climate change predictions of changes in rainfall, evaporation and drought frequency and duration, similar to those conducted by NIWA for KAPII (NIWA, 2008a, 2008b) rely on Global climate models (GCMs) to predict future rainfall patterns. Rainfall in Tarawa is critically dependent on El Niño Southern Oscillation (ENSO) events. GCMs at present do not simulate ENSO events which are key determinants of extreme events in Tarawa. All that can be concluded at present is that the impacts of climate change on the climate drivers of groundwater recharge in small islands in the Pacific are uncertain (Ali *et al.*, 2001).

The NIWA (2008a) study of changes in drought and rainfall unfortunately concentrated on changes in rainfall intensity. For groundwater recharge and sustainable groundwater use in coral atolls, because of the high permeability of the regolith, rainfall amount rather than intensity is important, as is the expected change in evapotranspiration. The NIWA study did not provide details of the increased quantities of rainfall expected nor did it consider evapotranspiration. Generally, the predicted higher atmospheric temperatures might be expected to increase evapotranspiration so there might be no net increase or even a decrease in groundwater recharge with increased greenhouse gas emissions. In a study using GMCs for Tongatapu, the predicted increases in rainfall due to increased greenhouse gas emissions to 2095 were completely offset by the predicted increases in evapotranspiration so that predicted annual recharge decreased by 5 to 25% (depending on the greenhouse gas emission scenario assumed) by 2095 (White *et al*, 2009).

The GMC predictions do not incorporate ENSO events and the predictions on changes in annual rainfalls in NIWA (2008a) give a poor representation of rainfall in Tarawa. It will be assumed here that to 2030, the pattern of groundwater recharge will remain unchanged from the historic pattern (1947 to 2008) although land area may shrink due to sealevel rise. This means that the estimated yields in Table 11 are relevant as far as rainfall and evaporation are concerned.

4.2 Impacts of Sea Level Rise

The impacts on freshwater lenses from projected mean sea level rises and possible changes in recharge have been studied on several atoll islands using groundwater models (see e.g. Buddemeier and Oberdorfer 1990; Alam *et al*. 2002). It was found that sea level rises of up to 1 m would have little impact on freshwater lenses provided that land was not lost at the edges of the island. Alam *et al.* (2002) specifically studied Bonriki water reserve. They predicted the freshwater zone would slightly increase in thickness and volume as more of the freshwater lens will be within the upper, lower-permeability, Holocene sediments. When, however, land is lost due to erosion at the edges of an island, the island area is reduced, decreasing the volumes of freshwater lenses. The World Bank (2000) predicted that sealevel rise would inundate 24 to 54% of the land area in Bikenibeu, South Tarawa, (Figure 15) and 55 to 80% of Buariki by 2050.

In addition to the change in groundwater yield produced by sealevel rise, the elevation of the freshwater lens further up in the unconsolidated Holocene sediments could also increase direct evaporation and transpiration losses from the lens and increase its vulnerability to contamination from surface and buried pollutants.

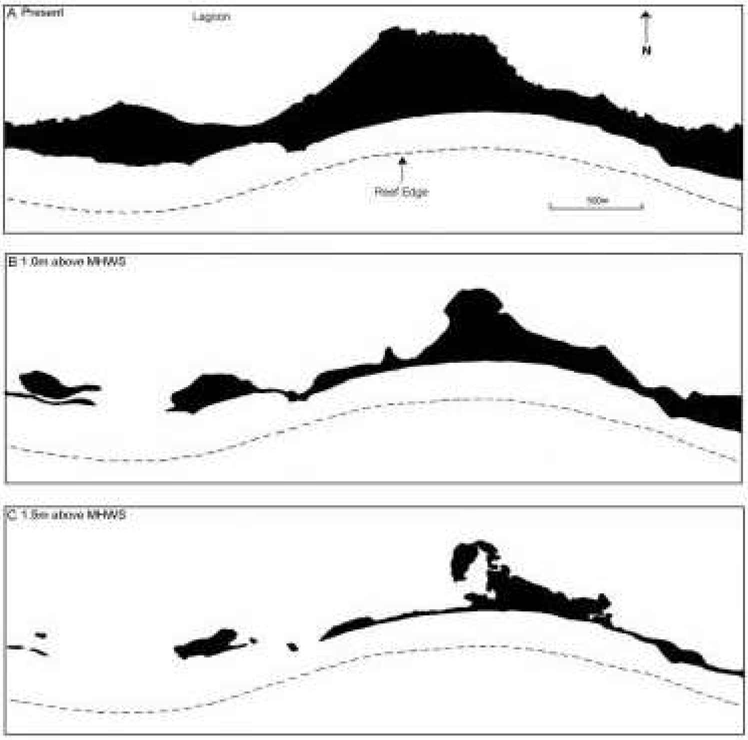


Figure 15 Projected Inundation of Bikenibeu (South Tarawa) under the Worst-Case Scenario A: Present status, B: Residual island under a worst case scenario, 2100; C: Residual island under worst case scenario and storm surge, 2100 (World Bank 2000).

The World Bank study found that the combined effect of sea level rise, changes in rainfall, and changes in evapotranspiration due to higher temperatures could result in a 19-38 percent decline in the thickness of the main groundwater lens at Bonriki by 2050.

The modelling studies, however, found potential changes in recharge resulting from changes in rainfall were more likely to have a larger impact on freshwater lenses in the intermediate period. Since this Plan is to cover the period to 2030 and since the rainfall and groundwater recharge is dominated by ENSO, it has been assumed here that sustainable yields, estimated from the historic rainfall record and past groundwater behaviour, is as reliable a guide to the future in to 2030 as any predicted changes.

Recently, NIWA has used some of the latest climate change scientific findings from the IPCC for the Kiribati region, under KAP II Component 1.4 (NIWA, 2008a, b). NIWA applied climate change scenarios, based on the IPCC 2007 data, to produce detailed information on waves, water levels and storms that were used in the Pilot Study Risk Assessments by Kay (2008). The study (NIWA, 2008b), using IPCC predictions, assumed two possible sea level rises relative to 1980-99 mean levels up to 2090 (2080-99) of 0.49 to 0.79 m and produced possible inundation maps for Tarawa. Importantly for the Tarawa Master Plan, Figure 16 shows the expected inundation of the southern, lagoon side of Bonriki Island that may occur in 2030 and 2070 due to predicted sealevel rise (NIWA, 2008a). Since the fresh groundwater lens at Bonriki is the main source of treated freshwater for South Tarawa, and since there are up to 5 of the 23 infiltration galleries at Bonriki that appear to be affected by the predicted inundation in 2030, it might be expected that by 2030 the safe yield of Bonriki may be reduced by about 20%.

Any estimates of the land area that may be impacted by sealevel rise require accurate topographic information. With low atolls these require resolution down to contours intervals between 0.05 and 0.1 m elevation. These topographic details are seldom available on atolls such as Tarawa.

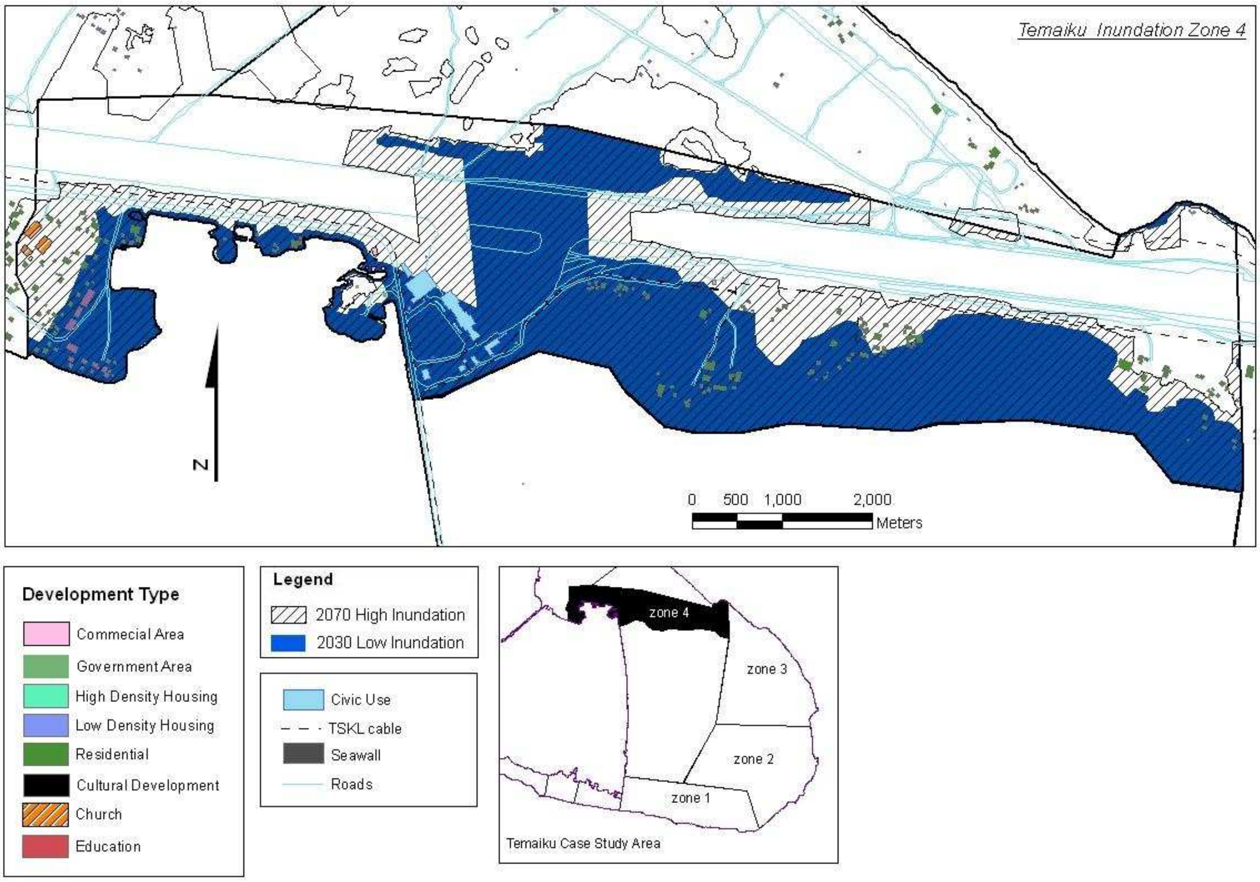


Figure 16 Predicted low inundation by 2030 and high inundation by 2070 of the lagoon side of Bonriki Island due to sealevel rise (NIWA, 2008b).

4.3 Other Predictions of Sea Level Rise

Hansen *et al.* (2007) dispute the predictions of the IPCC (2001a, b; 2007), which foresee little or no contribution to twenty-first century sea-level rise from the melting Greenland and Antarctic ice sheets. They believe IPCC analyses and projections do not properly account for the non-linear physics of wet ice sheet disintegration, ice streams and eroding ice shelves, nor do they see them as consistent with the paleoclimate evidence for the absence of a discernable lag between ice sheet forcing and sea-level rise. They conclude that the change in the albedo between ice and wet ice, the albedo “flip”, over large portions of ice sheets in combination with warming of the nearby ocean and atmosphere, would produce multiple positive feedbacks leading to eventual non-linear ice sheet disintegration, producing a situation which Hansen *et al.* (2007) describe as “imminent peril”.

They believe that climate forcing of this century under “business as usual” GHG emissions would dwarf natural forcings of the past million years, and may probably exceed climate forcing of the middle Pliocene, when the planet was not more than 2–3°C warmer and sea level 25 ± 10 m higher than at present. The timescale for such an event is difficult to predict in such a non-linear system. Hansen *et al.* (2007) could find no evidence of millennial lags between forcing and ice sheet response in paleoclimate data. They conclude an ice sheet response time of centuries seems probable, but could not rule out large changes on decadal time-scales once wide-scale surface melt is underway. With green house gas emissions continuing to increase, they concluded the planetary energy imbalance provides ample energy to melt ice corresponding to several metres of sea level per century.

While the NIWA (2008b) study included some possible melting of the Greenland and West Antarctic ice sheets, it did not envisage the catastrophic sea level rise envisaged by Hansen *et al.*

4.4 ENSO Events and Sea Level Changes

In discussing sea level changes it must also be remembered that the sea level in Tarawa also changes during ENSO events. The severe 1998 to 2001 ENSO event in Figure 17 shows that such events can produce mean sea level changes of at least 0.46 m.

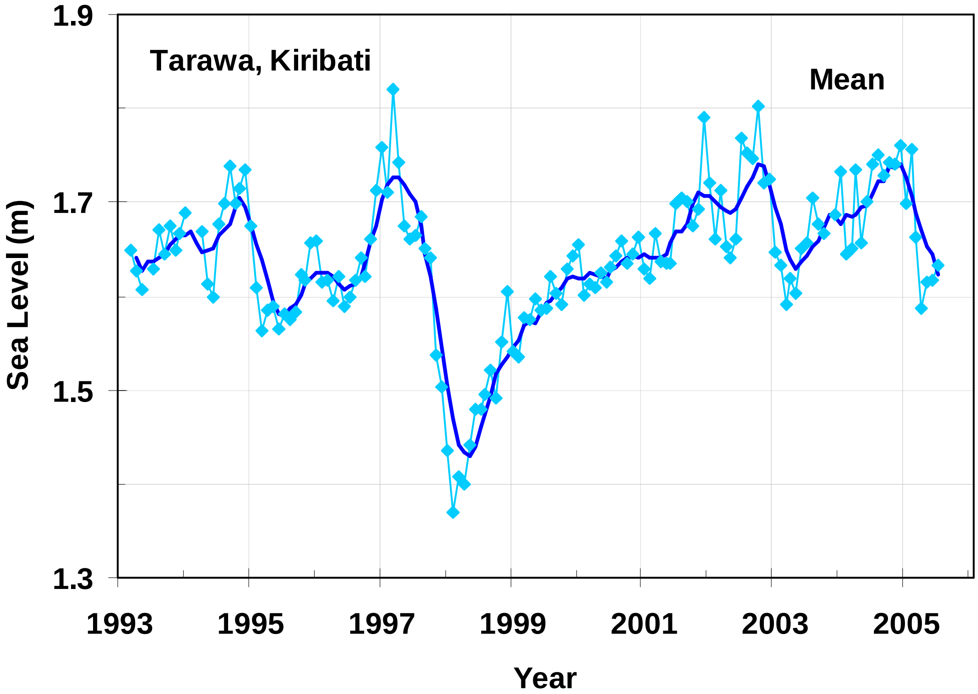


Figure 17 Change in monthly and running mean sea level (above an arbitrary datum) at Betio, Tarawa due to the 1998-2000 La Niña event

4.5 Assumed Impacts of Sea Level Rise on Groundwater Yield

The projected sea level rises in section 4.2 above suggest that groundwater yield may change as a result of sealevel rise due to a decrease in the area of the groundwater reserve. To accommodate those changes, estimates of assumed percentage changes in the groundwater yields for South and North Tarawa are given in Table 12.

Table 12 Assumed percentage changes in the safe groundwater yield of South and North Tarawa due to sealevel rise

Year	Change in Yield (%)
2005	0
2010	0
2015	+5
2020	0
2025	-10
2030	-20

These assumed changes will be applied to the estimated yield data in Table 11.

4.6 Impacts of Overtopping on Groundwater

There are major concerns that climate change may increase the severity and frequency of extreme events in small low islands with increased frequency of drought, enhanced cyclone activity, rising mean sea levels and increased risk of island overtopping in storm surges (Ali et al. 2001). Overtopping of low islands from storm waves or by seawater inundation due to storm surges, sometimes associated with high sea levels has salinised fresh groundwater on low-lying islands in the past (Richards 1991; Oberdorfer and Buddemeier 1984). Six months after a storm

surge which sent waves across part of Enewetak Island in Enewetak Atoll, Marshall Islands, the salinity of the groundwater dropped sharply to 15–25% of the immediate post-storm values during a period of negligible rainfall (Oberdorfer and Buddemeier 1984), indicating that recharge was not the factor that decreased salinity. More recently, saline intrusion into freshwater lenses as a result of cyclone-generated waves and storm surge on the three islands on Pukapuka Atoll, northern Cook Islands in 2005 was found to have dissipated within 12 months due to density-driven downward migration of the seawater (Terry and Falkland, journal paper in preparation).

In the next section other threats to fresh groundwater on Tarawa are considered.

5 Threats to Groundwater Sources

In order to develop a plan to provide future safe drinking water for Tarawa, it necessary to identify the principle threats to the main sources of drinking water. It is clear that the main source of drinking water in Tarawa, whether in urban or rural areas, is from groundwater obtained from local household wells (NSO, 2007a).

The high permeability and lack of adsorptive capacity in the unconsolidated coral island soils means that closed wells are only marginally less prone to pollution than open wells, since there is a rapid pollution pathway through the soil to the groundwater. Both open and closed wells will therefore be treated as a single source. The principal pollution threat to household wells and human health is from faecal contamination. There are two sources of faecal contamination in Tarawa, humans and animals (including birds).

5.1 Human Faecal Contamination of Household Water Wells

Dillon (1997) reviewed the pollution of groundwater by sanitation systems on tropical islands. There are three sources of local faecal contamination: human, due to open defecation, due to pit latrines and due to discharge from septic tanks; in South Tarawa, leakage of sewage; and animal defecation. The 2005 Census (NSO, 2007a, Table H37) lists data on the sources of sanitation used in Tarawa which is contrasted in Table 13 and Figure 18 with other rural outer islands in the Gilbert group.

5.1.1 Saltwater sewage system

It is immediately obvious from Table 13 that households use multiple sanitation sources. One third of houses in South Tarawa have access to the salt-water sewage systems operated by the PUB, compared with less than 5% in North Tarawa. Since PUB sewage systems only operate in South Tarawa at Bikenibeu, Bairiki and Betio, it is assumed that the 5% in North Tarawa have access either at work or visits to sewered location in South Tarawa. That may also account for the 0.6% of outer island households claiming access to the PUB sanitation systems. The extent to which leakage and spillage from the saltwater sewage system contaminates local groundwater is unknown.

Table 13 Percentage of households in Tarawa using different sanitation sources compared with other rural areas in the Gilbert Group (NSO, 2007a)

Location	Total House-holds	Percentage of Households (%)						
		Flush PUB	Flush Own	Compost	Sea	Beach	Latrine	Bush
South Tarawa	**5245**	33.3	27.3	3.7	20.0	29.1	34.0	6.8
North Tarawa	**867**	4.7	18.6	1.3	51.0	66.0	29.8	27.3
Other Rural Gilbert Group*	**6,540**	0.6	4.6	3.8	34.8	68.3	34.6	41.7

*Excluding North and South Tarawa

5.1.2 Septic systems

A further 27% of households in South Tarawa have access to flush septic tank systems, greater than the 19% of houses in North Tarawa, and less than the 5% in other rural areas in the Gilbert Group. These require regular pumping or, in the absence of a tanker, digging out, which is often not recognised. Most of these septic tank systems are constructed with cemented concrete blocks which leak effluent into the groundwater. In the urban are of London in Kiritimati, leakage from septic tanks, and also petroleum leakage has made the local groundwater unfit for use (ADB, 2007a).

5.1.3 Beach or sea

The percentage of households using the beach in North Tarawa is very similar to that in other outer islands in the Gilbert Group and about twice that in South Tarawa. The percentage of households in North Tarawa using the sea (51%) is higher than that in other Gilbert outer islands (35%) and in South Tarawa (20%). Both these systems of sanitation are considered potentially hazardous (WHO/UNICEF, 2008) although they pose a minimal threat to groundwater for drinking.

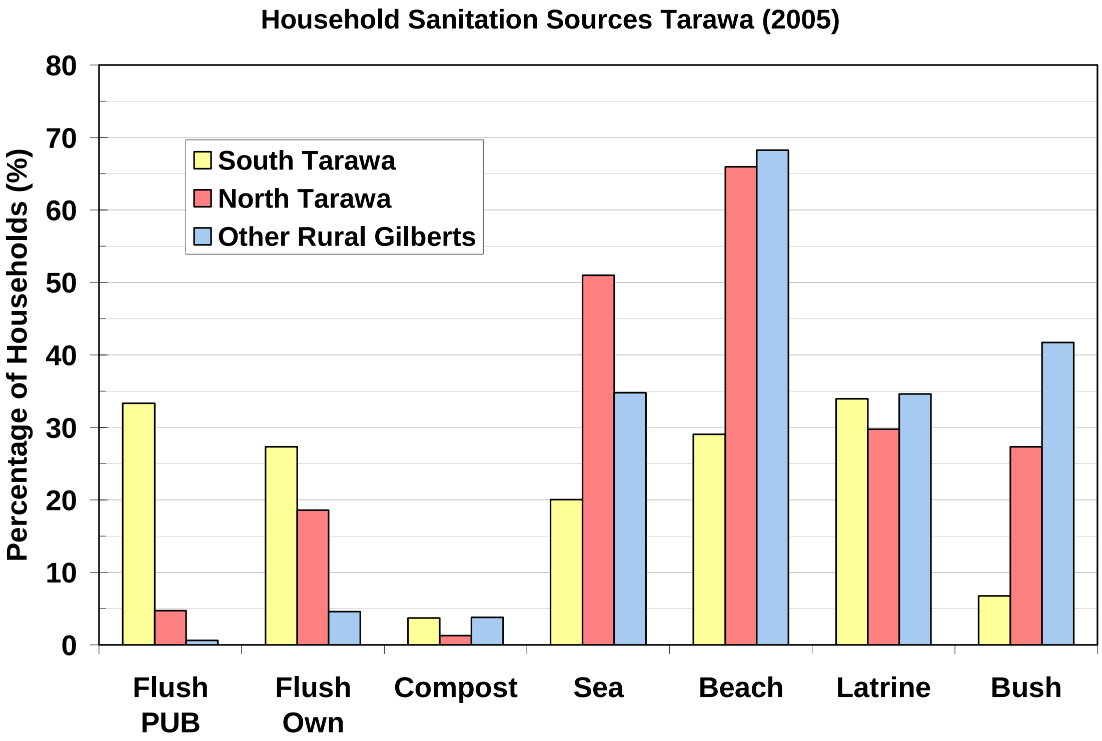


Figure 18 Comparison of the percentage of households using different sanitation sources for urban South Tarawa, rural North Tarawa and other rural areas in the Gilbert group

5.1.4 Pit Latrines and the bush

Besides possible leakage and spills from the saltwater sewerage system and seepage from septic tanks, the other two systems that pose a significant contamination threat to household groundwater are use of pit latrines and use of the bush. The household use of latrines in South Tarawa, North Tarawa and other outer islands in the Gilbert Group is very similar at about 33%. This may reflect the WHO-supported initiative to install latrines throughout Kiribati.

Pit latrines are excavated down to the shallow groundwater and are supposed to be installed at least 30 m down gradient from the nearest water well, on the ocean or lagoon edge of the island. These discharge directly into the shallow groundwater. There is a misconception that latrines or septic tanks are an improved and safer sanitation system in coral atolls (WHO/UNICEF, 2008).

There is no routine monitoring to determine if latrines are installed in the recommended manner or whether contamination of household water wells from these sources occurs. Crennan (2001) in a study of water quality in village household wells on the island of Lifuka, Tonga, in the villages of Pangai and Hihifo, with a population density of approximately 3,000 people/km^2, found, in most cases, the presence of faecal indicators was at an unacceptable level of concentration for human and environmental health. Wells outside villages were better suited for use. She found that an injected bromide tracer introduced into the groundwater took only 14 days to travel 5 m in any direction. She concluded that putting latrines closer to the coast than the household well did not safeguard against contamination[6].

[6] Presumably this is due to tidally induced fluctuations of the water table.

5.1.5 Density of sanitation sources

Dillon (1997) pointed out that areas with more than 15 septic tanks/km^2 were designated by the US Environmental Protection Agency (EPA) as areas having potential contamination problems. In South Tarawa, with population densities as high as 2,558 people/km^2 (2005 Census), equivalent to about 340 households/km^2, it is expected from Table 13 that there are on average about 100 septic tanks/km^2 and 110 pit latrines/km^2, far in excess of the US EPA density. When this is added to the 6.8% of households in South Tarawa that use the bush, equivalent to more than 2,600 people or about 180 people/km^2, it can be seen that there is a major risk in using household well water for human consumption in South Tarawa irrespective of whether the well is covered or open. Since there is little free space in South Tarawa, these average values are probably widely relevant.

The potential pollution of household wells in crowded areas on Tarawa has long been recognised. As mentioned previously, 34 years ago when Betio had an estimated population of 8,000, AGDHC (1975, para 4.03) remarked that *"water from the wells on Betio… is not of good quality and further drinking of it is to be discouraged."* A further 17 years later Shalev (1992) was even more forceful "*…the introduction of pit latrines in numerous villages in recent years, their proximity to hand-dug wells is causing many wells to become unsafe for drinking … In high-density housing areas such as South Tarawa, all the remaining old open wells are now a severe health hazard and must be earth filled and abandoned."*

In North Tarawa, the population density is lower at 372 people/km^2, equivalent to about 57 households/km^2. Using Table 13 it is expected on average that there will be less than 11 septic tanks/km^2 and 17 pit latrines/km^2. Together these still exceed the US EPA density of potential contamination problems. In North Tarawa 27.3% of households use the bush, equivalent to about 1,540 people or just over 100 people/km^2. In North Tarawa, populations are centred in villages, with considerable space in between. It is therefore expected that local wells within villages will have an increased risk of contamination while groundwater removed from villages may be less prone to contamination.

The risk posed by consuming water from household wells is demonstrated in health statistics from clinics in Kiribati for 2005 which show that South Tarawa, with 43.5% of the countries population had over 55% of the nation's reported diarrhoea and dysentery cases. Just over one in three of the population was affected. The crowded township of Betio, with 31% of South Tarawa's population, had over 54% of South Tarawa's diarrhoea and dysentery cases. These figures demonstrate that, in atoll communities, higher density populations with significant concentrations of septic tanks and pit latrines lead to higher incidences of water-borne diseases.

5.2 Animal Faecal Contamination of Household Water Wells

In Tarawa there are significant numbers of generally, free-ranging domestic animals, particularly pigs[7], dogs and chickens. Table 14 shows the number of domestic animals estimated from the 2005 Census for North and South Tarawa.

Table 14 Estimated total numbers of domestic animals and the number of animals per household from the 2005 Census for North and South Tarawa compared with rural outer islands in the Gilbert Group

Location	Number of Animals[8]			Number Animals per Household		
	Pigs	Dogs	Chickens	Pigs	Dogs	Chickens
South Tarawa	13,184	3,729	3,740	2.51	0.71	0.71
North Tarawa	2,479	937	2,131	2.86	1.08	2.46
Other Rural Gilberts	23,668	5,728	35,133	3.62	0.88	5.37

[7] Regulations under the Local Government Ordinance prohibit keeping pigs close to houses, however, these regulations are seldom observed.
[8] The number of animals shown is a lower bound estimate since the highest category in the 2005 Census, tables H6 to H12 is 15 or more animals/chickens.

It can be seen that the average number of pigs and chickens per household in South Tarawa is less than those in North Tarawa, which in turn is less than that in outer islands in the Gilbert Group. The number of dogs per household in North Tarawa is greater than that in the Gilbert outer islands which is greater than that in South Tarawa. The number of animals listed in Table 14 may be an underestimate. According to the SAPHE household survey in 2000, the average in South Tarawa was 3.53 pigs/household.

If it is assumed that the amount of faecal waste produced by a pig, dog and chicken is equivalent to 0.5, 0.2 and 0.02 of a human load, then together the free ranging animals in Tarawa are equivalent to an extra 480 equivalent people/km^2 in South Tarawa and an extra 97 equivalent peope/km^2 using the bush in North Tarawa.

With both the human and animal loads combined the total pollutant load on the groundwater in South Tarawa is equivalent to 100 septic tanks/km^2, 110 pit latrines/km^2 and 660 equivalent people/km^2 using the bush. In North Tarawa the load is much lower at 11 septic tanks/km^2, 17 pit latrines/km^2 and about 200 equivalent people/km^2 using the bush. Again it is emphasised that in South Tarawa this average load across all of South Tarawa is a reasonable estimation of average risk. In North Tarawa, it is expected that loads will be higher than the average result in villages and lower in the bush. This emphasises the risks involved in using local household wells within villages for drinking.

In crowded areas in South Tarawa, such as Betio and Bairiki, the above analysis indicates that there are major risks in using local groundwater from household wells for human consumption.

5.3 Burial Practices and Household Wells

It is often customary to bury relatives close to the family home and the household well. This practice has the potential to cause significant initial contamination of well water. There is a still-used public cemetery almost directly in the middle of the Bonriki water reserve from which much of South Tarawa's potable water supply is drawn, close to pump station 15 (Figure 19). During cholera epidemics, burial of victims of the disease could well be a source of spreading the disease widely.

5.4 Leakage of Petroleum Products

Groundwater contamination on many small islands, caused by a variety of chemical sources including waste and rubbish disposal areas, fuel tanks, fertilizers, and agricultural chemicals (van der Velde et al. 2007), poses significant health risks. Human settlements over freshwater lenses used for water supply are of major concern because of the potential for rapid pollution due to the shallow permeable soils and short travel times to the water table. This has caused the contamination of large areas of urban Tarawa from a variety of biological and chemical sources such as petroleum and oil storages in Betio, so that nearby groundwater is only fit for non-potable purposes at best.

5.5 Leakage from the Saltwater Sewerage System

Saltwater flushed reticulated sewerage systems are used In Betio, Bairiki and Bikenibeu. Leaks from these systems have the potential not only to contaminate local household wells with sewage but to salinise the local groundwater. Impacts from such leakages would be most pronounced during prolonged dry spells when their impacts are not diluted by recharge. Breadfruit tree die-back and death in some locations during droughts in South Tarawa has been periodically blamed on leakages from saltwater sewage systems.

5.6 Safety of Household Wells in Tarawa

Household wells are the major source of drinking water in Tarawa. Despite their obvious importance, and relatively frequent outbreaks of water-borne diseases, especially in South Tarawa, there is no program of systematic monitoring of water quality in household wells.

Given the above analyses of the risk of using household water wells for drinking and since there is no information on the quality of groundwater accessed by communities in North and South Tarawa, it will be assumed in this plan that in North Tarawa, all local groundwater, without disinfection treatment, is safe for only for non-potable water use. In South Tarawa it will be assumed in this plan that 50% of household wells are in crowded areas where local groundwater is not safe for any non-potable water use so that all water will need to be supplied to 50% of households through the PUB piped water system. The assumption here is that, as in London in Kiritimati, with smaller population densities than either Betio or Bonriki, pollution has made groundwater too risky to use even for non-potable use.

5.7 Potential Contamination of Groundwater Reserves

An earlier report, which was a preliminary study for the Tarawa Master Plan, examined the protection of South Tarawa's current operating water reserves at Bonriki and Buota, the sources of treated, reticulated water in South Tarawa (White *et al.*, 2008). The report pointed out that a water reserve at Teaoraereke – Antebuka, declared in April 1968, had to be abandoned before 1993 due to encroachment of settlers on the reserve and pollution of the groundwater source. A similar water reserve in Betio, declared in May 1968 was also abandoned due to understandable concerns over water pollution. This occurred despite adequate existing regulations to control encroachment on water reserves under the Public Utilities Ordinance, 1977. The report pointed out that there is continuing encroachment onto and misuse of the remaining reserves, especially at Bonriki and an apparent inability by government agencies to control that encroachment despite the existing strong regulations and Acts of parliament.

The report also documented continued threats to the major Bonriki water reserve which have included: planning failures, with approved developments on the water reserve in contravention of regulations; increasing settlement on the reserves; continued sand and gravel mining in water reserves; inappropriate land use on water reserves including: digging of open water wells; continued use of graveyards on the water reserves; raising of pigs on reserves; growing crops and babwai which use animal manure and fertilisers; direct pollution of galleries; and vandalism of infrastructure. These on-going problems were shown to have direct impact on the quality of pumped water from infiltration galleries (Figure 19).

Figure 19 Presence of *E.Coli* (red areas) a faecal indicator in water pumped from infiltration galleries at Bonriki water reserve (White *et al.* 2007)

In part some of the above problems appear to be due to the decision to allow settlement on the Bonriki water reserve within a 50 m border from the lagoon or ocean. This was designed to alleviate overcrowding in Bonriki village. The assumption was that households in this border zone would be supplied with reticulated water since the groundwater in the border area can be too saline for use. The non-supply of reticulated water to the border zone has meant that many households have constructed open wells within the water reserve, adding to the potential for contamination.

White *et al.* (2008) found five main threats to the long term viability of Bonriki and Buota water reserves, Tarawa's only current major groundwater sources for reticulated water supply. These are:

- Lack of effective protection of water reserves, despite adequate regulations;
- Ineffective management of water reserves;
- Failure to engage the local landowners and communities in protection and management of water reserves;
- Continued settlement on the water reserves; and
- Inappropriate land use and vandalism on water reserves.

The report concluded that unless these problems are attacked with determination, future water supplies of reasonable quality water from these reserves cannot be guaranteed.

5.8 Exceeding the Sustainable Yield of Groundwater Reserves

The report on the protection of South Tarawa's water reserves at Bonriki and Buota also examined the current rate of pumping from infiltration galleries at Bonriki and Buota (White *et al*., 2008). It found that the groundwater at Bonriki has been pumped at 17% greater than the estimated sustainable yield (Table 5) since 2006. During long droughts there is a significant risk that salinisation could cause the failure of the public water supply.

The report concluded: "*What is needed if these water reserves are to be protected and managed into the future is a radically different approach to the problem and one that includes the local landowners as part of the solution.*" Several recommendations were given:

1. Make protection of water reserves the highest priority, superseding all other considerations (this acknowledges that good quality water is essential for life)
2. Appoint a single water reserve manager in the lead water agency whose sole task is to ensure the protection, improved management and monitoring of water reserves in Tarawa
3. Form a multi-agency monitoring team under the manager to visit and inspect water reserves regularly, monitor, analyse and report to the National Water and Sanitation Coordination Committee, NWSCC on: the rates of extraction of groundwater compared with the sustainable yields of water reserves; microbiological, salinity and other water quality parameters; the condition of water reserves including number of settlers and land use activities on water reserves
4. Ensure that the NWSCC meets regularly to discuss the above issues and to prepare a succinct annual report to Cabinet
5. Review all regulations and legislation relevant to the declaration and protection of water reserves and ensure that they are applicable to all potential water reserves throughout Tarawa and Kiribati and make deliberate pollution of public water sources a serious offence.
6. Reform and resource the community-government *Committee for the Management of Water Reserves in Bonriki and Buota*, ensuring that local landowners and their communities participate in the management and protection of water reserves.
7. Make payment of lease fees to landowners a contractual agreement between the government and the landowners with payment conditional on the landowners acting as custodians and protectors of the water reserves who will improve management and protection[9]

[9] Simple performance indicators for improved management and protection

8. Introduce school curricula on the protection and care of public water sources
9. Provide alternate venues for burials so that the cemeteries on water reserves are no longer used.
10. Ensure that all groundwater pumps are operating at the design sustainable rate
11. Fill in all household water wells, babwai pits and sand and gravel pits on the water reserves
12. Install a backflow stop valve between Bonriki and Buota.

Almost one year on from that report, none of these recommendations have been acted on. The next section estimates how much water is being used from household water wells in Tarawa.

5.9 Exceeding the Sustainable Yield of Local Groundwater Sources

As people in Tarawa become more affluent, the use of groundwater pumps, rather than buckets, to extract household well water will increase. Uncontrolled groundwater pumping of the local, shallow groundwater can draw up saline water from underlying seawater, particularly in narrower islands. Thus one household or business has the potential to salinise all the local groundwater wells in the neighbouring region or even an island. There is no current legislation to protect communities from individuals or organisations that excessively use water. It is therefore imperative that all groundwater pumps be licensed and that the sustainable pumping rates are set as part of the licence conditions. Indeed it may be appropriate to licence all water wells. This would provide a mechanism for identifying which wells are safe for use and for applying licence conditions to the rate of extraction of water from all wells.

6 Contribution of Household Wells to Supply and Demand

Household water wells in both South and North Tarawa provide a significant contribution to household water supplies (NSO, 2007a). There has been no investigation of how much water is derived from household wells in Tarawa. In this section an attempt is made to estimate the current contribution of household wells to the water supply in Tarawa.

6.1 Water from Household Wells

There are two recent studies of household water use in Kiribati (ADB, 2004, and ADB 2007a; b). A brief study of water use in a few households in Routima village (ADB, 2004) in the outer Gilbert island of Nonouti (White and Falkland, 2009b, Table 11) showed the average household water use was 35 L/pers/day with a further 7 L/pers/day used for irrigation of crops. This average is probably more relevant to North Tarawa and Temaiku where crops are grown for South Tarawa. A more detailed survey of all villages in Kiritimati (ADB, 2007b) covered urban, semi-urban and rural water use (White and Falkland, 2009b, Table 12). The villages of Banana and Tabwakea are probably more relevant to South Tarawa, since they obtain water from both reticulated water and household wells in areas with low salinity groundwater. On average, households in Banana used about 49 L/per/day with about 27 L/pers/day coming from piped water. This suggests about 22 L/pers/day is supplied from household wells. In Tabwakea, average household water use is 52 L/pers/day with 29 L/pers/day supplied by the piped water system. This suggests 23 L/pers/day is sourced from household wells.

It will be assumed here that these surveys are relevant to North (35 to 42 L/pers/day) and South (23 to 35 L/pers/day) Tarawa. NSO (2007a) indicates that about 65% of households in South Tarawa and 96% of households in North Tarawa[10] use household water wells. Using the 2005 Census figures, Table 15 shows that an estimated 800 to 1,150 KL/day of water used by households is sourced from local household wells in Tarawa.

Table 15 Estimated total daily use of household well water in Tarawa (2005 Census)

Location	Households	Average Size (persons)	Use of Wells[7] (%)	Water Use (L/pers/day)	Total Water Use (KL/day)
South Tarawa	5245	7.7	65	23 (Lower)	604 (Lower)
				35 (Upper)	919 (Upper)
North Tarawa	867	6.5	96	35 (Lower)	189 (Lower)
				42 (Upper)	227 (Upper)
Approximate Total Combined Household Well Supply Tarawa					**800 -1,150**

It is concluded that the daily water use from household wells in South Tarawa could be between 600 and 920 KL/day and that for North Tarawa between 190 and 230 KL/day with the total for Tarawa being between 800 and 1150 KL/day. It is noted here that pollution from human and animal wastes means that a significant proportion of this water could be of dubious quality.

The values in Table 15 strictly apply to the year 2005, since the number of households, average household size and use of wells all are from the 2005 Census. For South Tarawa, it is not expected that the range of volumes of water extracted from household water wells cannot increase significantly in the next 20 years. Most of the available space for settlement is taken up. The groundwater lenses that household wells tap into in South Tarawa are much smaller than those of Bonriki and Buota and any increase in extraction rates could salinise these lenses making them of limited use.

In North Tarawa, the situation is different. There is still plenty of room for increased settlement and the island widths are larger than in south Tarawa, particularly at Buariki.

[10] **Error! Reference source not found.** shows both open wells and closed wells. The values adopted here are the average of open wells and all wells (open plus closed).

6.2 Rainwater and Piped Water

In the rainwater component of this master plan (White and Falkland, 2009b) it was estimated that rainwater harvesting and storage had the potential to add up to 93 KL/day to the water supply in South Tarawa and up to 3.5 KL /day in North Tarawa, or a total of 97 KL/day for Tarawa. The average daily production of piped water from Buota and Bonriki for the period 2005 to 2008, following the SAPHE project ranged from 1,960 to 2,230 KL/day (White *et al.* 2008). However about 50% of this water is lost before it reaches most customers so that the supply to customers is about 980 to 1,120 KL/day. These existing amounts can now be compared with the estimated demand for freshwater to 2030.

6.3 Comparison of Total Water Supply and Demand.

Table 16 shows the estimated daily sources of drinking water in Tarawa versus the estimated daily required demand. It is noted that the estimate sources of rainwater and household well water are related to the 2005 Census. While it is not expected that the rainwater or household well water sources in South Tarawa can increase too dramatically, those in North Tarawa can.

Table 16 Estimated current sources of household drinking water in Tarawa compared with estimated demand

Water Source	Estimated Water Sources (KL/day)			
	South Tarawa		North Tarawa	
	Lower	Upper	Lower	Upper
Rainwater (2005)*	37	93	1.4	3.5
Household wells (2005)	600	920	190	230
Piped water less 50% Loss	980	1,120	-	-
Total Sources (2005)	**1,620**	**2,130**	**190**	**230**
Year	**Estimated Required Water Demand (KL/day)†**			
2005	3,100	3,100	200	200
2010	3,200	3,400	300	300
2020	3,500	4,200	500	400
2030	3,800	5,100	800	700

*From White and Falkland (2009b, Table 22)
† From White and Falkland (2009a, Table 24)

If the sources estimated for 2005 are compared with the estimated required demand for 2005 if all households were connected to piped water in South Tarawa, it is found that the estimated required demand would exceed the estimated supply by between 1,000 to 1,500 KL/day, close to the water that is estimated to be lost from the reticulation system. This shortfall and the fact that only two thirds of households are connected to the pipes water system forces communities in South Tarawa to rely increasingly on household wells in areas with a high risk of pollution. If no further water reserves are developed or extra water supplies found, the short fall will worsen as will the health impacts of drinking polluted water. In addition, increasing shortfalls of water are likely to increase the number of illegal connections to the reticulation system further worsening already excessive leakage rates.

In North Tarawa, the supply for 2005, matches almost exactly with the required demand for 2005. There, rainwater and household well water use can increase with increasing population.

Options for supplying the future water demands will now be considered.

7 Groundwater Options for Supplying Future Water Demands

In this section a number of options and strategies for meeting the anticipated demand for water out to 2030 by pumping and reticulating water from major groundwater lenses are considered. These are tentative because the sustainable yields of most of North Tarawa are only estimates. It is assumed in this section that the Bonriki and Buota water reserves will remain as groundwater source areas for Tarawa and not be abandoned due to encroachment of settlements, as happened in Betio and Teaoraereke-Antebuka. In the following estimations, South Tarawa includes Buota, and North Tarawa is all of North Tarawa less Buota. Two future population predictions will be used: a lower estimate based on the South Tarawa full estimate and an upper estimate based on the exponential growth prediction (White and Falkland, 2009a, Table 23). It will be assumed that the costs of these options will be amortized over a 20 year period to 2030.

7.1 "Do Nothing", Option 1

In this option household water supplies in North Tarawa[11] until 2030 are assumed to be sourced mainly from household wells with a minor component being supplemented from rainwater and seawater for non-potable uses. For South Tarawa it is assumed that treated water will continue to be supplied at the sustainable rate, 2.01 ML/d from Bonriki and Buota (Table 11) with an assumed 50% leakage rate as may be the case now. The rest of South Tarawa's water needs are assumed met by rainwater harvesting, with household wells and seawater supplying non-potable water use. The conditions are:

South Tarawa: Reticulated treated water from Bonriki and Buota water reserves
50% leakage from reticulation system
Demand supplemented by rainwater harvesting
Household water wells and seawater used for non-potable use

North Tarawa: Household water wells
Supplemented by rainwater harvesting
Seawater for non-potable use

With the "do nothing" option the daily amount of treated water that is can be supplied to each resident on South Tarawa decreases as the population increases because of the fixed sustainable pumping rate from the two water reserves. Table 17 shows the predicted average per capita daily water availability at households for South Tarawa after allowing for the estimated current 50% leakage and a 20% decrease in yield in 2030 due to sealevel rise. The estimated per capita supply for North Tarawa from household wells is listed in Table 18 based on the estimated lower and upper populations (White and Falkland, 2009a, Table 23) and the lower and upper estimates of North Tarawa yields (Table 11).

Table 17 Predicted range of average daily per capita water availability for South Tarawa households for two assumed leakage rates and the lower and upper population growth rates for the "do nothing" scenario

Year	Per Capita Treated Water Availability (L/pers/day)			
	25% Water Losses		50% Water Losses	
	Lower	Upper	Lower	Upper
2005	-	-	24	24
2010	34	33	23	22
2020	31	27	21	18
2030	23	17	15	12

Table 18 Predicted range of average daily per capita water availability for North Tarawa households for the lower and upper estimated yields for the "do nothing" scenario, combined yield 1.54 to 4.18 ML/day

[11] Buota already gets reticulated water supply because water is pumped from Buota to South Tarawa. Here and in the following Buota is included in South Tarawa and left out of North Tarawa unless stated.

Year	Per Capita Water Availability North Tarawa (L/pers/day)	
	Lower Yields	Upper Yields
2005	360	970
2010	270	770
2020	160	470
2030	75	230

Under the current estimated leakage rate of 50%, in the year 2010, each resident of South Tarawa will have only 22-23 L/pers/day of treated groundwater available for use in the household. The 50% leakage rate is a conservative estimate of the current leakage rate. If nothing is done to reduce leakage, by 2030 each person in South Tarawa will have available, on average, between about 12 and 15 L/pers/day of treated potable water. It is noted that any water used for institutional, industrial or commercial uses would reduce these figures further.

On average, people in North Tarawa should have fully adequate supplies of well water to 2030, even when a 20% reduction in yield by 2030 is assumed. However, this assumes that all the available groundwater is evenly distributed across North Tarawa. In some islands that are narrower and where population growth rates are higher than the North Tarawa average, this will not be the case. In Buariki, with the potential for a very large water lens, the average per capita availability of water will be much larger than in say Abaokaro.

There several are advantages and disadvantages for the “do nothing” option.

Advantages: No capital cost outlay for GoK
No new infrastructure required
No increase in PUB staff required
No increase in energy consumption by extra pumping
No new lengthy negotiations with landowners to create of water reserves
No increased rental payments for new water reserves
Increased use of rainwater
Lack of water in South Tarawa may discourage migration from Outer Islands

Disadvantages: By 2030 per capita water supply rate close to survival limit with significant risks if equipment fails or during dry periods.
Increasing reliance on polluted household well water with significant health and infant mortality risks.
Many household wells in South Tarawa will become brackish to saline intrusion during major droughts
Inequities in the treatment of communities in North and South Tarawa
Increasing reliance on rainwater harvesting with almost certain failure of household rainwater storages during droughts
Inefficiencies and costs of pumping water that is lost in leakages
Inequities in the treatment of communities in North and South Tarawa
Industrial and commercial development seriously restricted by lack of water
Costs of rainwater harvesting borne by households

Costs: Continued maintenance, operational and replacement costs
Increasing health costs due to increased incidences of infant mortality and water-borne diseases. The major cost is associated with the payment of rental to land owners in Bonriki and Buota.

Annual rental payments 71.31ha@$3,720/ha/year for 20 y = $8.24 M

7.2 Reduce Leakage to 25%, Option 2

This option is identical to the “do nothing” option, except that leakage losses will be reduced from 50% to one of the PUB’s goals of 25%. In this option household water supplies in North Tarawa until 2030 are again assumed to be sourced mainly from household wells with a minor component being supplemented from rainwater and seawater for non-potable uses. For South Tarawa it is again assumed that treated water will continue to be supplied at the sustainable rate, 2.01 ML/d from Bonriki and Buota (Table 11). The rest of South Tarawa’s water needs are again assumed to be met by using rainwater harvesting, with household wells and seawater being used for non-potable water use. The case for North Tarawa is identical to Option 1 (Table 18).

This component will have to have a considerable behavioural change component, since much of the leakage in the water supply system is caused by open-ended household connections, household leakage and illegal connections. These will have to be prevented if the gains made in reducing losses are to be preserved for the next 20 years.

South Tarawa: Reticulated treated water from Bonriki and Buota water reserves
25% leakage from reticulation system
Supplemented by rainwater harvesting
Household water wells and seawater used for non-potable use

North Tarawa: Household water wells
Supplemented by rainwater harvesting
Seawater for non-potable use

Table 17 also shows the predicted average per capita daily water availability for South Tarawa for 25% leakage rates and two population growth rates. Under a leakage rate of 25%, in the year 2010, each resident of South Tarawa would have about 33 - 34 L/pers/day of treated groundwater. By 2030, each person in South Tarawa is projected to have available at the household level on average about 17 to 23 L/pers/day of treated potable water. This is less than one third of the design figure of 68 L/pers/day for South Tarawa but a considerable improvement on the “do nothing” option. The advantages and disadvantages of this option are:

Advantages: An extra 135 ML/y of water available equivalent to the demand of 6,160 people
Increase in the efficiency of energy consumption from pumping per unit of water delivered to households
Halving of the amount of treated water lost from the supply system
No new lengthy negotiations with landowners to create water reserves
No increased rental payments for new water reserves
Increased use of rainwater
Lack of water in South Tarawa may restrict inward migration from Outer Islands

Disadvantages: Technically challenging
Significant capital costs required for major upgrading of the domestic reticulation and household water systems
Small increase in PUB staff required for leak detection and control
Considerable effort required to bring about behavioural changes necessary for water controlling losses and illegal connections.
Increasing reliance in the future on polluted household well water with significant health and infant mortality risks
Many household wells in South Tarawa will become brackish to saline intrusion during major droughts
Industrial and commercial development seriously restricted by lack of water
Inequities in the treatment of communities in North and South Tarawa
Increasing reliance on rainwater harvesting with almost certain failure of household rainwater storages during droughts
Costs of rainwater harvesting borne by households

Costs: Difficult to assess because magnitude of problem unknown. Continued maintenance, operational and replacement costs as per current system. Possible estimates follow.

Leakage investigation	= $150 k
Costs of reducing household leakages: 5400 households@$250/hh	= $1.35 M

Domestic reticulation system for households in Betio and Bairiki (?) installed in 1975. Domestic reticulation in villages along South Tarawa installed in the TWSP ending in 1987. Estimated pipelines replacement costs plus relaying roads affected = $10 M.

Estimated Total cost leak reduction	**= $11.50 M**
Extra water available over 20 years	= 3,700 ML
Capital Cost per KL	**= $3.11/KL**

7.3 Refurbish Bonriki Water Reserve and Reduce Leakage, Option 3

In this option household water supplies in North Tarawa until 2030 are again assumed to be sourced mainly from household household wells with a minor component being supplemented from rainwater and seawater for non-potable uses, and the available water supply there is given in Table 18.

In South Tarawa it has been assumed that the leakage rate has been reduced to 25%. Bonriki water reserve will be refurbished with removal of trees and deep-rooted vegetation from the centre of the island and the in-filling of brackish to saline ponds at the western end of the reserve. It is estimated this will increase the sustainable, safe yield of Bonriki by 0.5 ML/day so that the combined yield of Bonriki and Buota will be 2.51 ML/d (

Table 9).

Under this option, sports fields could also be created on the water reserve to give a benefit to Bonriki youth. The infilling of the ponds will require thorough cleaning of the pond bottoms.

Treated water will be supplied at the new sustainable rate from the water reserves in Bonriki and Buota with an assumed reduced 25% leakage rate. There may be a need for the installation of three extra infiltration galleries in the reclaimed pond area (Falkland, 2004). For the removal of trees the extra yield can be accommodated by increasing the pumping rates of existing galleries. The rest of South Tarawa's water needs are assumed to be met by using rainwater harvesting with household wells and seawater being used for non-potable water use. The assumed conditions are:

South Tarawa: Reduction in leakage to 25%
Enhancement of the safe yield at Bonriki by removing trees and deep-rooted vegetation from the centre of Bonriki and infilling of ponds at the western end of the reserve
New galleries constructed in infilled ponds
Produced water fed into Bonriki treatment plant
Reticulated treated water from Bonriki and Buota water reserves
Supplemented by rainwater harvesting
Household water wells and seawater for non-potable use

North Tarawa: Household water wells
Supplemented by rainwater harvesting
Seawater for non-potable use

Table 19 lists the predicted average per capita supply rate for South Tarawa for 25% leakage rates, two population growth rates and the refurbishment of Bonriki water reserve with a combined safe yield of 2.51 ML/d. Under the refurbishment and a reduced leakage rate of 25%, in the year 2010, each resident of South Tarawa will have an improved supply at the household of about 41-43 L/pers/day of treated groundwater available at the household level. By 2030, each person in South Tarawa would have available on average between about 21 to 29 L/pers/day of treated potable water. This is still less much less than the design figure of 68-80 L/pers/day but a significant improvement on the reduce leakage only Option 2. The advantages and disadvantages of this option are:

Advantages: An extra 137 ML/y (25%losses), equivalent to the water needs of 6,250 people
Improved per capita treated water available
No new lengthy negotiations with landowners in North Tarawa over the creation of water reserves

May increase participation of Bonriki and Buota landowners in the protection, care and management of reserves
No extra reticulation pipelines or treatment works required.
Limited water in South Tarawa may restrict inward migration from Outer Islands

Disadvantages: Politically challenging
Significant capital costs required for major upgrading of the domestic reticulation systems
Major capital costs associated with the dredging of material and in-filling of ponds
Possible lengthy negotiations with landowners over the cutting of trees and the in-filling of the ponds
On-going compensation costs for cutting of trees
Environmental Impact Statement (EIS) required
Small increase in PUB staff required
Continued reliance on polluted household well water with significant health and infant mortality risks.
Many household wells in South Tarawa will become brackish to saline intrusion during major droughts
Industrial and commercial development restricted by lack of water
Inequities in the treatment of communities in North Tarawa
Time taken for reclaimed pond area to start producing freshwater may be several years.
Reliance on rainwater harvesting with almost certain failure of rainwater storages during droughts
Costs of rainwater harvesting borne by households

Table 19. Predicted range of average daily per capita household water availability in South Tarawa for 25% leakage rates and two population estimates and the refurbishment of Bonriki option with combined yield of 2.51 ML/day

Year	Per Capita Water Availability South Tarawa (L/pers/day)	
	25% Water Losses	
	Lower	Upper
2010	43	41
2020	39	33
2030	29	22

Costs: Continued maintenance, operational and replacement costs

Tree removal option

Number of trees to be removed	= 1,700
Tree removal costs, $5/tree	= $8,500
Labour, Infilling of pits, 50 people@$10/day for 10 days	= $5,000
Compensation for tree removal, $20/tree	= $34,000
Development of sports fields	= $15,000
Increase pumping rates 22 pumps@$250/pump	= $5,500
Negotiation costs	= $2,000
Total costs tree removal	**= $70,000**
Extra water available over 20 years (with 25% loss)	= 1370 ML
Extra water available over 20 years (with 50% loss)	= 913 ML
Capital Cost per KL (25% loss)	**= $0.055/KL**
Capital Cost per KL (50% loss)	**= $0.077/KL**

For the infilling of the ponds it is assumed that fill materials will be dredged from the lagoon. One unknown cost with this option is possible payment of rental to land owners who may claim ownership of the ponds.

Continued maintenance, operational and replacement costs

Infilling ponds option

Area of ponds	= 5.1 ha
Average depth of ponds	= 2 m
Volume of dredged fill required	= 102,000 m^3
Cost of dredge fill and transport $15/$m^3$ (SOPAC, 2007)[12]	= $1.53 M
EIS	= $20,000
3xInfiltration gallery and extra pipes @$50K/gallery	=$150,000
Negotiation costs	= $5,000
Annual rental payments 5.1ha@$3,720/ha/year for 20 y	= $0.379 M
Total cost in filling ponds without compensation	**= $1.705 M**
Total cost in filling ponds with compensation	**= $2.084 M**
Extra water available over 20 years (with 25% loss)	= 1370 ML
Extra water available over 20 years (with 50% loss)	= 913 ML
Capital Cost per KL without compensation (25% loss)	**= $1.24/KL**
Capital Cost per KL without compensation (50% loss)	**= $ 1.87/KL**
Capital Cost per KL with compensation (25% loss)	**= $1.52/KL**
Capital Cost per KL with compensation (50% loss)	**= $ 2.28/KL**

7.4 Develop Sources at Betio, Bairiki, Bikenibeu, Option 4

In this option household water supplies in North Tarawa until 2030 are again assumed to be sourced mainly from household household wells with a minor component being supplemented from rainwater and seawater for non-potable uses, and the available water supply there is given in Table 18.

In South Tarawa, in addition to the leakage control (option 2) and the refurbishment of Bonriki, this option will assess whether it is possible to develop and protect groundwater sources in Betio, Bairiki and Bikenibeu. An extensive survey will need to be carried out of the water quality and yields of the sites in Betio, Bairiki and Bikenibeu. ***Only if*** the water quality and yield are acceptable, galleries will be constructed at these sites and feed to individual water treatment plants before discharge into the storage reservoirs at each centre. Water needs in South Tarawa will continue to be supplemented by use of household water wells and rain tanks. The assumed conditions are:

South Tarawa: Reduction in leakage to 25%
Enhancement of the safe yield at Bonriki by removing trees and deep-rooted vegetation from the centre of Bonriki and infilling of ponds at the western end of the reserve
New galleries constructed at Betio, Bonriki and Bikenibeu
Produced water treated locally and fed into existing large storage tanks
Reticulated treated water still produced from Bonriki and Buota water reserves
Supplemented by rainwater harvesting
Household water wells and seawater for non-potable u

North Tarawa: Household water wells
Supplemented by rainwater harvesting
Seawater for non-potable use

In this option, it is estimated between 110 and 200 KL (Table 10) will be added to the available water production in South Tarawa (Bonriki and Buota plus refurbished Bonriki) bringing the total production to between 2.61 ML and 2.71 ML/day. Table 20 lists the predicted average per capita supply rate for South Tarawa for 25% leakage rates, two population growth rates and the refurbishment of Bonriki water reserve with a combined safe yield of 2.61 to 2.71 ML/d. It is expected that only one gallery per site will be required for this option. An EIS will be required.

Under this option and a reduced leakage rate of 25%, in the year 2010, each resident of South Tarawa will have a slightly improved supply at the household of about 43-46 L/pers/day of treated groundwater available at the household level. By 2030, each person in South Tarawa would have available on average between about 23 to 31 L/pers/day of treated potable water. This is still less

[12] SOPAC (2007) gives the cost of dredging material in Tarawa at $10/$m^3$. Here an extra $5/$m^3$ has been added for possible transport costs.

much less than the design figure of 68-80 L/pers/day and involves the risk of possible contaminated water sources.

Table 20 Predicted range of average daily per capita household water availability in South Tarawa for 25% leakage rates and two population estimates and with additional South Tarawa groundwater sources and combined yield of 2.61-2.71 ML/day

Year	Per Capita Water Availability South Tarawa (L/pers/day)	
	25% Water Losses	
	Lower	Upper
2010	46	43
2020	42	35
2030	31	23

The advantages and disadvantages of this option are:

Advantages: An extra 27.5 to 55 ML/y, equivalent to the water needs of 1,250 to 2,510 people
Increased efficiency in energy consumption from pumping per unit of water delivered to households because of proximity of galleries
Halving of the amount of treated water lost from the supply system
No new lengthy negotiations with landowners to create of water reserves
No increased rental payments for new water reserves
Increased use of rainwater
Lack of water in South Tarawa may restrict inward migration from Outer Islands

Disadvantages: Significant capital costs required for major upgrading of the domestic reticulation and household water systems
Major water investigations required in South Tarawa
Increase in monitoring required
Costs associated gallery construction
Increase in PUB staff required to run three treatment plants
Increase in MPWU, MELAD AND MHMS water quality monitoring staff
Water supply system has to be managed carefully
Considerable effort required in bringing about behavioural change necessary for water controlling losses and illegal connections.
Increasing reliance on polluted household well water with significant health and infant mortality risks.
Many household wells in South Tarawa will become brackish to saline intrusion during major droughts
Industrial and commercial development seriously restricted by lack of water
Inequities in the treatment of communities in North and South Tarawa
Increasing reliance on rainwater harvesting with almost certain failure of household rainwater storages during droughts
Costs of rainwater harvesting borne by households

Costs **Additional water sourced from Betio, Bairiki, Bikenibeu option**

Extensive Water quality and yield assessments	= $95,000
EIS	= $30,000
3xInfiltration gallery and extra pipes @$75K/gallery	=$225,000
3x water treatment plants@$40,000/plant	=$120,000
Total cost of option	**= $0.47 M**
Extra water available over 20 years (with 25% loss)	= 550 -1100 ML
Extra water available over 20 years (with 50% loss)	= 370 - 730 ML
Capital Cost per KL (25% loss)	**= $0.43 – 0.86/KL**
Capital Cost per KL (50% loss)	**= $0.64 – 1.29/KL**

7.5 Abatao and Tabiteuea, Option 5

This option is added to Option 4. In this option two new infiltration galleries are installed at Abatao and three at Tabiteuea in North Tarawa (see

Figure 9) and are connected by pipes to the water supply pipeline from Buota and Bonriki. Pumps are powered by the electricity supply which currently extends to Tabiteuea. Households in Abatao and Tabiteuea will be supplied with water from the reticulation system. Households in other islands in North Tarawa until 2030 are again assumed to be sourced mainly from vertical household wells with a minor component being supplemented from rainwater and seawater for non-potable uses.

Bonriki water reserve will be refurbished with removal of trees and deep rooted vegetation from the centre of the island and the in-filling of brackish to saline ponds at the western end of the reserve. Extra sources of water will be exploited in Betio, Bairiki and Bikenibeu. It is estimated the connection of Abatao and Tabiteuea (combined 0.22 ML/d), plus the refurbishment of Bonriki (0.5 ML /day), plus additional water sources from Betio, Bairiki will give a combined yield of 2.83 to 2.93 ML/d. Water treatment plants will need to be built at Abatao and Tabiteuea to supply the villages with treated water. Treated water will be supplied from all islands at the new sustainable rate with an assumed reduced 25% leakage rate. The rest of South Tarawa's water needs are assumed to be met by using rainwater harvesting with household wells and seawater being used for non-potable water use. The assumed conditions are:

South Tarawa: Enhancement of the safe yield at Bonriki by removing trees and deep-rooted vegetation from the centre of Bonriki and infilling ponds at the western end of the reserve
Water sources in Betio, Bairiki and Bikenibeu developed
Reticulated treated water from Bonriki and Buota water reserves and from Abatao and Tabiteuea at a rate of 2.83 – 2.93 ML/d
25% leakage from reticulation system
Supplemented by rainwater harvesting
Household water wells and seawater for non-potable use

North Tarawa: Development of new groundwater reserves at Abatao and Tabiteuea
Villages in Abatao and Tabiteuea connected to reticulation system
Remaining villages in North Tarawa rely on household water wells
Supplemented by rainwater harvesting
Seawater for non-potable use

In order to assess this option it is necessary to determine the increased population in Abatao and Tabiteuea who will have access to reticulated water. The 2005 Census data only gives growth rates for North Tarawa, not individual islands within North Tarawa.

In the 2005 census, the populations of Abatao and Tabiteuea are 421 and 391 persons or a total of 812 for both islands (National Statistics Office, 2007a; Table 3). Two estimates will be made of the future population of Abatao and Tabiteuea. In the first it will be assumed that the percentage of total Kiribati population living in Abatao and Tabiteuea will grow linearly at the same rate as North Tarawa (Lower). In the second it is assumed that the population will grow exponentially at the same rate as the 2005 base year North Tarawa growth rate of 4.8%. The estimated ranges of future populations in these two islands are given in Table 21 which shows a combined population of both islands could be between 2000 and 2700 people by 2030. These population figures will be added to those of South Tarawa and Buota (White and Falkland, 2009a, Table 23).Table 22 shows the predicted average per capita water supply rate which is possible with 25% losses and the combined pump outputs from the refurbished Bonriki, Buota, Abatao and Tabiteuea with a combined safe yield of 2.83 to 2.93 ML/pers/day.

Under the refurbishment, extra sources in South Tarawa and the addition of water pumped from Abatao and Tabiteuea and with a reduced leakage rate of 25%, in the year 2010, each resident of South Tarawa will have about 45 to 49 L/pers/day of treated groundwater. This is only a marginal 10% improvement over the refurbishment alone option 3 (Table 19). By 2030, each person in South Tarawa, Abatao and Tabiteuea would have on average between about 24 to 33 L/pers/day of treated potable water available at the household. This is still much less than the design figure of 68 to 80 L/pers/day and is only a marginal 10% improvement over refurbishment of Bonriki alone.

Table 21 Projected range of future population numbers in Abatao and Tabiteuea

Year	Projected Number of People					
	Lower		Upper		Lower	Upper
	Abatao	Tabiteuea	Abatao	Tabiteuea	Total Both Islands	
2005	**421**	**391**	**421**	**391**	**812**	**812**
2010	512	475	534	496	987	1030
2020	764	709	868	806	1473	1673
2030	1075	999	1401	1301	2074	2703

Table 22. Predicted range of average daily per capita household water availability for South Tarawa, Abatao and Tabiteuea for 25% leakage rates for refurbished Bonriki and sources in South Tarawa added to extraction from Abatao and Tabiteuea with combined yield of 2.83 to 2.93 ML/day

Year	Per Capita Water Availability South Tarawa, Abatao & Tabiteuea (L/pers/day)	
	25% Water Losses	
	Lower Yield	Upper Yield
2010	45	49
2020	37	45
2030	24	33

If the groundwater resources in Abatao and Tabiteuea were only developed for residents in Abatao and Tabiteuea, then their expected future water availability is given in Table 23 for an assumed loss rate of 25%.

Table 23 Predicted range of average daily per capita household water availability for Abatao and Tabiteuea only for 25% leakage rates for extraction from Abatao and Tabiteuea with combined yield of 0.22 ML/day

Year	Per Capita Water Availability Abatao & Tabiteuea (L/pers/day)	
	25% Water Losses	
	Lower	Upper
2010	167	160
2020	112	99
2030	64	49

Under this option, if the villagers of Abatao and Tabiteuea elected to keep their reticulated water exclusively for their own use they would have by 2010 between 160 to 167 L/pers/day which would decrease to 49 to 64 L/pers/day by 2030. If they elect to contribute their water to the South Tarawa reticulation scheme and receive the average per capita share of water they would only receive the average allocation of between 45 and 49 L/pers/day by 2010 which would reduce to 24 to 33 L/pers/day by 2030. There is little incentive for the Abatao and Tabiteuea to participate in sharing their water resources with South Tarawa. For the substantial increase in cost in pipe lines there is very little per capita increase in daily water availability in South Tarawa.

For the remainder of North Tarawa, with supply continuing from household wells, there will be still be sufficient per capita water by 2030 (Table 24).

Table 24 Predicted range of average daily per capita water availability for the remainder of North Tarawa from household wells for the lower and upper estimated yields and the Abatao and Tabiteuea option, combined yield 1.32 to 3.96 ML/day[13]

Year	Per Capita Water Availability Rest of North Tarawa

[13] In this Table and following tables the lower estimate is calculated using the lowest yield estimate and the highest population estimate while the upper comes from the highest yield and the lowest population estimate.

	(L/pers/day)	
	Lower Yield	**Upper Yield**
2005	378	1134
2010	298	840
2020	183	467
2030	91	267

The advantages and disadvantages of this option are:

Advantages: An extra 60 ML/y equivalent to the water needs of 2,750 people
Abatao and Tabiteuea receive treated water
Limited water in South Tarawa may restrict inward migration from Outer Islands

Disadvantages: Politically difficult
Significant capital costs required for major upgrading of the household reticulation systems
Will need to revise legislation or introduce new legislation
Major capital costs of dredging of material and in-filling of ponds
Major capital costs associated with construction of infiltration galleries at Abatao and Tabiteuea and construction of pipelines from Tabiteuea to Buota
Some negotiations with landowners over the cutting of trees and the in-filling of the ponds at Bonriki
Major and lengthy negotiations with landowners of water reserve locations in Abatao and Tabiteuea
EIS required
Increase in compensation and land rental payments
Increase in PUB staff to manage pumping from North Tarawa
Inequities in water supply in North Tarawa
Industrial and commercial development seriously restricted by lack of water
Reliance on polluted household well water with significant health risks Many household wells in South Tarawa will become brackish to saline intrusion during major droughts

Costs **Water sourced from Abatao and Tabiteuea**

EIS	= $20,000
Infiltration galleries, 5 galleries @ $75,000/gallery	= $375,000
Treatment plants, 2 @ $40,000/plant	= $80,000
Pipeline from Tabiteuea to Buota	=$1,100,000
Household connections, 160 households @$1,000/hh	= $160,000
Negotiations with communities	= $30,000
Annual rental payments 7.5ha@$3,720/ha/year for 20 y	= $558,000
Total costs	**= $2.323 M**
Extra water delivered over 20 years (25% losses)	= 1,205 ML
Extra water delivered over 20 years (50% losses)	= 804 ML
Capital Cost/KL (25% losses)	**= $1.93/KL**
Capital Cost/KL (50% losses)	**= $2.89/KL**

7.6 Develop Buariki and Taratai Groundwater Lenses, Option 6

It is clear from Table 11 and Figure 10 that Buariki and Taratai in North Tarawa have the most substantial groundwater resources in North Tarawa. In this option, water is supplied from Buariki and Taratai in North Tarawa via land pipeline to Tabonibara, then by undersea pipeline across the lagoon to Ambo where it joins the Bonriki Betio pipeline (Figure 20). While solar powered pumps appear a sound way of supplying power for pumping, they are only able to provide power for less than 12 hours a day and would not have sufficient pressure to pump water across the lagoon. It is not feasible to use batteries to supply the power necessary for the required 24 hours/day operation option. To carry out this option a power station will need to be developed in North Tarawa to power the pumps which could additionally supply power to the remainder of North Tarawa which is currently without power.

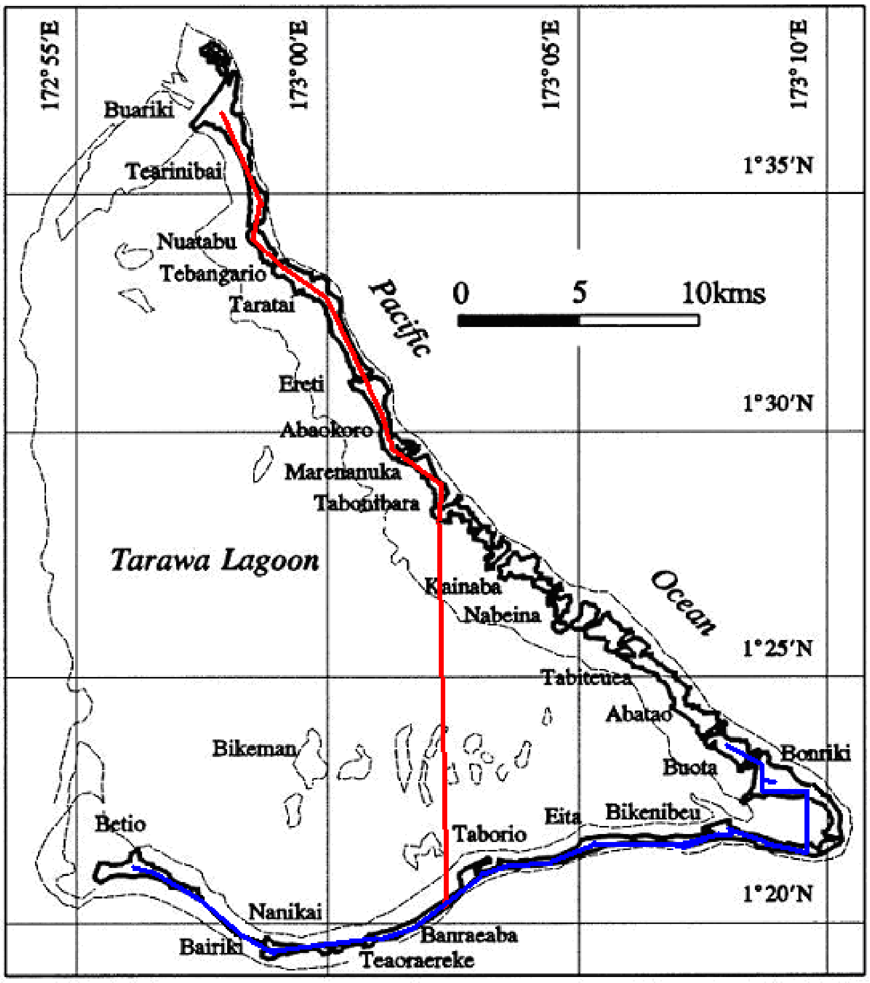


Figure 20 Option 6, development of the lenses at Buariki and Taratai with a pipeline from Buariki to Ambo (red line) to connect with the Bonriki to Betio pipeline (blue line)

This option will require extensive negotiations with the landowners and a major EIS to cover both the Buariki and Taratai galleries and pipeline construction. It will be assumed that this option will be developed after Options 2 to 5 have been carried out. It is estimated that 18 infiltration galleries and one treatment plant plus major water storage and treatment plant will be required. In this option, all of South Tarawa and all villages in North Tarawa are supplied from either the Bonriki-Betio pipeline or the Buarilki-Tabonibara-Ambo pipeline. The assumed conditions are:

South Tarawa: Enhancement of the safe yield at Bonriki by removing trees and deep-rooted vegetation from the centre of Bonriki and infilling ponds at the western end of the reserve
Water sources in Betio, Bairiki and Bikenibeu developed
Water sources in Buariki and Taratai developed
Reticulated treated water from Bonriki and Buota water reserves and from Abatao and Tabiteuea.
Water supplied by under lagoon pipeline from Taboniabara to Ambo
Total sustainable yield between 3.34 and 4.45 ML/day
Power station constructed in North Tarawa
25% leakage from reticulation system
Supplemented by rainwater harvesting
Household water wells and seawater for non-potable use

North Tarawa: Development of new groundwater reserves at Buariki and Taratai

Villages in North Tarawa, except Abatao and Tabiteuea to be supplied from Buariki
25% leakage assumed in North Tarawa
Abatao and Tabiteuea connected to South Tarawa reticulation system
All villages in North Tarawa are connected to piped treated water
Supplemented by rainwater harvesting
Seawater for non-potable use

Table 22 shows the estimated range of water available per person in all of Tarawa until 2030.

Table 25. Predicted range of average daily per capita household water availability for all of Tarawa, for 25% leakage rates all sources in South Tarawa added to extraction from Abatao, Tabiteuea, Buariki and Taratai with combined estimated lower and upper yields of 3.34 and 4.45 ML/day

Year	Per Capita Water Availability All Tarawa (L/pers/day)	
	25% Water Losses	
	Lower Yield	Upper Yield
2010	49	67
2020	38	58
2030	24	39

If this option were carried out immediately together with the improvements in South Tarawa, then there would be a reasonable amount of water per person currently available of 49 to 67 L/pers/day. By 2030, this will have shrunk to 24 to 39 L/pers/day.

If, however, the water resources in Buariki and Taratai were only developed the use of communities in North Tarawa, so that a reticulated water supply was established with a 25% loss rate (Table 26), then residents in North Tarawa would have 0.73 to 1.74 ML/day (range for Buariki and Taratai plus Abatao and Tabiteuea lenses) available for use. Currently, this would give households in North Tarawa between 100 and 229 L/pers/day which would be reduced to 31 to 62 L/pers/day by 2030. Supplying water to South Tarawa would therefore disadvantage communities in North Tarawa and to people in Buariki and Taratai in particular.

Table 26 Predicted range of average daily per capita water availability for all of North Tarawa households for the lower and upper estimated yields for supply from Buariki and Taratai with estimated yield between 0.73 to 1.74 ML/day

Year	Per Capita Water Availability North Tarawa (L/pers/day)	
	25% Water Losses	
	Lower Yield	Upper Yield
2010	100	229
2020	62	131
2030	31	62

The advantages and disadvantages of this scheme are:

Advantages: An extra 139 to 417 ML/y (25% losses) equivalent to the water needs of 6,300 to 19,000 people
All of North Tarawa receives treated water
Power station for North Tarawa
Modestly increased water supply for South Tarawa
Limited water in South Tarawa may restrict inward migration from Outer Islands

Disadvantages: Politically very difficult
Significant capital costs required for major upgrading of the domestic reticulation systems
Major capital costs associated with the dredging of material and in-filling of ponds
Major capital costs associated with construction of infiltration galleries in North Tarawa.

Major costs for the construction of pipelines from Buariki to Buota plus a possible power station to pump water from Buariki to Buota since solar-powered pumps may not be powerful enough
Major increase in pumping costs
Some negotiations with landowners over the cutting of trees and the in-filling of the ponds at Bonriki
Major, lengthy and difficult negotiations with the landowners of the water reserve location in Buariki and the owners of Babwai pits
EIS required
Considerable increase in compensation payments
Major Increase in PUB and MPWU staff to manage water supply and power station in North Tarawa
Industrial and commercial development restricted by lack of water
Significant increased cost of power generation
North Tarawa villages required to sacrifice water to South Tarawa
Limited
Some reliance on polluted household well water with significant health risks. Many household wells in South Tarawa will become brackish to saline intrusion during major droughts

Costs **Water sourced from Buariki & Taratai**

EIS	= $20,000
Infiltration galleries, 18 galleries @ $75,000/gallery	=$1.35 M
Major treatment plant, 1 @ $100,000/plant	= $100,000
Pipeline from Buariki to Ambo	= $3 M
Power station	= $6 M
2 ML holding tank	= $1.5 M
Household connections, 900 households @$1,000/hh	= $ 0.9 M
Negotiations with communities	= $30,000
Annual rental payments 80 ha@$3,720/ha/year for 20 y	= $5.95 M
Total costs	**= $17.35 M**
Extra water delivered over 20 years (25% losses)	= 2,800 to 8,300 ML
Capital Cost/KL (25% losses)	**= $2.08 to $6.23/KL**

7.7 Develop All Major Groundwater Lenses in North Tarawa, Option 7

In this option, new infiltration galleries are progressively installed at all islands with significant freshwater lenses in North Tarawa. These are then connected to the water supply pipeline from Buota and Bonriki, so that Tarawa has a complete water supply pipeline from Buariki to Betio. From Buariki in North Tarawa there will be a land pipeline to Tabonibara, and then water is transferred by undersea pipeline across the lagoon to Ambo where it joins the Bonriki Betio pipeline. Household water supplies throughout North and South Tarawa will be supplied with water from the reticulation system whose loss rate will be reduced to 25%. Bonriki water reserve will be refurbished with removal of trees and deep rooted vegetation from the centre of the island and the in-filling of brackish to saline ponds at the western end of the reserve, water will be sourced from Betio, Bairiki and Bikenibeu and Abatao and Tabiteuea.

With this option it is not possible to determine with full confidence the sustainable yield of all freshwater lenses since the island groundwater sources have been surveyed in a wet period (Table 11). The data in Table 11 suggest that there may be up to an extra 3.87 ML/day. Experience with Abatao and Tabiteuea suggests that the actual safe yield may be as low as an additional 1.44 ML/day (including Abatao and Tabiteuea) due to encroachment of settlements and babwai pits over groundwater source areas. Here, a conservative approach is adopted and it is assumed that the extra safe yield in North Tarawa is between 1.44 to 3.87 ML/day[14]. This added to the refurbished Bonriki, gives a safe yield of between 4.0 and 6.4 ML/day with no losses. It is assumed

[14] It is expected that encroachment of more northern villages in North Tarawa on potential groundwater source areas may be less than in Abatao and Tabiteuea, so it may be expected that this lower limit is too conservative. Because of the lack of information, however, this lower limit will be used.

that this water will be shared equally between North and South Tarawa. Treated water will be supplied from all islands at the new sustainable rate with an assumed reduced 25% leakage rate. The rest of Tarawa's water needs are assumed to be met by using rainwater harvesting with household wells and seawater being used for non-potable water use.

The assumed conditions are:

All Tarawa: Enhancement of the safe yield at Bonriki by removing trees and deep-rooted vegetation from the centre of Bonriki and infilling of ponds at the western end of the reserve
25% leakage from reticulation system
Development of possible groundwater sources in Betio, Bairiki and Bikenibeu
Progressive development of new groundwater reserves at Abatao, Tabiteuea, Tabiang, Marenanuka, Abaokoro, Taborio, Taratai, Tebangaroi, Nuatabu, Tearinibai and Buariki.
Reticulated treated water from Bonriki and Buota water reserves and Abatao and Tabiteuea piped to South Tarawa
Reticulated treated water from all the remaining major lenses in North Tarawa piped to those islands and transported by under lagoon pipeline from Tabonibara to Ambo
Combined yield between 4.0 and 6.4 ML/day
Supplemented by rainwater harvesting
Household water wells and seawater for non-potable use

Table 27 shows the predicted average per capita water supply rate which is possible with 25% losses and the combined outputs from the refurbished Bonriki, Buota, and the larger groundwater systems of Abatao and Tabiteuea with a conservatively estimated combined safe yield of 4.05 ML/pers/day.

Table 27 Predicted range of average daily per capita household water availability for all of Tarawa, with 25% leakage rates for refurbished Bonriki and potential South Tarawa sources together with combined groundwater from all major lenses in North Tarawa, combined yield of 4.0 to 6.4 ML/d.

Year	Per Capita Water Availability All Tarawa (L/pers/day)	
	25% Water Losses	
	Lower Yield	Upper Yield
2010	58	97
2020	46	83
2030	29	56

Under the refurbishment, extra sources in South Tarawa and the addition of water pumped from all the main islands of North Tarawa and with a reduced leakage rate of 25%, currently, each resident throughout Tarawa will have on average about 58 to 97 L/pers/day of treated groundwater. This is close to the design range of 68 to 80 L/pers/day. This amount, however, quickly declines as the population increases. By 2020 it is predicted to fall to between 46 and 83 L/pers/day and by 2030, with possible impacts of sealevel rise, each person in Tarawa would have on average between about 29 to 56 L/pers/day of treated potable water, less than the design figures. It must also be recognised that the upper estimate assumes that the population of South Tarawa will not exceed 50,000 by 2030. This decrease in water availability in North Tarawa would also limit the potential for continued irrigation of crops for South Tarawa.

While this option does increase the amount of water available per person in South Tarawa, it greatly decreases the average daily amount of water available per person in North Tarawa. If the entire estimated groundwater yields available in North Tarawa, 1.44 to 3.87 ML/day were allocated only to villages in North Tarawa, then residents there would have a larger supply of water than in South Tarawa, as shown in Table 28. In 2010, it is estimated that if all North Tarawa's estimated sustainable yield were shared only between the residents of North Tarawa with 25% leakage rate then each resident would have between 198 to 508 L/pers/day. This is predicted to decrease to a range of 60 to 172 L/pers/day by 2030 as population increases and sealevel rises. These latter rates still equals the design rate of 60 L/pers/day for rural communities, are close to the design rates for urban communities and allow allocation for irrigation to grow crops for South Tarawa. It is noted that if North Tarawa residents supply water to all of Tarawa then the water available her head will drop between one third and one half of the amount that would be available if the water is produced and used in North Tarawa.

Table 28 Predicted range of average daily per capita water availability for North Tarawa, for 25% leakage rate from major water sources in North Tarawa with a conservatively estimated combined yield of 1.44 to 3.87 ML/d

Year	Per Capita Water Availability North Tarawa (L/pers/day)	
	25% Water Losses	
	Lower Yield	Upper Yield
2010	198	509
2020	122	292
2030	60	172

The advantages and disadvantages of this option are:

Advantages: An extra 360 to 1,085 ML/y equivalent to the water needs of 16,500 to 49,500 people North
Tarawa receives treated water
Power station established in North Tarawa
Modest increased water supply for South Tarawa

Disadvantages: Politically very difficult
Significant capital costs required for major upgrading of the domestic reticulation systems
Major capital costs associated with the dredging of material and in-filling of ponds
Major capital costs associated with construction of infiltration galleries in North Tarawa.
Major costs for the construction of pipelines from Buariki to Buota plus a power station and major reservoir to pump water from Buariki to Buota since solar-powered pumps not suitable for 24 hour operation
Major increase in pumping costs
Some negotiations with landowners over the cutting of trees and the in-filling of the ponds at Bonriki
Major and lengthy negotiations with the many landowners of water reserve locations in North Tarawa
EIS required
Considerable increase in compensation payments
Major increase in PUB staff to run water system twice current size and MPWU staff to monitor water lenses
Industrial and commercial development restricted by lack of water
North Tarawa villages required to sacrifice water to South Tarawa
Initial increase in water availability may attract more settlers to South Tarawa
Some reliance on polluted household well water with significant health risks.
Many household wells in South Tarawa will become brackish to saline intrusion during major droughts

Costs **Water sourced from all major lenses North Tarawa**

EIS	= $60,000
Infiltration galleries, 60 galleries @ $75,000/gallery	=$4.50 M
Major treatment plant, 1 @ $100,000/plant	= $100,000
Pipeline from Buariki to Ambo	= $3 M
Power station	= $9 M

2 ML holding tank	= $1.5 M
Household connections, 900 households @$1,000/hh = $ 0.9 M	
Negotiations with communities	= $90,000
Annual rental payments 233 ha@$3,720/ha/year for 20 y	= $17.3 M
Total costs	**= $36.45 M**
Extra water delivered over 20 years (25% losses)	= 7,900 to 21,200 ML
Capital Cost/KL (25% losses)	**= $1.72 to $4.63/KL**

7.8 Cost of Leakage Reduction

The above estimated cost of leakage reduction, option 2 (section 7.2) is speculative, since the extent of leakage in the domestic reticulation system is unknown and therefore the cost of repairing tem is also unknown. The cost per KL was also based on the amount of water saved in option 2 alone. If these options are to be developed sequentially, then the cost per KL of water saved in reducing the leakage to 25% will decrease as more water is saved. Table 29 shows the progressive decrease in the cost per KL for reducing the water loss rate from the South Tarawa supply system as more water is produced. It can be seen from Table 29 that the early investment in leakage control pays dividens in future water development.

Table 29 Decrease in the cost per KL with successive amounts of water saved by reducing the loss rate from 50 to 25%

Option	Description	Additional Water Saved over 20 Years (ML)	Cost per KL ($/KL)
2	Leakage reduction South Tarawa	3,700	3.11??
3	Refurbishing Bonriki	910	2.49
4	Extra Sources South Tarawa	180 - 370	2.31 - 2.40
5	Abatao and Tabiteuea	401	2.14 - 2.22
6	Buariki	930 - 2,800	1.41 - 1.88
7	All remaining North Tarawa	2,630 - 7,070	0.92 - 1.47

7.9 Summary of Options

Five of the seven options advanced in this section were designed so that they could be implemented sequentially as demand increases. Option 1, “do nothing” is clearly not a viable option. If nothing is done to secure additional water supplies then there is a very high risk of failure of the system to provide adequate treated water for South Tarawa and greatly increased health risks due to the use of local polluted household well water.

Table 30 shows a summary of the estimated range of per capita water availability for households in South Tarawa for the seven options up to the year 2030 using the lower and upper estimates of population growth. The average of the range for the options and years 2010, 2020 and 2030 are shown in Figure 21. For options 2 to 7, a 25% leakage rate is assumed. It can be seen that the range of available per capita water almost doubles between option 1 and option 3. There is, however, only a slight increase between options 3 and 5, despite the significantly increased costs and other complexities of developing risky water sources in South Tarawa and bringing water from Abatao and Tabiteuea to South Tarawa. There is approximately a 50% increase between options 3 and 7 but for a major capital cost outlay. The cheapest option that brings about the biggest gain appears therefore to be option 3, reducing leakage to 25% and refurbishing of Bonriki water reserve.

Table 30 Estimated ranges of future per capita household water availability in South Tarawa (plus Buota) for lower and upper population growth rate and yield estimates for all options

Average Per Capita Water Availability South Tarawa (L/pers/day)

Year	2010	2020	2030
Option 1	22-23	18-21	12-15
Option 2	33-34	27-31	17-23
Option 3	41-43	33-39	22-29
Option 4	43-46	35-42	23-31
Option 5*	45-49	37-45	24-33
Option 6†	49-67	38-58	24-39
Option 7†	58-97	46-83	29-56

*Includes Abatao and Tabiteuea
† Includes all of North Tarawa

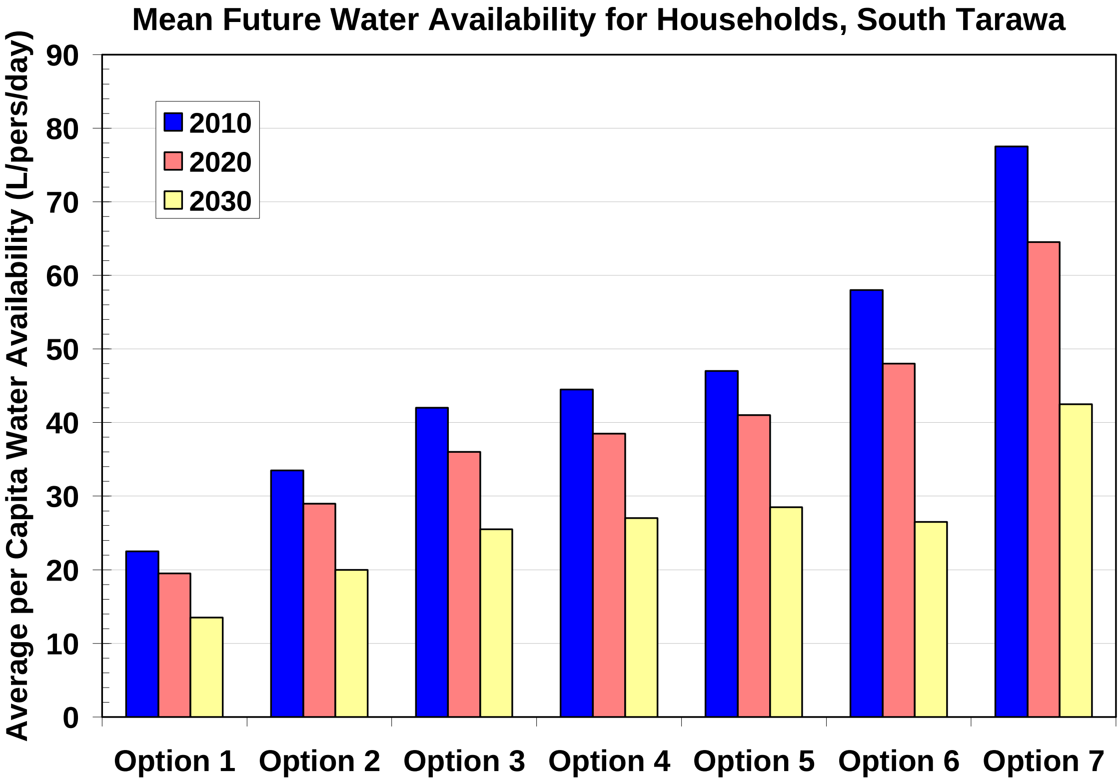


Figure 21 **Estimated average future per capita water availability for households in South Tarawa for the seven supply options to 2030.**

Table 31 shows a summary of the estimated ranges of per capita water availability for households in North Tarawa for the seven options up to the year 2030 using the lower and upper population growth figures and yields. Options 6 and 7 assume 25% water losses. Options1 to 4 do not alter the water availability in North Tarawa, Option 5 shows a slight increase as water is transferred from Abatao and Tabiteuea, since these islands have lower per capita water than the estimated rest of North Tarawa. In Option 6, Buariki water is shared with all of Tarawa and in Option 7 all North Tarawa water is shared equally with South Tarawa. Figure 22 shows the average of the estimated range for North Tarawa. The dramatic decline in water availability for North Tarawa residents can be clearly seen once North Tarawa water is shared with South Tarawa.

Table 31 **Estimated ranges of future per capita household water availability in North Tarawa (less Buota) for lower and upper population growth rate and yield estimates for all options**

Average Per Capita Water Availability North Tarawa (L/pers/day)			
Year	**2010**	**2020**	**2030**
Option 1	250-680	145-390	68-220
Option 2	250-681	145-391	68-221
Option 3	250-682	145-392	68-222
Option 4	250-683	145-393	68-223
Option 5*	275-774	170-431	84-246
Option 6†	49-67	38-58	24-39
Option 7†	58-97	46-83	29-56

* Less Abatao and Tabiteuea
† Includes South Tarawa

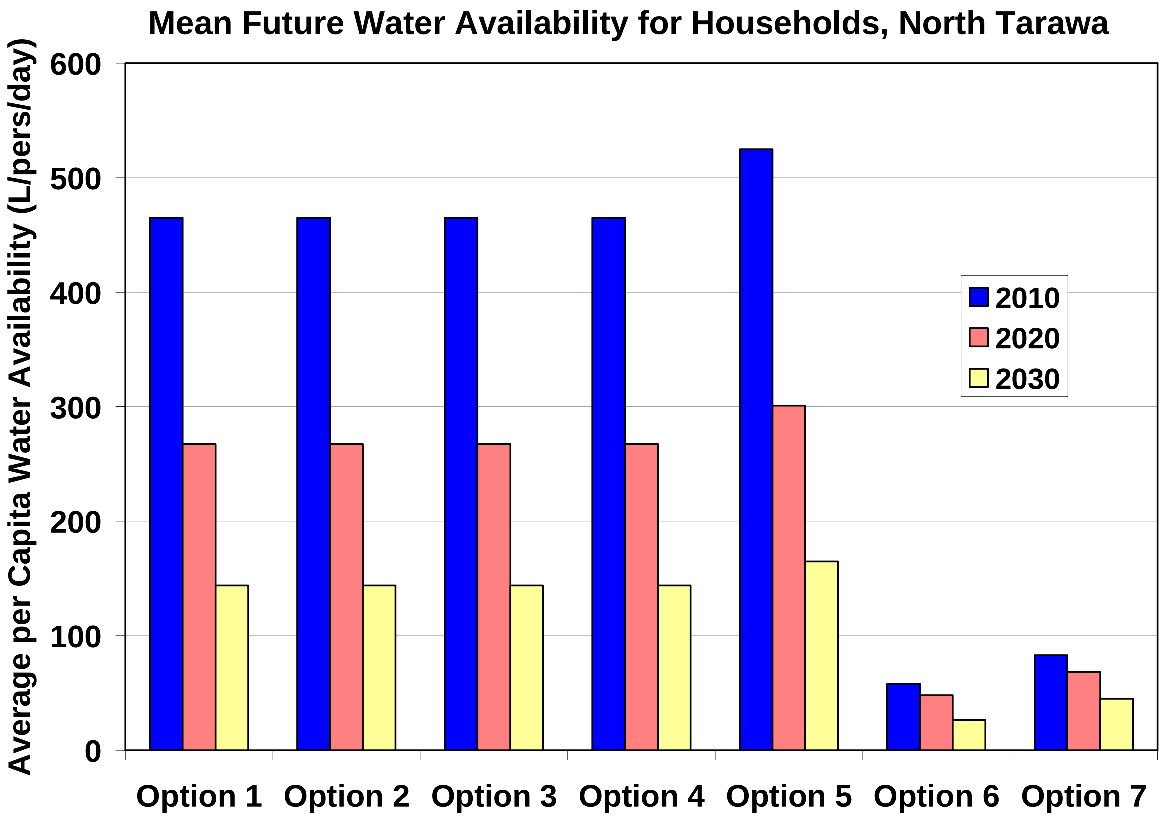


Figure 22 **Estimated average future per capita water availability for households in North Tarawa for the seven supply options to 2030.**

Table 32 provides a summary of the estimated total costs, the land rental costs over 20 years, the total extra water produced over 20 years and the cost per KL of the option. It can be seen in the Table that the cost of option 3, refurbishing Bonriki, and particularly tree removal is relatively cheap and could provide extra water, relatively quickly.

Examination of Table 32 also shows the high cost of land rental payments over 20 years. This amounts to between 18 and 45% of the total costs of the water development options with the total percentage cost of land rentals for options 1 to 5 and 7 being 43.3% of the total costs. The 1977 PUB Regulations include the purchase, but not rental of land required for water reserves. Purchasing the land outright would be a significant costs saving.

Table 32 Summary of total costs, rental costs over 20 years, extra water produced and the cost per KL of the groundwater options assuming 25% water loss rate.

	Option	Estimated* Total Cost Including Land Rental ($million)	Rental Costs 20 years ($million)	Extra Water Produced in 20 years (ML)	Capital Cost/KL ($/KL)
1	Do Nothing	8.24	8.24	0	3.80†
2	Leakage reduction South Tarawa	11.50	0	3,700	3.11‡
3a	Bonriki Remove Trees	0.07	0	1,370	0.06
3b	Bonriki Fill Ponds	2.08	0.38	1,370	1.52
4	Extra Sources South Tarawa♪	0.47	0	550-1,100	0.43-0.86
5	Abatao & Tabiteuea	2.32	0.56	1,205	1.93
6	Buariki & Taratai	19.35	5.95	2,800-8,300	2.08-6.23
7	All remaining North Tarawa	38.45	17.3	7,900-21,200	1.72-4.63
	Total Options 1-5&7	**61.13**	**26.48**	**14,900-28,740**	**2.13-4.11**

* Excludes maintenance, depreciation and operations costs
† Includes current operational, maintenance and land rental costs
‡ Price/KL on water saved in this option. Cost decreases as more sources used as per Table 29. Accurate cost unknown since extent and location of leakage unknown.
♪Requires extensive water quality testing

Some of the above tasks could be carried out as a staged project and there are a number of short-term high priority tasks that can be identified as part of that staging which are discussed in the following section.

8 Short Term Priority Tasks

8.1 Assess and Reduce Leakage from Domestic Reticulation Systems

It is clear that the current rate of water loss from the domestic reticulation system is unacceptable. A large amount of water, energy and resources are being wasted by water leaking from poor joins, illegal connections and open-ended pipes in the domestic reticulation system. It is probably that all the aging domestic reticulation system may need replacement. It is a matter of the highest priority that leakages are identified and replacement of the domestic reticulation system be commenced as soon as possible. It is recommended here that a permanent leakage control unit be established in PUB. Control of leakage will also require a change in behaviour of South Tarawa residents and will involve a major public communications and participation campaign.

8.2 Assess the Current Water Use

The absence of household water meters means that it is not possible to assess how much piped water is being used by households. Estimates here of current household water use in Tarawa have been based on a limited survey of households in Nonouti and a more detailed survey in all villages in Kiritimati. A survey of household, institutional, commercial and industrial water use from various sources should be carried out throughout Tarawa to provide accurate information for planning.

8.3 Assess Accurately Operations, Maintenance and Depreciation Costs

It has not been possible to determine the operational, maintenance and depreciation costs of the current system. This data is needed to determine the cost of supplied water in South Tarawa.

8.4 Monitor Water Quality of Household Wells

The suitability of local groundwater from household wells in Tarawa for use by households should be monitored over the atoll and through time. Household wells are still a major source of water for drinking in Tarawa and the safety of the water needs to be assessed. The assessment here and previous studies (e.g. Shalev, 1992) suggests that many household wells could be significantly polluted. Monitoring will need to include faecal indicators, petroleum products, heavy metals, nutrients and salinity.

8.5 Extra Sources of Water in South Tarawa

It has been suggested here that there may be small additional sources of water available in Betio, Bairiki and Bikenibeu. Because of the significant risk that the sources could be contaminated, detailed assessment of their water quality is absolutely essential as is accurate assessment of the safe yield of these sources and the type of water treatment plants required to treat the water.

8.6 Establish a Community-Government Water Reserve Management Committee

Current government agency management of water reserves has proved inadequate. It is fundamentally important to involve landowners in the protection and management of water reserves. The increased protection and the refurbishment of the Bonriki and possibly Buota water reserves will need the approval and involvement of landowners and the local communities. It is essential that a Community-Government Water Reserve management Committee is established as soon as possible to commence negotiations and planning and to involve the local community as much as possible in any planning decisions and to ensure that any works use as much local labour as possible. Past efforts have failed because of lack of interest by government agencies. The continuing problems at these reserves indicate that current management strategies are inadequate. In the past it has been suggested that instead of paying compensation to landowners the same mount be paid to them as custodians of the land with payment dependent on landowners fulfilling obligations to and care for the reserves and prevent misuse of the reserves (White *et al.*, 1999b). This will probably require enacting legislation.

8.7 Removal of Trees from the Centre of Bonriki Water Reserve

The removal of many trees and deep rooted vegetation from the centre of the Bonriki water reserve and perhaps from Buota as well will increase the sustainable yield of the system. Some trees on the reserve are used by local communities and the impacts of tree removal will need to be assessed. In addition, filling in of no longer operational babwai and gravel mining pits will lower direct evaporation losses and lessen the risk of direct pollution of groundwater. Negotiations should commence as soon as practicable with the water reserve land owners about seeking their permission and employment in clearing the centre of the reserve and in maintaining the area as clear as possible. Thought should be given to making land rental payments to landowners conditional on care for the reserves, with the landowners considered custodians of the reserves. The establishment of playing fields on the cleared areas of the reserve would provide some compensation for the local communities and particularly the young.

8.8 Infilling Ponds on Bonriki Water Reserve

The ponds on the western, lagoon side of the Bonriki reserve were excavated to provide fill for the Bonriki runway. These ponds which are normally brackish contribute salinity to the groundwater. After cleaning of organic matter from the base of the ponds they could be infilled with clean sand dredged from the lagoon. Negotiations should commence as soon as possible with local landowners and the community over the feasibility of this proposal as ponds are used for soaking pandanus leaves for thatch. A feasibility study of reclaiming the ponds should be commenced as soon as practical.

8.9 Accurate Assessment of the Groundwater Resources of North Tarawa

It has only been possible in this report to provide conservative ranges of estimates of the safe yield of most groundwater sources in major islands in North Tarawa since their safe yield has only just been assessed (GEP, 2010). Since these assessments were in a wet year it is essential that all groundwater resources in North Tarawa be monitored to ensure that the safe yields are appropriate and that the water quality is acceptable. This monitoring should be a high priority. All communities in these islands need to be consulted and involved in the groundwater investigations.

8.10 Connecting North Tarawa to the South Tarawa Water Supply System

It has been pointed out above that the conservative estimates of safe groundwater yields in North Tarawa are more than ample for the population of North Tarawa until at least the year 2030. When, however, these resources are shared with South Tarawa, the population in North Tarawa suffer a major reduction in the amount of water available per capita. This is a highly sensitive political issue. It is very important that wide debate particularly with North Tarawa representatives over the possibility of transferring water from North to South Tarawa be commenced and that the legal basis for doing this should be reviewed and if necessary established.

8.11 EIS for Groundwater Development

It appears that the 2007 Environment Act requires that an environmental impact statement (EIS) be carried out in all water resource development projects. MPWU should start collaborations with MELAD to determine the information required in EISs and should commence work on collecting that information.

8.12 Legal Basis for Operations

The statutory basis for MPWU’s responsibilities in water, apart from those specified for the PUB in the 1977 PUB Act, is uncertain. The existing laws and draft legislation should be reviewed with the objective if necessary that give clear directions to ownership of water, protection of water and management responsibilities in the water sector.

8.13 Drought Contingency Plan

Tarawa is subject to frequent, severe droughts in which almost all rainwater harvesting and storage systems will fail and household wells in narrow islands will become too brackish to use. A drought contingency plan, which specifies community training and engagement, should be developed as a matter of high priority.

8.14 Training and Succession Plan

The tasks outlined above are complex and are expected to increase in complexity. It is clear that that MPWU and PUB will require highly trained staff to carry them out. Plans should be developed for provision of training to staff. The GoK's policy of retirement of public servants at age 50 means that expertise is soon lost from Ministries. A succession plan will need to be developed with the training plan to ensure that the GoK has an adequate supply of appropriately trained water and sanitation specialists.

9 The South Tarawa - North Tarawa Dilemma

Early water supply projects (see AGDHC, 1982) have either implicitly or explicitly assumed that groundwater sources in North Tarawa will be readily available to supply South Tarawa's growing demand for water. This assumption has been carried over to more recent studies (Falkland, 1992; OEC 2000). Many of these were carried out when North Tarawa was sparsely populated. They also involve an assumption about the existence of a legal basis for such a transfer.

10.1 Growth of Population in North Tarawa

The 2005 Census (National Statistics Office, 2007b) shows that North Tarawa grew at a much faster rate (4.8%) between 2000 and 2005 than South Tarawa (1.9%). It may well be that North Tarawa has become a *de facto* grow centre. If this trend continues, then North Tarawa communities may wish to retain their groundwater to service the growth of North Tarawa. There is therefore no guarantee, that North Tarawa communities will be willing to supply water to South Tarawa. In addition, North Tarawa, and particularly Abatao and Tabiteuea, are an important source of fresh produce for South Tarawa, where good quality groundwater is used to irrigate crops. By sharing water with South Tarawa, communities in North Tarawa will have lower quantities of water available and therefore this option may decrease the opportunity to produce and sell crops and therefore impact on livelihoods.

10.2 Legal Assumptions

An underlying assumption in the ability to transfer water from North to South Tarawa is that the GoK owns the water resources used for public water supply. There is no national water legislation and the ownership of water is not included in the 1977 PUB Act. Traditionally, in Kiribati, the ownership of groundwater resides with the landowner. This appears to suggest that the GoK has no legal entitlement to water from North Tarawa. In addition, it appears that the PUB regulations may be specific to the water reserves identified in the regulations. Currently those remaining are Bonriki and Buota. It is not clear that the GoK has the necessary legal basis to declare water reserves in other locations. Finally it is unclear whether the Water Engineering Unit of MPWU, designated in 2004 as the lead national water agency, has any statutory basis for this role.

10.3 Involving the Community

The creation of water reserves over water source areas in Bonriki and Buota has created continuing problems over the past 35 years. If these problems were multiplied by making water reserves throughout North Tarawa then the conflicts would be unmanageable and the rent charges very large (Table 32). White *et al.* (1999b) proposed the formation of a local community-government water reserve management committee to oversee management aspects of water reserves, the payment of fees to landowners and to act as caretakers of water reserves rather than as a rental payment. Government agencies have shown little interest in forming joint community management committees.

These three aspects, the future planning of growth in North Tarawa, the legal basis for managing and protecting water in Tarawa (and in Kiribati as a whole) and the involvement and participation of the community in the management of water source areas and require urgent attention.

10 Concluding Remarks

This draft plan has examined groundwater resources available in Tarawa and has estimated their ability to meet future water demand in Tarawa until the year 2030. It has been based on a number of key assumptions.

10.1 Key Assumptions Underpinning this plan

The main assumptions underpinning this plan are discussed below

Groundwater sourced from groundwater reserves will continue to be the main source of drinking water supply in Tarawa

Groundwater contained in thin freshwater lenses, floating over seawater have traditional been the main source of drinking water in Tarawa. Projects since the 1960s have developed reticulation systems to supply communities in South Tarawa with disinfected water. It has been assumed here that fresh groundwater lenses will continue to be the main source of freshwater to communities up to at least 2030.

Rainwater, household wells and seawater will supplement groundwater use.

Currently many households in South Tarawa and most in North Tarawa rely on household water wells to supplement their water supply. It has been assumed here that in South Tarawa local household wells in 50% of households will be too polluted to use. In South Tarawa, a substantial number of households and in North Tarawa a lesser number also use rainwater tanks to supplement water supply. It has been assumed here that that will continue into the future.

Populations in Tarawa will continue to grow at the estimated rates

Two population growth models have been assumed here in order to estimate future water demand in Tarawa. In the first, an upper estimate, the exponential growth model has been used together with the growth rates given by the NSO for North and South Tarawa, 4.8 and 1.9% per year respectively, for the period 2000 to 2005. These growth rates are assumed to hold until 2030. In the second, a lower estimate, it is assumed that South Tarawa is full so the population of South Tarawa will only reach 50,000 by 2030. In North Tarawa a linear fit of the percentage of the total Kiribati population living in North Tarawa from 2000 to 2005 is assumed to hold until 2030. These percentages are then applied to the NSO's total Kiribati 'most probable' population projection growing at an exponential rate of 1.8% per year from 2005 until 2030. The lower and upper population estimates span the expected population increases. Population growth projections have not taken into account any impacts of climate change on population growth.

The amount of per capita water needed in Tarawa is between 50 to 80 L/pers/day.

The SAPHE project used a design consumption figure for South Tarawa of 40L/pers/day. This is less than the current average supply rate. Here, a brief survey from Nonouti and a more detailed survey from all villages in Kiritimati suggest that with institutional, commercial and industrial use and increasing temperatures due to climate change the amount of water needed is assumed to be 50 L/pers/day for rural areas, 68 L/pers/day in urban areas where local groundwater is fit for non-consumptive use and 80 l/pers/day, for areas where local groundwater is too polluted for use. It has been assumed that water for toilet flushing will either be sourced from seawater or from local well water. It has also been assumed that 50% of the household wells have water that is too polluted for use.

Leakage rates will decrease to 25%

The current rate of leakage in South Tarawa from the main reticulation pipeline is around 22%. The amount of leakage from the domestic reticulation system to households is unknown but is estimated to be at least 50%. This is enormously wasteful and means that it is not possible to supply sufficient treated water to meet current demand. NSO data shows that this forces many households in South Tarawa to rely on probably polluted household well water for consumption.

This plan has assumed that in the future total leakage rates will be reduced to 25%, one of the target values in the PUB business plan.

Climate change impacts on sealevel

As global temperatures continue to increase it is expected that sealevel will continue to rise. This plan has used the results of a NIWA (2008b) study of sealevel rise in Tarawa and has assumed that the sustainable groundwater yield will decrease by 20% in 2030.

Climate change impacts on rainfall will be less than historic variation

The predicted impacts of climate change on rainfall, droughts and groundwater recharge are equivocal because the current GCMs do not predict historic tropical rainfall or ENSO events well. The relatively short records of historic rainfall, drought and groundwater recharge show very large variations and no significant trends with increasing global warming over the 60 year record. For that reason we have used the historic record to estimate sustainable groundwater yields in order to estimate the adequacy of supply.

Groundwater reserves will continue to be protected

A major assumption here is that the current water reserves at Bonriki and Buota will continue to be viable until 2030. Past groundwater reserves in South Tarawa have had to be abandoned due to the encroachment of settlements on the reserves. Maintaining the water reserves at Bonriki and Buota will require a commitment by government and the involvement of local communities.

Statutory basis

It is assumed here that both MPWU and PUB have the legal basis for sourcing water from North Tarawa, for declaring water reserves in North Tarawa and for protecting groundwater resources. It is also assumed that the Lands Division of MELAD has the legal basis for paying rentals to land owners in areas declared water reserves,

10.2 Design Demand

When the various options for using groundwater to supply treated water to Tarawa were considered it was found that only one option, that of augmenting Bonriki and connecting and pumping from all major groundwater lenses in Tarawa would meet the design demands and only for 2020, assuming leakage losses were reduced to 25%. Since the actual sustainable groundwater yields of the majority of islands are unknown, this remains a conjecture. As time goes by, less of the water needed by households in Tarawa will be able to be supplied from the treated groundwater reticulation system. This means there will be increasing reliance by households on household wells and rainwater. Almost all household rainwater tanks, while very useful during normal rainfalls, will fail during Tarawa's frequent prolonged droughts. It is expected that, with the increasing growth of population in Tarawa, groundwater from local household wells will be increasingly polluted. Increased reliance on household wells therefore presents an increased risk of disease outbreaks. With this survival design demand, any failure of the water supply system could be catastrophic.

10.3 Reducing Leakage

The SAPHE project reduced leakage from the main reticulation pipeline from the Bonriki water treatment plant to Teaoraereke to about 22%. Leakage from the household reticulations systems in South Tarawa, which supply water from the head tanks to households is unknown but is believed to be at least 50% and probably higher. This leakage is an enormous waste, imposing unnecessary costs on the Government and hardship on households. As a matter of urgency, every effort should be made in a systematic fashion to reduce this leakage rate to the 25% target identified as one of the possible targets in the PUB (2004) business plan.

10.4 Population Growth, the Main Threat to Adequacy of Water Supply

The current population on South Tarawa is already above the limit of being able to be supplied sustainably with treated drinking water from the PUB system. It is clear that the main threat to future water supplies is the continued growth of population in South Tarawa. The NSO (National Statistics office, 2007b) suggests that Tarawa was 'full' in 2005. The continued growth of population in South Tarawa at even the current rate, which is significantly reduced from the rate in the 1990s, presents a major threat to the entire community of South Tarawa. The Government and the community need urgently to acknowledge this threat and seek acceptable ways of addressing it.

10.5 The North Tarawa Dilemma

It has been shown here that the overall gains in average per capita supply made by developing and connecting to South Tarawa the known groundwater sources in Abatao and Tabiteuea are marginal. Were the groundwater sources in these islands to be developed and used only for the households in Abatao and Tabiteuea, then households would have very good per capita supplies. Connecting their pumped groundwater into the South Tarawa reticulation system and sharing the water equally between all populations would be a substantial sacrifice for Abatao and Tabiteuea communities but only a slight gain in South Tarawa at major cost.

Attempts in this plan to estimate the gains possible by connecting all of the major groundwater sources in North Tarawa with South Tarawa are hampered by the absence of information on sustainable or safe yields of those sources in North Tarawa. The experience in Abatao and Tabiteuea, where the actual groundwater source area has been restricted to 40% of first order estimates of safe yields by settlement and land use, has been applied to North Tarawa to tentatively suggest safe yields. When it is assumed that these systems are connected to South Tarawa and the water shared equally between North and South Tarawa, then there is an approximately 50% increase in per capita water availability in South Tarawa by 2030. In North Tarawa, however, it would come at significant sacrifice to households. On the other hand, were groundwater sources developed and used only for residents in North Tarawa, residents there would have a generous supply of water until 2030.

This is an issue which needs widespread discussion within the Government, its Ministry and agencies and especially in the community, particularly in North Tarawa. The legal basis for supplying water from other locations in North Tarawa is also doubtful.

10.6 Priority Tasks

A number of immediate, short-term priority tasks have been identified in this component of the plan.

- The urgent reduction of leakage from the domestic reticulation system.

Without leak reduction, there is no point in seeking additional groundwater sources to connect into the leaky piped system.

- Assessment of the current per capita water use in Tarawa from different sources.
- Accurate assessment of operational, maintenance and depreciation costs of water supply system.
- Extensive systematic monitoring and recording of water quality in household water wells.
- Detailed assessment of possible additional groundwater sources in South Tarawa.
- Establishment of a community-government water reserve management committee to oversee the management, conservation and development of the existing Bonriki and Buota water reserves.
- Commence negotiations over the possible removal of trees vegetation, the infilling of babwai and mining pits from the centre of Bonriki and possible Buota water reserves.

This will involve use of local landowners and could employ local landowners as custodians and managers of the reserve (tied to compensation payments). It also could involve establishment of sports fields on the reserve.

- Start negotiations with landowners and the local community over the possible infilling of the brackish water ponds at the western end of the water reserve.

A plan for cleaning the bottom of the ponds and using dredging to infill the ponds will need to be developed and cost/benefit studies conducted.

- Finalise and report an accurate assessment of the groundwater resources in North Tarawa.

Monitoring of the safe yield of these sources needs to be completed before any full plan for Tarawa can be developed.

- Commence discussions with communities in North Tarawa over options for development and use assessment of all major groundwater sources in North Tarawa.
- Start discussions with MELAD over the information necessary for EISs for groundwater development.
- Examine the legal basis for proclaiming and managing water reserves in North Tarawa and pumping water from in North Tarawa to South Tarawa and for the WEU of MPWU to act as the lead water agency.

The examination may show that the statutory basis needs to be revised, modified or established.

- Develop a drought contingency plan for South Tarawa which engages the community.
- Develop staff training and succession plans to ensure that PUB and MPWU staff have the necessary skills and training to carry out the complex tasks required in the future.

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