Government of the Republic of Kiribati

Tarawa Water Master Plan: 2010-2030

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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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 Tarawa Water Master Plan 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, 2003); 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 and discussions with all relevant Ministries, private companies and NGOs were undertaken. From these, draft reports summarising the critical issues in five key areas 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 the draft plan were made 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. Revisions were then undertaken from the subsequent discussions and are incorporated in the current draft Tarawa Water Master Plan.

Acronyms

ADB	Asian Development Bank
AusAID	Australian Agency for International Development
CRF	Capital Recovery Factor
EC	electrical conductivity
GoK	Government of Kiribati
GCM	Global climate model
GW	Groundwater
ha	hectare (= 10,000 m^2)
IDA	International Desalination Association
IHP	International Hydrological Programme (of UNESCO)
IPCC	Intergovernmental Panel on Climate Change
KAP	Kiribati Adaptation Program (Phases I, II & III)
kL	kilolitre (= 1,000 L = 1 m^3)
kL/day	Kilolitre per day (= 1 m^3/day)
km	kilometre
km^2	square kilometre
KMS	Kiribati Meteorological Service
ICI	Institutional, commercial and industrial
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 meter
m^3	cubic metre (= 1kL = 1,000 L)
ML	mega litre (one million litres = 1,000 kL =1,000 m^3)
ML/day	mega litre per day
mm	millimetre
MELAD	Ministry of Environment, Lands and Agricultural Development
MHMS	Ministry of Health and Medical Services
MPWU	Ministry of Public Works and Utilities
mth	month
NASC	National Adaptation Steering Committee
NGO	non government organisation
NSO	National Statistics Office
NWRP	National Water Resources Policy
NWRIP	National Water Resources Implementation Plan
NWSCC	National Water and Sanitation Coordination Committee
NZaid	New Zealand International Aid and Development Agency
OB	Office Te Beretitenti (the President)
pers	person
PUB	Public Utilities Board (within MPWU)
RO	reverse osmosis (desalination technique)
SAPHE	Sanitation, Public Health and Environment Improvement Project
SOPAC	Applied Geoscience and Technology Division, Secretariat of the Pacific Community
SWRO	seawater reserve osmosis
T_a	amortisation period (years)
ToR	Terms of Reference
TWSP	Tarawa Water Supply Project
UPC	unit production cost
UNESCO	United Nations Educational, Scientific and Cultural Organization
WB	World Bank
WEU	Water Engineering Unit (within MPWU)
WHO	World Health Organisation

Summary

The water issues faced in Tarawa atoll are amongst the most complex, vital and varied in the world. They will be exacerbated by future impacts of future climate change, population growth and development. There are no simple solutions. Instead a mix of approaches is required based on an analysis of the current situation, estimation of future needs and impacts and consideration of the options available. The draft Tarawa Water Master Plan, TWMP, provides that analysis.

The draft TWMP

The draft TWMP is a planning document providing options for the sustainable future development, protection and use of fresh water in Tarawa over the next 10 to 20 years. It is a direct response to the Kiribati National Water Resources Policy (NWRP) and its accompanying 10 year National Water Resources Implementation Plan (NWRIP). The TWMP summarises priority issues, estimates existing and expected future water demands for freshwater by Tarawa's growing population, and assesses current and potential freshwater resources. It takes into account, where possible, projected impacts of climate change, and provides a range of options, with their estimated costs, for meeting those demands. Finally it provides recommendations for protecting, conserving and managing Tarawa's fragile freshwater resources over the next 20 years.

Priority Issues

Using 50 years of water studies and projects and drawing on the experiences of people in Tarawa, the TWMP has identified a wide range of continuing priority issues which need to be addressed. Principal concerns are: unacceptably high rates of preventable deaths, illnesses and social and economic impacts due to water-borne diseases, particularly among infants; large, wasteful, and expensive losses of treated freshwater from the reticulation system, especially the domestic supply system; growth in demand for water; and a range of institutional and management issues.

Present and Future Water Needs

Households and organisations in Tarawa use a range of water sources to meet their water needs. There is limited information on how much water is currently used from these sources. The TWMP has assumed that water for toilet flushing will continue to be sourced from seawater or household water wells as currently. The TWMP employed data from urban, semi-urban and rural areas in Kiritimati and Nonouti to provide estimates of the average per capita freshwater needs in South Tarawa of 68 L/pers/day and 65 L/pers/day, sufficient to improve standards of public health. Preliminary results from the 2010 Census for Tarawa were combined with results from previous Censuses dating back to 1985, and the National Statistic Office's exponential growth model, to produce upper and lower bound estimates for the population in South and North Tarawa over the next 20 years. When combined with estimated per capita water use, this gave estimates of the total freshwater needs for South and North Tarawa. These show the most significant threat to the availability and quality of freshwater in South Tarawa is its ever-increasing population.

A major problem in meeting current water needs in South Tarawa is the estimated 50% losses of water from the reticulation system, and particularly from the domestic system. Reducing this excessive leakage and addressing the underlying causes should be highest priority. There is no point in introducing new water sources into South Tarawa if leakage rates are not reduced.

Water Sources and Availability of Water to meet Needs

The water sources examined included rainwater harvesting, household water wells, reticulated groundwater from water reserves in South Tarawa, potential new groundwater sources in North Tarawa, as well as non-conventional sources of water.

Rainwater

Although an important source of freshwater, rainwater harvesting cannot be relied on as a continuous source of water because of the frequent, severe ENSO-related droughts in Tarawa, the limited roof catchment areas and rain tank volumes available and the large average number of people per household. There is the potential to increase rainwater harvesting, especially from large public buildings but this requires a communal system of management.

Household wells

Over 35 years ago, it was recommended that the use of local household wells be South Tarawa be

abandoned because of the threat of contamination from dense urban settlements. Since then, the population has grown by over 330%. There is no systematic data on the quality of groundwater in Tarawa, so it was assumed that household wells in South Tarawa were unsuitable for potable use.

South Tarawa Groundwater

The sustainable yield of the current groundwater sources of Bonriki and Buota water reserves is 2,010 kL/day. There is the potential to increase this by 500 kL/day by removing trees from the centre of Bonriki to establish sports fields and by infilling brackish saline ponds at the western end of the island. This will involve negotiations with land owners and increased compensation and possibly land rental payments. Even with this increase, this supply is inadequate to meet the current needs of South Tarawa and will be totally inadequate to meet the needs of the increasing population and the impacts of climate change, so additional sources of water are required.

North Tarawa Groundwater

The water resources of Rural North Tarawa have been recently assessed, however, the actual availability of water due to current land use practices, such as babwai pits, has yet to be determined. It is estimated that the sustainable yield of all major freshwater lenses in North Tarawa is between 1,400 and 3,900 kL/day. When combined with the groundwater sources in South Tarawa this is sufficient to meet the needs of Tarawa until at least 2020. Exploitation of groundwater sources in North Tarawa, however, will require the installation of a power station and a cross-lagoon pipeline to supply water to South Tarawa. This will change the character of North Tarawa and may not be acceptable to communities there. The development of groundwater sources in North Tarawa will require lengthy and extensive negotiations with landowners and expensive, continuing land rental payments.

Other Freshwater Sources

The other sources of freshwater considered were: bottled water; recycling of “grey” and “black” water, bulk importation of water by ship; constructed rainwater catchments; a constructed island for groundwater harvesting; solar stills and seawater reverse osmosis, RO, desalination. A unit production cost (UPC) analysis using the cost recovery factor (CRF) was carried out for the groundwater and other options for meeting future water needs. Seawater RO desalination was the most attractive in terms of UPC provided that its lifetime is 10 years. This is problematic since the experience in the Pacific an in Kiribati is that RO plants have very limited lifetimes and are expensive and technically complex to operate. It is suggested that the maintenance and training of staff of any PO plant be contracted out to the plant supplier.

Seawater RO Desalination

The advantages of seawater RO desalination are: it can be installed and started quickly; removes pathogens from product water; only a small land area is required; minimal land rental and compensation payments will be required; minimal negotiations with landowners; no new legislation required; can be supplied in container modules; units can be located in areas of highest demand; can be connected directly into existing water supply pipeline; energy recovery systems are available; and maintenance and training contracts are available. Their disadvantages are: poor track record of RO in Pacific Island Nations and Kiribati; requires well trained operators; requires regular maintenance and monitoring; energy intensive (6 to 18.8 MWh); environmental impacts of rejected brine; very expensive if operational life is short. To offset the energy requirements of RO, other governments throughout the world are installing equivalent renewable energy sources such as wind generators. In Tarawa there is also the possibility of using locally-produced coconut oil as a direct substitute for diesel fuel.

Impacts of Climate Change

Climate change has the potential to influence both future demand as well as the availability of freshwater in Tarawa. Future demand could be influenced by changes in both population numbers and per capita consumption. Water availability could alter in the future due to changes in rainfall and evaporation as well as from increased encroachment of seawater due to sealevel rise. A small allowance was made for an increase in per capita consumption due to rising temperatures by 2020. It was estimated that by 2030 the sustainable yield of groundwater could be cut by 20% due to rising sealevels. Predictions are that the frequency of drought may not change under climate change, although the models employed are questionable since the do not simulate ENSO events.

Management Recommendations

It is recommended that:

1. the Government of Kiribati (GoK) consider the options for supplying Tarawa's urgent, future water needs presented in the TWMP,
2. the 1992 draft national water legislation should be reviewed together with all relevant water legislation, necessary revisions completed and the revised draft legislation submitted to Cabinet,
3. the National Water and Sanitation Coordination Committee, NWSCC, develop and implement a work plan,
4. the NWSCC be placed under the control of Office Te Beretitenti to improve reporting to Cabinet and to ensure progress of the NWRIP,
5. the GoK clearly articulate its vision for the future development of North and South Tarawa and develop plans to work towards the realisation of that vision,
6. a drought contingency plan be developed and approved by the NWSCC and submitted to Cabinet for consideration,
7. the protection of groundwater reserves be recognised as being of high priority in maintaining and improving the public health and safety of communities in South Tarawa,
8. a single agency be given the responsibility of preventing encroachment, inappropriate use and improving management of water reserves,
9. settlements be removed from water reserves, only land uses which do not pose a threat to groundwater quality be allowed,
10. a comprehensive water resources monitoring and reporting plan be developed along with the resource requirements and organisational responsibilities for ensuring that good quality information, necessary for managing water in Tarawa is available,
11. payment of land rentals to land owners in water reserves be linked to land management criteria,
12. the community-government Committee for the Management and Protection of Water Reserves be re-established and supported,
13. the groundwater pumping rate from Bonriki be reduced to the sustainable rate as soon as practical,
14. water losses from the reticulation system be reduced to the target level of 25% or less. As a contingency plan, excessively leaky portions of the system should be isolated with water needed by households being supplied by bulk distribution,
15. installation of water meters should be considered in any upgrading of the domestic distribution system and that a system for discouraging wasteful use of water be introduced,
16. a more equitable and financially robust method of cost recovery for water supply be developed and introduced,
17. a database be established and maintained on the location and characteristics of rainwater harvesting systems in Tarawa,
18. a community education program on the installation, operation and maintenance of rainwater systems be developed[1],
19. a system for ensuring that the existing building regulation and codes detailing the installation of adequate rainwater systems in new buildings are enforced,
20. the potential and rules for communal rainwater distribution from large public buildings be explored and developed,
21. the water quality of representative household wells in Tarawa be monitored and reported,
22. a long-term coordinated and continuing program be established to bring about behavioural change in the use and sharing of water, and in its protection and conservation. This program must include a comprehensive water education program for schools, and
23. a whole-of-government plan be developed for the training of staff in the water sector and a succession plan developed for ensuring passing on of expertise

[1] SOPAC has excellent educational materials on rainwater harvesting

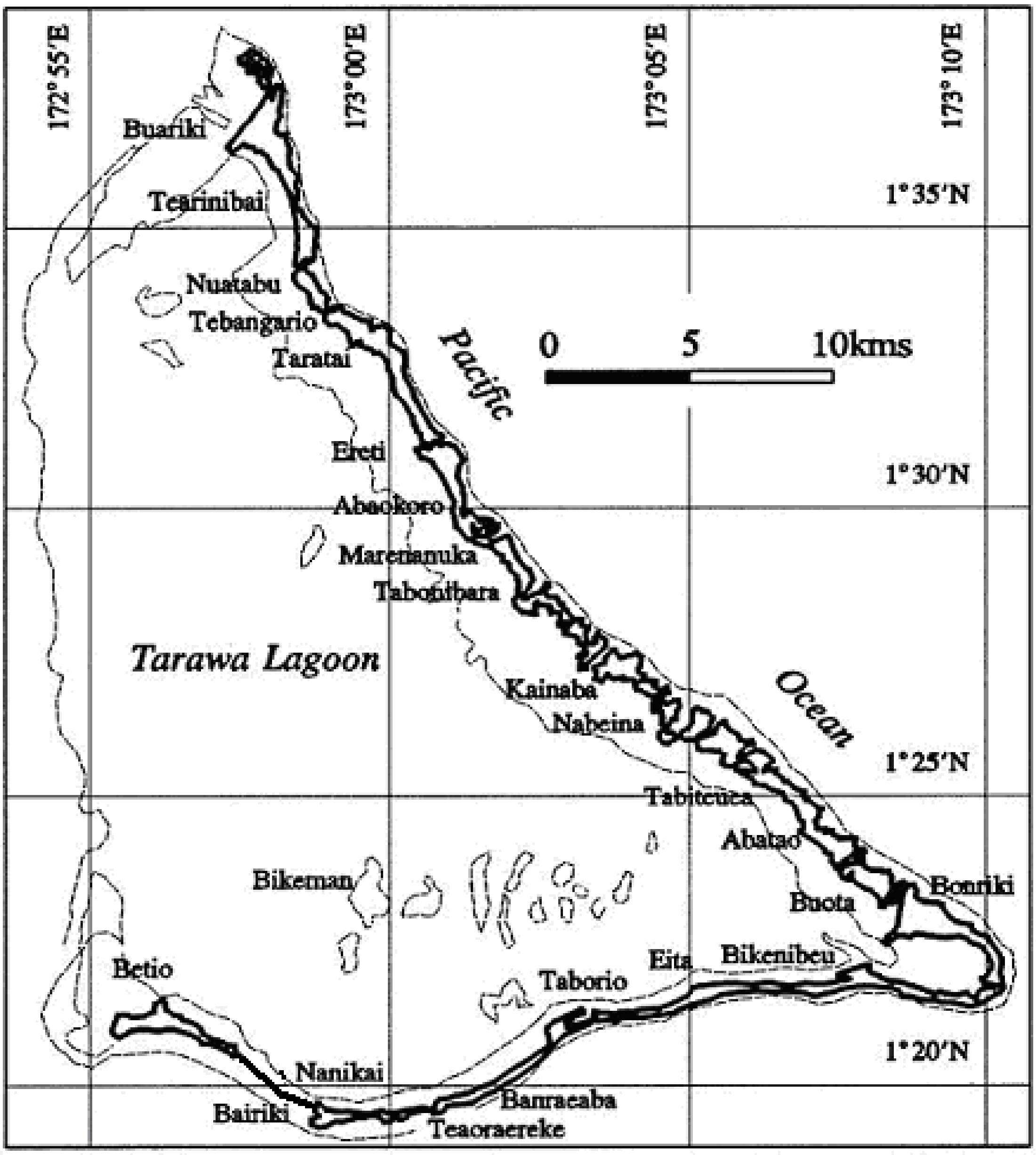

Figure 1 The islands of Tarawa Atoll, Republic of Kiribati. South Tarawa extends from Betio to Bonriki and North Tarawa from Buota to Buariki.

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1. What is the Tawara Water Master Plan?

The draft Tarawa Water Master Plan, TWMP, is a planning document providing options for the sustainable future development, protection and use of fresh water in Tarawa over the next 10 to 20 years. It is a direct response to the Kiribati National Water Resources Policy (NWRP) and its accompanying 10 year National Water Resources Implementation Plan (NWRIP), endorsed by Cabinet of the Government of Kiribati (GoK) in January 2009, and to the widespread public concern over the availability and quality of freshwater revealed in public consultations during KAPI. The three goals and accompanying policy objectives of the NWRP are to:

1. Provide safe, socially equitable, financially and environmentally sustainable water supplies to enhance the welfare and livelihood of I- Kiribati
   - 1. 1. Increase access to safe and reliable water supplies
   - 1.2. Achieve sustainable water resource management
2. Protect and conserve freshwater sources for public water supplies
   - 2.1. Improve understanding and monitoring of water resources and their use
   - 2.2. Improve protection of public water source areas
   - 2.3. Increase community participation in water management and conservation
3. Deliver freshwater efficiently and effectively.
   - 3.1. Improve governance in the water and sanitation sector
   - 3.2. Decrease unaccounted for water losses and improve cost recovery

These form the basic objectives of the TWMP

The TWMP builds on previous water supply development project documents, reports and papers, government decisions and statements stretching back almost 50 years and on the experiences of a wide range of agencies, organisations and people both in Kiribati and with experience in Kiribati.

The TWMP provides a summary of priority issues, estimates of existing and expected future water demands for freshwater by Tarawa's growing population, and an assessment of current and potential freshwater resources. It takes into account, where possible, projected impacts of climate change, and then provides a range of options, with their estimated costs, for meeting those demands. Finally it provides suggestions for protecting, conserving and sustainably managing Tarawa's fragile water resources over the next 10 to 20 years.

Highlights of issues being addressed in the TWMP are the analysis of water demand projected for the next 20 years based on estimates of per capita requirements, estimation of the ability of te *karau*, rainwater, *te ran*, groundwater and other sources to meet the expected demand and the impacts of climate change on the availability of those resources. Assessment of the impact of Tarawa's frequent severe droughts is a feature of the plan. Management issues associated with the conservation and protection of fresh water, assessment of resources, monitoring supply and water quality are also covered. A range of options for meeting the rapidly increasing demands is given. The TWMP can be used as a basis for discussions with donors.

The planning principles used to develop the Tarawa Water Master Plan were adapted from Ackoff (1999). Ackoff, one of the founders of Operations Research, identified 5 phases in an interactive planning process, together with objectives, components and principle outputs of each phase. The 5 phases are: I. Formulation of the Issues; II. Ends Planning; III. Means Planning; IV. Resource Planning; and V. Implementation and Control. These have formed the basis of the development of the TWMP. Endorsement, implementation and revision of the Plan are the responsibility of the Government of Kiribati (GoK), its Ministries and agencies, as well as non government organisations (NGOs) and the communities of North and South Tarawa. The magnitude and complexity of these tasks are challenging and require commitment, determination and dedication.

In developing this plan a series of in-depth reports, which address different components of the TWMP, have been produced (White, 201a,b; 2011a,b) which were circulated to and then workshopped with all lead water agencies, other government agencies and NGOs. Feedback from comments received and the workshops was then used to refine the component reports and the key findings of the revised reports are presented in this plan.

2. What Priority Issues Need to be Addressed?

Studies undertaken as precursors to water supply projects in South Tarawa (Figure 1) over the past 50 years have identified critical water supply and management issues that need to be addressed (see e.g. AGDHC, 1975; Falkland, 1992; Shalev, 1992; WEU, 2000; ADB, 2004). Many of the priority concerns were summarised by Falkland (2003). In some issues, there has been little progress in the intervening years. The NWRP and the in-depth reports accompanying the TWMP have summarised the main issues in Tarawa which include:

2.1 Health

- The unacceptably high rate of preventable deaths, particularly in infants, due to water-borne diseases
- The unacceptably high rate of preventable illnesses due to water-borne diseases
- Contamination of fresh groundwater, the major source of freshwater, by human settlements, sanitation systems, livestock, wastes, and aggregate mining

2.2 Climate and Geography

- Frequent, La Niña-related, severe droughts
- Vulnerability of shallow groundwater systems to seawater intrusion
- Vulnerability of groundwater lenses to sealevel rise and storm surges

2.3 Water Supply

- Unacceptably large water losses from piped water systems
- Intermittent and inadequate supply of reticulated freshwater
- Illegal connections to water supply pipelines
- Vandalism of water supply infrastructure
- Encroachment of settlements onto groundwater reserves
- Groundwater pumping at greater than the long-term sustainable rates
- Inequities in the provision of services to rural and urban communities
- Reliance on potentially contaminated household wells in densely-populated urban areas
- Inadequate use of rainwater harvesting and storage on large buildings
- Poorly installed and managed household rainwater harvesting and storage systems

2.4 Demand

- Continuing rapid population growth, particularly in South Tarawa
- Increase in per capita demand as development progresses
- Conflicting demands for water

2.5 Economic and Financial

- High rates of absenteeism due to water-borne diseases
- Constraints on development, commerce and industry due to limited water supplies
- Financially unsustainable water supply system
- The large cost of land rental payments to landowners of water reserves
- The large cost of leakages from the water supply system

2.6 Institutional

- The absence of National Water Resources Law
- No drought contingency plans despite frequent drought
- Conflict between traditional and public ownership of groundwater

- Fragmented and ineffective control, management and protection of freshwater resources
- Poor communication between agencies with responsibilities in water
- Inadequate knowledge and monitoring, analysis and reporting of freshwater resources
- Decrease in the number of trained water specialists and technicians
- Limited training scheme and succession planning

2.7 Community

- Limited community participation in freshwater management and conservation
- Limited community understanding of responsible water use, conservation and protection of water sources and water supply infrastructure
- Conflict between subsistence traditions and practices and the demands of urban society
- A need for enhanced water education in schools

2.8 Knowledge Gaps

- Limited information on the quantity and quality of groundwater resources in Tarawa
- Very limited information on household use of water from various sources
- Very limited information on rainwater harvesting systems
- No information on institutional, commercial or industrial water use
- The overall rate of water losses from the water supply system is large but unknown
- Sparse groundwater monitoring data

3. How Much Freshwater is Needed over the Next 20 Years?

I-Kiribati have always recognised that freshwater is a vital and limited resource (Talu *et al.*, 1979). For the past 4,000 years I-Kiribati have faced major natural challenges and have adapted to large variations in climate with limited supplies of freshwater. Over the last 50 years, however, demographic and socio-economic factors have changed dramatically, particularly in the urban parts of Tarawa. These have propelled residents in South Tarawa from a largely low-density, subsistence lifestyle to a high-density, urban situation and one in which traditional adaptation strategies are largely ineffective in coping with the demands of a highly urbanised society living under a highly variable climate.

The question of Tarawa's freshwater needs over the next 20 years is a difficult question since it involves estimating the current water needs for urban South Tarawa and rural North Tarawa and projecting those 20 years into the future. It is made doubly difficult because there is no data on current freshwater use in Tarawa by the various sectors and from various water sources. That is compounded by the difficulties of estimating the change in water demand due to population growth, development, the result of climate change and water losses[2] over the next 20 years.

3.1 Public Health and the Availability of Freshwater

The World Health Organisation (WHO, 2006) has estimated the public health risks for various levels of service and per capita daily availability of water (Table 1). Currently it is estimated that, with the high rate of leakage in the South Tarawa water supply system, each person on South Tarawa has available about 21 L/pers/day on average of safe, treated freshwater (White 2011). Table 1 suggests that there are high public health risks associated with this low quantity and recommends that there is a high priority for intervention and action. There is therefore a clear priority to increase the quantity and availability of safe water in Tarawa.

Table 1 Service level, quantity of water available and public health risk (WHO, 2006)

Service level	Distance/time	Likely volumes of water collected	Public health risk from poor hygiene	Intervention priority and actions
No access	More than 1 km / more than 30 min round-trip	Very low – 5 litres per capita per day	**Very high** Hygiene practice compromised Basic consumption may be compromised	**Very high** Provision of basic level of service Hygiene education
Basic access	Within 1 km / within 30min round-trip	Average approximately 20 litres per capita per day	**High** Hygiene may be compromised Laundry may occur off-plot	**High** Hygiene education Provision of improved level of service
Intermediate access	Water provided on-plot through at least one tap (yard level)	Average approximately 50 litres per capita per day	**Low** Hygiene should not be compromised Laundry likely to occur on-plot	**Low** Hygiene promotion still yields health gains Encourage optimal access
Optimal access	Supply of water through multiple taps within the house	Average 100–200 litres per capita per day	**Very low** Hygiene should not be compromised Laundry will occur on-plot	**Very low** Hygiene promotion still yields health gains

Source: Howard & Bartram (2003)

The approach taken in the TWMP to estimating Tarawa's freshwater needs are described in detail in the in-depth report on *Te Ran-Maitira ae Kainanoaki, Future Water Demand* (White, 2011). The assumptions that have been made in the estimation are listed in the following.

[2] Water losses from water supply systems have a wide range of names such as "unaccounted for water" or "non-revenue water". Here, water losses includes leakaes from the pipeline, water stolen through illegal connections, water evaporated from head tanks, overflows at head tanks and from the 500 L trickle-feed household tanks.

3.2 Assumptions Used in Estimating Future Population Numbers

The National Statistic Office (NSO) in Kiribati has adopted an exponential growth rate model for population projections:

$$P_t = P_0 \exp(rt) \quad (1)$$

where P_t is the estimated population, P_0 is the population at the census period or base year, r is the annual growth rate between the two census years and t is the time in years since the census or base year. Since 1985, annual percentage exponential growth rates in both North and South Tarawa have varied between a low of 1.9%, close to the mean national population growth rate for Kiribati for the period1985 to 2005, to a high of 5.2%. The fitted mean annual percentage exponential growth rate for South Tarawa for the period 1985 to 2010 is 3.43% and for North Tarawa it is 2.76%.

It will be assumed here that:

- the lower bound for population growth for both North and South Tarawa will be 1.9%, close to the national growth rate for 19885-2005. This is equivalent to assuming that net inward migration to Tarawa will be zero.
- the upper bound for population growth will be the mean annual percentage exponential growth rates for the period 1985 to 2010 of 3.43% for South Tarawa and 2.76% North Tarawa. These assume that net inward migration to both North and South Tarawa will continue at the current mean rate.

With these assumptions and using the NSO's preliminary estimates of the population in North Tarawa (6,309) and in South Tarawa (51,162) from the 2010 Census as the base year, Table 2 gives the predicted populations for water supply[3] in North and South Tarawa in 2020 and 2030.

Table 2 Estimated ranges of populations using water from the South Tarawa (including Buota) water supply system and household wells in North Tarawa (without Buota) based on the preliminary 2010 census results

Year	North Tarawa†		South Tarawa*		Tarawa	
	Lower	Upper	Lower	Upper	Lower	Upper
2010	4,799	4,679	52,672	52,792	57471‡	
2020	5,803	5,931	63,693	72,514	69,497	78,446
2030	7,018	7,603	77,021	102,207	84,039	109,810

† Does not include Buota, * Includes Buota, ‡ Value from the preliminary 2010 Census results

3.3 Assumptions Used in Estimating Water Demand

Household wells in South Tarawa have groundwater that is too polluted for use

Previous studies in South Tarawa have identified the risk in crowded urban areas of using local wells for general use. There is currently no systematic monitoring of the quality of local, household well water quality. It has been assumed that local household wells are unsafe for potable water use and even for bathing. This does not preclude local well water from being used for toilet flushing and, where not too saline, for irrigation and stock watering.

The water requirements of institutional, commercial and industrial, ICI, sectors is 10% of the per capita domestic consumption in South Tarawa and 5% in North Tarawa

There is very little information on the amount of water required by the ICI sectors in Tarawa. The assumption used here, that the ICI sector demand is 10% in South Tarawa and 5% in North Tarawa, is consistent with previous design estimates. It also allows these sector demands to grow at the same rate as the population. This assumption precludes the establishment of more water intensive industries.

[3] For water supply, the South Tarawa water supply system includes the island of Buota in North Tarawa.

No piped freshwater will be allocated for irrigation in South Tarawa
Most irrigation requirements in South and North Tarawa are assumed to be met from household wells or other wells with sufficiently fresh groundwater. A proportion will come via recycling of grey water, washing, bathing and kitchen waste water sources from the piped supply.

No piped freshwater will be allocated for toilet flushing
It is assumed that all toilet flushing requirements will either be met from seawater for the existing or future piped sewerage systems or from local household water wells, as in current practice.

A small allowance is made for climate change.
Increasing temperatures may lead to an increase in water use. A small allowance of 2 L/pers/day is allocated to this use after 2020.

All households will be supplied with piped, treated freshwater
The 2005 Census suggests that about two-thirds of households in South Tarawa access the piped water system. Previous designs have been based on assumptions that large houses with rainwater tanks will, except for droughts more severe that 1 in 10 years, be independent of the piped freshwater system. Others have assumed that only a fraction of total households will be supplied piped freshwater. These assumptions are rejected here. It is assumed that all households will be supplied with piped freshwater.

Domestic water needs are best estimated from actual water use data
Previous design estimates of per capita domestic consumption have been often based simply on the quantity of water available without considering household and other water needs. There is very limited survey data on how much water is used by households. The earliest survey in Tarawa shows small demands and is largely irrelevant to modern Tarawa. A brief survey from rural Nonouti and a more detailed survey from all villages in Kiritimati, which covers urban, semi-urban and rural use, suggest that with ICI use and a small allowance for climate change after 2020, the amount of water needed is about 65 – 68 L/pers/day.

Pipeline water loss rates will either remain unchanged or decrease in the future
The current water loss rate in South Tarawa from the main transmission pipeline between Bonriki and Teaoraereke is around 22%. The losses from the urban distribution system to households is unknown but is estimated to be at least 50%. These losses are enormously wasteful and mean 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 Master Plan has assumed that in the future total water loss rates will either remain around 50% or be reduced to 25% of total production, consistent with the Public Utility Board (PUB) Business Plan 2004-6.

With these assumptions, Table 3 lists the estimated required components of water demand in North and South Tarawa. If the assumed per capita demand values in Table 3 are compared with the WHO public health risk figures in Table 1, it can be seen that the design demand adopted in Table 3 should result in lower the public health risks. The population projections in Table 2 can now be combined with the estimated required per capita water demand in Table 4 to give estimates of the total daily amount of safe, treated water required to meet the future demand in North and South Tarawa. These are given in Table 4 for a system with no water losses.

3.4 Water Production Needed to Meet Future Demand and System Water Losses

The estimates in Table 4 are not realistic because they assume zero water losses from the distribution system. In order to estimate the water supply required for future demands, estimates of the water losses from the distributions systems are required. It is assumed here that in South Tarawa all water to meet demand will be met by piped water. In North Tarawa it is assumed that piped water will be used after 2015. Although the actual water losses are unknown two design estimates of current (50%) and future loss rates (25%) in Table 3, are used (Pipeline Network Analysis, 2010). The lower estimate is a target loss rate objective of the PUB, while the upper loss rate may be an underestimate.

Table 3 Summary of the components of water demand used in the TWMP

Component	Demand (L/pers/day) South Tarawa	Demand (L/pers/day) North Tarawa	Comments
Per capita household demand, excluding toilet flushing (potable)	60	60	Provided from safe sources: treated piped water in South Tarawa, and wells remote from settlements or eventually piped water in North Tarawa
Toilet flushing (non potable)	30	30	Provided from seawater for piped sewage system or well water not contaminated with hydrocarbons.
Institutional, Commercial & Industrial use (potable)	6	3	10% of per capita domestic demand in South Tarawa, 5% in North Tarawa provided from safe sources
Irrigation	0	0	Household irrigation and livestock water will be sourced from groundwater wells where suitable and from recycled "grey" water.
Livestock and domestic animal water	0	0	
Climate change (potable)	2	2	Allowance for 1°C rise in atmospheric temperature after 2020
Total per capita demand excluding toilet flushing	**68**	**65**	Provided from safe sources only
Total per capita demand all components	**98**	**95**	Provided from potable and non-potable sources (for toilet flushing)
Water losses – present system No change	50%	0%	Percentage losses of total water production from piped water system
Water losses – rehabilitated system in S. Tarawa and new systems in N. Tarawa	25%	25%	

Table 4 **Estimated total daily water supply (kL/day) required to meet the projected needs for South, North and all of Tarawa to 2030 for lower and upper bound estimates of future population with zero water losses.**

Year	Required Freshwater Demand (kL/day)					
	North Tarawa †		South Tarawa*		Tarawa	
	Lower	Upper	Lower	Upper	Lower	Upper
2010	300	290	3,500	3,500	3,800	3,800
2020	380	390	4,300	4,900	4,700	5,300
2030	460	490	5,200	7,000	5,700	7,400

† Does not include Buota, * Includes Buota

The daily water production rates required to meet a 25% leakage rate and the future demand estimated in Table 4 are listed in Table 5, while the necessary daily production rate to satisfy demand and 50% losses are given in Table 6. It is assumed here that all water to meet demand will be sourced from leaky piped water systems and that, after 2020, all villages in North Tarawa will be connected to a piped water system with 25% or 50% losses.

Table 5 **Estimated daily water production rates needed to meet the projected future demands in Tarawa and a water loss rate of 25%.**

Year	Required Freshwater Production, 25% Losses (kL/day)					
	North Tarawa †		South Tarawa*		Tarawa	
	Lower	Upper	Lower	Upper	Lower	Upper
2010	300	290	4,600	4,600	4,900	4,900
2020‡	500	510	5,800	6,600	6,300	7,100
2030‡	610	660	7,000	9,300	7,600	9,900

† Does not include Buota, * Includes Buota

‡ All villages in North Tarawa connected to piped water system, prior to 2010 no losses

Table 6 **Estimated daily treated freshwater production rates needed to meet the projected future demands in Tarawa and a water loss rate of 50%**

Year	Required Freshwater Production 50% Losses (kL/day)					
	North Tarawa †		South Tarawa*		Tarawa	
	Lower	Upper	Lower	Upper	Lower	Upper
2010	300	290	7,000	7,000	7,300	7,300
2020‡	750	770	8,700	9,900	9,400	10,600
2030‡	910	990	10,500	13,900	11,400	14,900

† Does not include Buota, * Includes Buota
‡ All villages in North Tarawa connected to piped water system, prior to 2010 no losses

It is now necessary to determine whether the existing water resources in Tarawa can meet these demands.

3.5 What can be Done to Limit Future Demand?

Tarawa oscillates rapidly between having too much water and being in major drought. With too much water, there are few incentives to conserve water until the onset of drought when it is often too late for conservation. Demand management has long been recognised as a critical issue in conserving scarce water supplies in Tarawa. In the past and in rural areas in Kiribati currently, managing water from local groundwater wells was the responsibility of *kaainga*, a group of extended families sharing a piece of land (Talu *et al.,* 1979). The prime responsibility of a householder was to the *kaainga*, not to neighbours sharing the same groundwater lens. In many ways, this attitude still pervades practices even in highly-urbanised areas in South Tarawa.

3.5.1 Behavioural Change

Short duration community awareness campaigns appear to have very limited effectiveness. What is needed is a long-term coordinated and continuing program, starting with the earliest aged school children and involving the church and community groups to bring about behavioural change and the recognition that all will benefit from cooperative, community-focussed actions. It is suggested that the following could be useful indicators for a behavioural change program:

1. Widespread recognition that fresh water is a scarce resource in Tarawa that must be conserved and used wisely
2. Widespread recognition that groundwater is easily polluted so that the community is involved in protecting sources of fresh water from contamination and misuse.
3. Widespread recognition of the rights of others to have equal access to good quality water so that our actions do not diminish the access to or quality of our neighbour's water.
4. Evidence that the next generation is being trained in these values

3.5.2 Demand Control Mechanisms

There appears to be currently no legal mechanism in place for controlling excessive water use in Tarawa, since there is no national water legislation specifying who owns groundwater resources and what are the responsibilities of groundwater users.

The traditional way of controlling demand in a reasonably equitable way is to meter water use and to charge for the quantity of water used by the consumer. The only mechanism presently available to the PUB to control demand is to supply piped water intermittently to various regions in South Tarawa, currently for a brief time every two or three days. This has three disadvantages: households leave taps open to collect water in containers, so losses are high; customers are very reluctant to pay for an intermittent water supply; and intermittent supplies are prone to bacterial build-up in supply lines.

One of the problems faced in introducing water tariffs in Tarawa is the number of households with very limited capacity to pay for water. Metering consumption of water and tiered charging appear the only sensible means of controlling excessive demand provided that it is well managed and contains measures to provide for the disadvantaged. Installation of water meters should be considered in any upgrading of the domestic distribution system.

3.5.3 Leakage Control

Reduction of water losses is also part of demand management as large losses incur high costs and excessive inefficiencies. The urban distribution systems in Tarawa were installed in the 1970's and 1980's. Tampering with these systems and household losses has led to large (but as yet unmeasured) losses in the urban distribution systems. It is absolutely imperative in South Tarawa that these losses be identified and lowered if future, adequate water supplies are to be maintained.

3.5.4 Population Pressure

The preliminary Census results for 2010 show that the population in South Tarawa continues to grow at a faster rate than the national average. This is leading to heavy demands on life support systems such as the water supply. People in South Tarawa and Buota are provided with services that are not available to people in other islands in Kiribati. They are being inequitably subsidised by the rest of Kiribati. Mechanisms to lower the population growth in South Tarawa need to be found.

3.5.5 Drought Contingency Planning

Lengthy, severe droughts are common in Tarawa (White and Falkland, 2010). During these droughts, almost all rainwater tank storages will fail and many smaller island groundwater lenses will become salty. It is imperative to develop a drought contingency plan to conserve freshwater and control water use during droughts.

3.5.6 Demand Management, Difficult but Necessary

There are long-standing cultural and social customs in Kiribati that make demand management a difficult issue. These, however, have led to a situation in water supply where the distribution of water in South Tarawa is inequitable, where wastage is encouraged and anti-social and even illegal actions are condoned, and where the water supply system is not financially sustainable. If these problems are to be addressed then difficult decisions regarding demand management must be made. They will have to be made in concert with a determined, long-term campaign to promote behavioural change and underpinned by the necessary legal framework.

4. How Much Water is Available in Tarawa?

The 2005 Census (NSO, 2007) shows that households in Tarawa access freshwater for drinking from a range of multiple sources:

- piped or reticulated treated water from groundwater reserves at Bonriki and Buota,
- local groundwater from household wells,
- rainwater collected from roofs, and
- bottled water, both imported and locally produced using reverse osmosis (RO) desalination (Table 7).

Table 7 Percentage of households in Tarawa using various sources for drinking water compared with other rural areas in the Gilbert Group (2005 Census).

Location	Total House-holds	Percentage of Households (%)				
		Rain	Piped	Open Well	Closed Well	Bottled Water
South Tarawa	5245	42.8	67.0	54.1	18.1	3.8
North Tarawa	867	12.1	1.6	87.3	19.6	0.9
Other Rural Gilbert Group*	7407	11.4	2.8	81.9	27.0	0.7

*Excluding North and South Tarawa

In addition to these sources, seawater is also used for bathing, washing clothes and flushing toilets. The three public reticulated sewerage systems in South Tarawa all use seawater for toilet flushing because of the scarcity of freshwater in South Tarawa.

The reticulated freshwater supply system in South Tarawa, operated by the PUB, is only able to supply water intermittently to households and other users. Households, consequently, have to use multiple sources for fresh water. The increasing population density also imposes a significant risk that local shallow groundwater, on which many households rely, will be polluted by human and animal wastes, increasing the hazards of using domestic wells in urban areas. The TWMP has examined the ability of rainwater (White, 2010a), groundwater (White, 2010b) and other sources (White 2010c) to supply the projected freshwater demand in Kiribati.

4.1 Using Te Karau, Rainwater, to Meet Freshwater Demands

Rainfalls in the Tarawa are highly correlated with the El Niño – Southern Oscillation (ENSO) or sea surface temperatures (SST) in the central western Pacific. Variations in ENSO events produce large variations in rainfall in Tarawa, with La Niña phases corresponding to droughts in Tarawa. Severe droughts occur in Tarawa with an average frequency of about once every 7 years. Because of the certainty of severe drought, development of a drought contingency plan for Tarawa in which the Cabinet, householders, commerce, industry and institutions are given early warning of droughts and are provided with advice on the management and maintenance of rainwater harvesting and storage systems is strongly recommended.

Monthly rainfall in Betio, South Tarawa is extremely variable (Figure 2). It ranges from zero to 825 mm with an overall mean monthly rainfall around 170 mm. There is, on average, a wetter season from December to about April and a longer, drier season from May to November. Highest rainfall variability occurs in the driest months of the year.

Because the mean monthly rainfall and mean annual rainfall (over 2,000 mm) in Tarawa are large, it appears at first impression that there is excellent potential for significant rainwater harvesting over extended periods in Tarawa. This, however, ignores the large variability in monthly rainfall and the frequent, La Niña-related severe droughts which last on average for nearly two years (Figure 2). These droughts have significant implications for water resource management and especially for rainwater storage.

The Council Bye-Laws and the draft National Building Code for new buildings require all new houses and buildings with suitable roof materials to have rainwater harvesting and storage systems installed. The Bye-Laws also specify these systems must be maintained properly. These, however, are not enforced and many new buildings with large, suitable roof areas have been built in Tarawa without rainwater harvesting and storage systems. Since building approvals are at the Council level and because there are currently no qualified building inspectors in Tarawa, there is no mechanism to enforce the Bye-Laws.

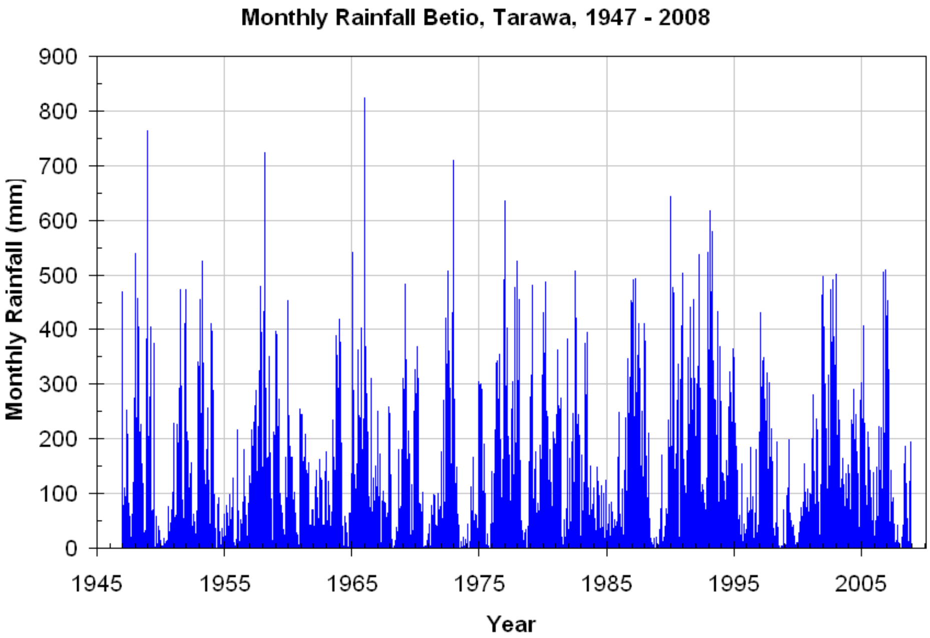

Figure 2 Historic monthly rainfalls for Betio, Tarawa for the period January 1947 to December 2008

The 2005 Census results (NSO, 2007) show that Tarawa and particularly South Tarawa leads the Nation in the use of rainwater harvesting. About 43% of all households in South Tarawa and 12% in North Tarawa harvest and store rainwater. Despite the importance of rainwater harvesting, there is a lack of information on the amount of rainwater used and the characteristics of the rainwater systems installed in Tarawa. It is therefore not possible to identify the future potential for expanding the use of rainwater. It is strongly recommended that the lead water agencies conduct surveys of household rainwater use and develop a data base of the location and physical characteristics of rainwater systems in Tarawa.

4.1.1 Risk of failure of rainwater storages in Tarawa

Estimations were made on the risk of failure of rainwater storages in Tarawa (White, 2010a). There are five key parameters on which the risk analysis depends: the number of people per household; the per capita water demand; the size of the roof catchment; the roof catchment runoff coefficient (which incorporates losses) and the volume of the rainwater storage tank. Because of the lack of information in Tarawa, reasonable values for the rainwater harvesting and storage parameters and per capita demand were assumed together with the average size of households in South and North Tarawa from the 2005 Census.

For the average household size in South Tarawa, and for average-sized roof catchment areas and rainwater tank storage capacities, rainwater harvesting can only supply water at a modest rate of about 5 L/pers/day, sufficient for drinking and cooking only, without the risk of excessive rainwater tank failures. For average roof areas, the storage capacity of the rainwater tank needed to supply water without failure was 6 times the average total household monthly water use for drinking and cooking. For a rainwater tank capacity of 6,000 L, it was found that a rather large roof area of about 7.7 m^2/pers was required to prevent rainwater tank failure at a per capita demand of 5 L/day. The above calculations contain no water use conservation strategies. Conservative rainwater use strategies which limit water use when the stored water volume reaches a specified level, such as half tank full, can lower the risk of failure. Such strategies need to be complemented by warnings from the government on predicted drier periods determined by the Kiribati Meteorological Service using the SCOPIC program. These strategies would limit failure of rainwater storage but require a major public education campaign on managing and using rainwater systems.

It is concluded that because of the frequent severe droughts, rainwater harvesting and storage in Tarawa can only supplement household water requirements rather than meet all household water needs was therefore confirmed by the daily model.

4.1.2 The costs and advantages of rainwater harvesting

It was estimated, using historic Tarawa rainfall data, that the cost to households of harvested rainwater exceeds $8/kL which is considerably greater than the current charge for PUB supplied groundwater water but much less than bottled water. If properly managed, rainwater harvesting and storage systems, however, have several distinct advantages in Tarawa. These are : a source of good quality water for drinking and cooking; limited risk of human or domestic animal faecal contamination; constant, limited supply of water always continuously available; under the direct control of the household; a convenient household water storage for deliveries during droughts and, conservation messages are clearly signaled by decreasing volumes of water in rainwater tanks.

4.1.3 Contribution of rainwater harvesting to meeting future water needs

Estimating the amount of rainwater that is currently harvested in Tarawa is problematic since there is insufficient information on rainwater harvesting and storage systems in Tarawa. In order to make a rough estimate, the 2005 Census results for the number of households in South and North Tarawa harvesting water, together with the average number of people per household and a consumption rate of 5 L/pers/day were used. These indicate that, on average, about 100 kL/day of rainwater is harvested in Tarawa currently. If it is assumed that a further 1,750 houses in South Tarawa will have rainwater harvesting and storage systems installed by 2030, then the amount of rainwater water supplied could increase to about 160 kL/day. Rainwater harvesting will not meet the projected shortfall in continuous water supply in South Tarawa because of long, severe droughts. It is none-the-less an important source of good quality water and its proper use should be encouraged.

4.1.4 Public education in rainwater harvesting

The NWRP recognizes that rainwater harvesting is an important and relatively safe source of the several available sources for meeting water needs in wetter periods. Rainwater harvesting and storage bye-laws need to be enforced. Extensive community education and training are required in the judicious and careful use of rainwater from harvesting and storage systems, as well as in their installation, proper maintenance. There is a significant opportunity for community rainwater harvesting schemes from the many large public buildings in Tarawa. Thirty years ago, South Tarawa had a system of rainwater collection, storage and distribution from communal cisterns and tanks. In order for this to be re-established, an equitable management system and a major community training and participation program would need to be developed and put into practice.

4.2 Using Te Ran, Groundwater, to Meet Freshwater Demands

The 2005 Census shows that predominant source of drinking water in Tarawa is groundwater sourced from local household wells. In South Tarawa, only about two thirds of households use water supplied by the PUB piped water system sourced from groundwater 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 of the large year-to-year variability in rainfall in Tarawa, and the frequent ENSO-related severe droughts, the thickness and salinity of these lenses also varies. During these droughts, groundwater lenses in narrow islands can become brackish or saline. Only groundwater in larger islands, such as Bonriki, Buota and Buariki can survive severe droughts.

4.2.1 Sustainable groundwater yields in Tarawa

The sustainable yields[4] of groundwater, which are estimated to permit pumping at the specified rate throughout the longest drought on record, have only been accurately determined for four islands in Tarawa: Bonriki, Buota, Abatao and Tabiteuea (Falkland *et al.*, 2003). Estimates have been made recently under KAPII of the gross safe yield for the other major water lenses in North Tarawa (GWP, 2010); although the actual yield will depend on the area of land available for groundwater harvesting. The combined safe yield of Bonriki, Buota, Abatao and Tabiteuea is 2,230 kL/d. Remediation of Bonriki water reserve and other potential areas for groundwater pumping were identified in South Tarawa, although their suitability needs to be investigated (Table 8).

Table 8 Summary of the estimated safe groundwater yields of significant, actual and 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)
[‡] Upper bound values for North Tarawa from GWP (2010)

The estimated sustainable yield of all major groundwater lenses in both North and South Tarawa lies between 4,100 and 6,600 kL/d (Table 8), slightly less than the estimated demand for all of

[4] Sustainable yield is defined as the continuous rate of pumping that maintains the freshwater lens so that the salinity of the pumped water remains acceptable for use.

Tarawa by 2030 with no losses (Table 4). North Tarawa has sufficient groundwater to meet local demand until 2030, however South Tarawa is already in water deficit and this will be significantly worse in 2030. Whether North Tarawa will share water with South Tarawa remains to be determined.

4.2.2 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 estimated that use of local household wells in South Tarawa is supplying currently between 600 and 920 kL/day of water for local used. It is strongly recommended, however, that intensive monitoring of household water wells in Tarawa be undertaken to determine their suitability for continued use.

4.2.3 Protection of groundwater reserves

The current water reserves at Bonriki and Buota are vital for supply treated freshwater for South Tarawa. It has been assumed here that they 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. Encroachment on the reserves at Bonriki and Buota is increasing. Maintaining the water reserves at Bonriki and Buota will require commitment by government and the involvement of local communities.

4.3 Using Other Sources of Water to Meet Freshwater Demands

Previous studies in Tarawa have suggested a range of potential other sources of freshwater to supply the atoll's needs. These have included:

- Bottled water
- Recycling
- Bulk importation of water by ship
- Constructed rainwater catchments
- Constructed island for groundwater harvesting
- Solar stills
- RO seawater desalination

It is emphasised that development of any other water sources should only be considered once the existing leaks in the reticulation systems are dramatically reduced and the causes of those leaks are addressed. There is no point in investing in new water sources when losses from the domestic reticulation system are as high as 50%.

4.3.1 Bottled water

Bottled water is currently a minor component of household water use, with 3.8% of households using this as one of their sources in South Tarawa, compared with 0.9% in North Tarawa (Table 7). It is clear that the cost of bottled water, currently around $1.50/L, whether local or imported, is a significant constraint on its use. While economic development will increase the number of households using bottled water by 2030, it is expected to remain a minor component of total household freshwater use, particularly in North Tarawa.

Total imports of bottled water are currently between about 300 to 500 kL/year of which about 93% is used in South Tarawa, or 280 to 470 kL/year. A private RO plant in South Tarawa also supplies some bottled water.

4.3.2 Recycling

Recycling through a separate piped “grey” water system can be dismissed as an additional water source in Tarawa. Most household “grey” water is disposed of on the ground where it waters plants, evaporates or recharges the shallow, local groundwater, from which it is recycled back though household wells. In addition to household “grey” water disposed on the ground, local groundwater in South Tarawa contains water lost from piped fresh water, leakage from the seawater-flushed sewerage system and drainage from septic tanks and pit latrines as well as human and animal wastes disposed on the ground. In North Tarawa, local groundwater in villages also is open to pollution from septic tanks, pit latrines, human and animal wastes and “grey water disposed on the ground. This recycling of “grey” and even “black” water through household wells is a key factor in the poor health statics for water-borne diseases in Tarawa.

Recycling of “black” water from the seawater-flushed sewerage system used by about one third of South Tarawa’s population for non-potable water use is not possible because of the use of seawater to flush toilets and the fact that sewage is not treated but only macerated by pumps prior to discharge into the ocean. There are no envisaged current or future uses for recycled, untreated, saline sewage.

4.3.3 Bulk importation by shipping

Previous reports have concluded that it is impractical to ship bulk water to Tarawa as a method of augmenting the regular water supply. It is expensive, logistically difficult, potentially unreliable and not suited to long-term, continuous supply in populous areas such as Tarawa. Instead it is more suited to short-term, emergency relief for smaller island communities. It also requires the approval of the island communities from which the water is sourced. Because of these factors bulk importation is not considered as a viable option for long-term water supply for Tarawa.

4.3.4 Constructed rainwater catchments

Large-scale constructed rainwater catchments in Tarawa require very large constructed roof areas and large storage capacities in order to safeguard against failure during droughts. Because of this, it is prohibitively expensive and occupies too large an area on the ground. The life-time would have to be extended to at least 50 years in order for this option to be even contemplated. If a cheaper system with smaller constructed roof catchment areas and smaller storage tanks is used then there is high probability that the system will fail in droughts, when water supply is most needed. Coupling the roof catchment system with a large-scale solar power photo-voltaic array makes the option more attractive but is still very expensive and requires a large area of land. The only suitable area in South Tarawa appears to be government-owned land at Temaiku.

There are large areas of existing roofs on public buildings in Tarawa, particularly maneabas and government buildings, which have no or limited capacity to collect and store rainwater. Consideration should be given to improving communal rainwater harvesting from such buildings.

4.3.5 Solar stills

Solar stills use the sun’s energy to distil freshwater from seawater. Although there are claims for higher production rates from optimised solar stills, experience in the tropical Pacific, and Kiribati in particular, suggests that freshwater production rates of 2 to 5 L/m^2 of solar collector are generally achievable. While these are suitable for providing emergency drinking water requirements for isolated islands where energy sources and freshwater are scarce, they are not suited for providing daily household freshwater for urban areas such as Tarawa, which would need a solar collector area of up to 1 km^2 to meet daily demand.

4.3.6 Constructed island for groundwater collection and pumping

Earlier proposals to reclaim areas in Temaiku to use for groundwater pumping have fallen into disfavour because of their perceived environmental and social impacts. Instead, it has been proposed that a complete island be reclaimed by dredging in an area of the lagoon midway along North Tarawa where sand and sediment accumulate (Falkland, 2003).

An island constructed by dredging up lagoon sediments and dedicated to supplying water has the advantages that it would be new government-owned land, with no requirement to pay rental to land owners, and is possibly much easier to protect and manage than the Bonriki and Buota water reserves. It is however, expensive, even with the assumption of the smallest possible cost of fill. While, the time required to build up a fresh groundwater lens to supplement water supply is too long to meet South Tarawa's immediate water needs, it is proposed as a longer-term investment in future water supply. The possibility of major environmental impacts from dredging sediment from the lagoon has also been raised.

Reclaimed islands are usually viable if they are associated with a high-value land use. Unfortunately, water although vital, is not of sufficient high-value in Tarawa. If a higher value land use, such as the positioning on the constructed island of a major solar, photo-voltaic array for renewable energy generation, then it may be a more attractive option.

4.3.7 Seawater RO desalination

Early design studies for water supplies for South Tarawa rejected the use of seawater desalination to supplement water supply because of its cost, energy consumption and complexity. The history of their use in Pacific Island Nations in the past is not encouraging. Seawater RO desalination has advanced significantly in the last 20 years. The current use of pre-treatment ultra filtration membranes decreases clogging of the RO membrane and eliminates human pathogens. The salinity of water from even a single-stage RO plant is equivalent to that pumped from Bonriki and Buota water reserves. In addition, energy recovery systems using the high pressure, rejected brine reduce energy costs. Although costs and energy requirements have decreased over the past 20 years, the complexity of RO plants and the skills required to maintain them are largely unchanged, particularly in tropical small island islands. Some of the lower unit production costs in the literature appear exaggerated. For small islands the major challenges are the production costs and the difficulty of finding and maintaining trained personnel.

Here, capital costs, and unit production costs for different capacity seawater RO plants were estimated from a recently published relationship. It is probable, because of its remoteness, that costs will be considerably higher in Tarawa. Nonetheless, RO desalination in terms of its capital and operating costs appears to be the most economic alternate means of augmenting water supply, provided it can be managed and maintained over a period longer than 10 years.

RO desalination produces human pathogen free water, and it has a small land area footprint so that land rental costs are minimised. In addition, its small footprint means that it can be located close to areas of highest need. It is suggested here that four 500 kL/day RO desalination plants that fit into a standard shipping container could be located in Betio, Bairiki, Bikenibeu and one other area of high demand. This means that four times the number of skilled technicians is required and abandons the economy of scale from a single 2,000 kL/day RO desalination plant but reduces risk of failure. The possibility of using solar rather than fossil fuel produced electricity was rejected because of significantly increased cost, the area required for the solar array; problems with batteries needed in tropical islands; and the low (40%) operational time of a battery-less solar powered system. There is the possibility in Tarawa of using coconut oil as a diesel substitute for power generation for desalination. This has the advantage of being a renewable fuel, decreasing import costs and increasing economic opportunity for outer islanders.

In Kiribati, and particularly in Banaba and Tarawa, there is considerable recent experience in running sweater RO desalination plants following the 1998-2000 drought. They consumed about 16 times the energy of current groundwater pumping systems. The fact that none of the public RO systems are now running, point to the significant technical difficulties in their maintenance and operation in small, tropical islands. It is suggested here that if the RO option is considered then the suppliers should be contracted for regular maintenance of the systems, as has been done in Nauru.

A summary of the potential yields, estimated lifetime and capital costs of the above options is given in Table 9. A more accurate costing of some of these options is given in **TABLE 14**

Table 9 Summary of the main features of other potential sources of freshwater in Tarawa

Source	Potential Production	T_a ‡ (years)	Approximate Capital Costs (A$million)	Unit Capital Cost (A$/kL)	UPC§ (A$/kL)	Comments
RO Desalination	2 ML/day	2	8.6	6.5	18.6	Too expensive if short lifetime, technically complex, poor past record of RO performance in Tarawa
		10		1.3	3.72	
Bulk Importation by Ship	0.25 ML/day	0.5	?	2.5 - 30 times GW *	-	Expensive, logistically complex, suitable only for brief emergencies for small communities
Constructed Rainwater Catchments - 200 ML storage capacity	2 ML/day	20	160 - 520	12-36	-	Extremely capital expensive, takes up large area of land, poor past record in Tarawa
		50		4.6 - 14	-	
Constructed Rainwater Catchments - 600 ML storage capacity	2 ML/day	20	126 - 160	9.1-11	-	Very capital expensive, takes up large area of land, poor past record in Tarawa
		50		3.6 - 4.4	-	
Recycling	0.6-0.92† ML/day	1000	0	0	0	Extensive recycling of second-class local GW through household wells to homes occurs throughout Tarawa. No potential for recycling the seawater-based sewage.
Constructed Island	2.1 ML/day	20	31.5 -45	9.4 -12.9	-	Highly capital intensive, long construction, potential major environmental impacts
		50		1.4 -1.8	-	

‡ T_a = amortisation time
§ UPC = unit production cost
* GW = groundwater
† Estimated current recycling of local groundwater through domestic wells

4.4 Deficit between Demand and Water Sources in South and North Tarawa

Table 10 summarises the current and potential groundwater and rainwater harvesting sources of freshwater in North and South Tarawa. Using the design per capita water demand, the current project water needs for South Tarawa are 3,500 kL/day without water losses. With the expected growth in population, this will expand to between 5,200 and 7,000 kL/day by 2030 (Table 4). The sustainable pumping rate from the current groundwater sources is 2,000 kL/day and with the estimated rainwater harvesting, this increases to 2,100 kL/day. There is the potential to increase the groundwater yield in South Tarawa to between 2,600 to 2,700 kL/day. Even if this is done, the deficit in 2030 will be between 2,500 to 4,400 kL/day, assuming no water losses. It is clear that this deficit cannot be met by existing safe freshwater sources in South Tarawa.

It is estimated that the safe yield of groundwater from North Tarawa is between 1,400 and 3,900 kL/day. This groundwater is more than adequate for local needs in North Tarawa. Were it to be shared with South Tarawa, it would significantly reduce the deficit there. There are a number of significant factors that detract from this. These are that it:

- requires approval from communities in North Tarawa
- requires protracted, difficult negotiations with North Tarawa
- requires the installation of a power station and a pipeline in North Tarawa
- would involve major, continuing land rental payments, and
- increases the complexity of management.

Table 10 Summary of estimated actual and potential daily yields from groundwater and rainwater 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 Potential Sources	***610***	***700***	Potential new groundwater sources South Tarawa
Household Wells	***600***	***920***	Requires detailed water quality & use study
Rainwater harvesting†	***90***	***160***	Requires investigation of storage & use rainwater
Total South Tarawa	***3,310***	***3,790***	
North Tarawa			
Groundwater N. Tarawa	**1,440**	**3,870**	Requires motoring, island permission & EIS
Rainwater harvesting†	*2*	*100*	Requires investigation of storage & use rainwater
Total for Tarawa	***4,750***	***7,670***	

* Values in italics are estimated values
† During severe droughts almost all rain water storage systems will fail in Tarawa (White and Falkland, 2009c)

If the water resources of North Tarawa were shared equitably with South Tarawa, Table 11 shows that even if this is done there is a minimum shortfall of 2,200 kL/day between supply and predicted demand by 2030, provided water losses are reduced to 25%. Table 11 also emphasizes the importance of reducing these losses as quickly as possible.

Table 11 Estimated surplus or deficit of supply (kL/day) over demand in Tarawa by the year 2030

Component (ML/day)	**25% Losses**		**50% Losses**	
	Lower	**Upper**	**Lower**	**Upper**
Estimated Demand	7,600	9,900	11,400	14,900
Estimated Potential Yield	4,800	7,700	4,800	7,700
Surplus or Deficit 2030	**-2,800**	**-2,200**	**-6,600**	**-7,200**

Because of these expected water deficits and the difficulties faced in sourcing water from North Tarawa, seawater RO desalination appears an attractive alternative for South Tarawa provided water losses can be reduced and the effects of climate change are not too severe.

5. How Will Climate Change Affect Water Use and Availability?

Climate change has the potential to influence both future demand for water as well as the availability of freshwater in Tarawa. Future demand could be influenced by changes in both population numbers and per capita consumption. Water availability could alter in the future due to changes in rainfall and evaporation as well as from increased encroachment of seawater due to sealevel rise. These are highlighted in the following.

5.1 Population Growth and Distribution

Climate change poses risks to the health of human populations. Adverse health impacts could occur directly, such as death from extreme weather events or indirectly, such as through changes in conditions favouring vector-borne diseases. If global warming increases the frequency and/or severity of extreme weather events, then more deaths, injuries, infectious disease outbreaks, and psychological disorders could result particularly in vulnerable sectors such as infants or the elderly (McMichael and Martens, 1995). Vector-borne diseases such as malaria, dengue, and yellow fever are sensitive to factors such as temperature, rainfall, and humidity.

Rainfall is generally expected to increase with increasing temperatures, in small island countries in the central Pacific and it is expected that the frequency of water-borne disease outbreaks could increase in Tarawa. Models predict an additional 50-80 million cases of malaria world-wide would result from a mean temperature increase of 3.0ºC (Ali *et al.* 2001).

Fertility rates could also decrease with increasing temperatures. If these predictions are accurate, a slowing of the population growth might also occur in Tarawa with increasing global temperatures. The lower bound South Tarawa population estimate could be considered to reflect the impact of climate change. I

Severe droughts in the past have forced the mass migration of entire populations from small islands in Kiribati. While the water supply system in South Tarawa and the large groundwater sources in North Tarawa provide a considerable buffer against such events, severe droughts could increase migration to Tarawa. Rising sea-levels could also force an increase in inward migration from lower-lying outer islands to Tarawa or outward migration to other countries. Since there is little information on the magnitude of these impacts, and since the time horizon for the TWMP is 2030, it is assumed here that the range of estimated future populations in Tarawa given in Table 2 spans the plausible lower and upper bounds of future population numbers in Tarawa under climate change.

5.2 Per Capita Demand

The rise in atmospheric temperatures accompanying climate change (Ali *et al.* 2001), may be as high as 1°C by 2050 (Metutera, 2002). This has the potential to lead to an increase in the per capita demand for water. Since there is currently little information on the current per capita demand for water in Tarawa, it is difficult to estimate any increase in per capita water demand due to climate change. It has been assumed in the TWMP that the increase in water consumption due to climate change will be 2 L/pers/day from 2020 as shown in Table 3.

5.3 Rainfall and Droughts

Rainfall in Tarawa is highly variable and extreme events are strongly coupled to ENSO events. Severe droughts occur about every 7 years and last on average for nearly two years. The failure of almost all climate change predictions of future rainfall using global climate models (GCMs) to simulate ENSO events means that they are of little relevance in predicting future rainfalls or drought in Tarawa.

NIWA (2008a) used GCMs in a KAPII study which concentrated on the predicted change in rainfall intensity with increasing greenhouse gas emissions. For the period 2015-2034, the predicted future rainfall intensity-average return interval results do not differ significantly from the 1980 to 1999 values. The maximum expected change in intensity is approximately 13% which is probably within the measurement error.

NIWA (2008a) also analysed past droughts in Kiribati and attempted to estimate the impacts of climate change on future droughts. The report acknowledges that the GCMs used do not reproduce ENSO events, which dominate droughts in Tarawa during La Niña phases and, in particular, that they do not reproduce the severe droughts in Tarawa or Kiritimati. The report predicts that "*drought characteristics will generally remain much the same over the next 100 years*"

Because of the considerable uncertainties in GCM predictions of tropical rainfall, it has been assumed in the TWMP that the variability of rainfall over the next 20 years in Tarawa will be similar to that experienced in the historic rainfall record over the past 62 years. That is that frequent severe droughts will occur with similar frequency and longevity.

5.4 Groundwater Recharge and Sustainable Yields

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.

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 about the same with climate change over the next 20 years. 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). It has therefore been assumed here that up to 2030, groundwater recharge and the sustainable groundwater yield per unit land area will remain unchanged from the historic pattern, although land area may shrink due to sealevel rise.

5.5 Sealevel Rise and Groundwater Source Areas

The impacts on freshwater lenses from projected mean sea level rises and possible changes in recharge have been modelled at the Bonriki water reserve (Alam *et al.*, 2002). It was the freshwater zone would initially slightly increase in thickness and volume with sealevel rise, as more of the freshwater lens will be within the upper, lower-permeability, Holocene sediments. When, however, land is lost due to erosion and inundation at the edges of an island, the island area is reduced. This decreases the volumes of freshwater lenses and hence the total sustainable yield.

NIWA (2008b) 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. From these it was estimated that inundation of Bonriki could lead to a decrease in the sustainable groundwater yield of Bonriki of about 20%. This has been factor has been applied to all groundwater yields and incorporated into the estimates of the water deficits in Table 11.

5.6 Comparison with Other Risks

While the expected decline in groundwater yields of an estimated 20% by 2030 is a significant risk, it should be compared with other risks to the water supply. The population projections carried out for the TWMP estimate that population in South Tarawa will grow between 46% and 94% by 2030. These large increases will severely stress water supply systems and will greatly increase the risks of death, diseases and illnesses from contaminated groundwater.

6. What are the Options for Meeting Expected Demands?

The TWMP has summarised some of the current challenges facing public water supply in Tarawa and has identified major, future shortfalls. While I-Kiribati use a range of water sources to meet potable and non-potable household water needs, some involve risks to public health, particularly in South Tarawa. Thirty five 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), nineteen 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."* Because of that we have discounted the use of household wells in South Tarawa until they are proven to be acceptable for use.

The TWMP has concluded that the current treated water supply in South Tarawa is inadequate to provide the quantity of freshwater necessary for the health and well-being of communities in urban South Tarawa. With the expected population growth in South Tarawa, Tarawa's extreme rainfall variability, continued system water losses and the predicted impacts of climate change, the situation will worsen over the next 20 years. There are a number of options available for the GoK, whose unit production costs are given in section 7. The choice of options, however, requires a clear vision for the course of the development of Tarawa over the next 20 years.

6.1 Future Development of North and South Tarawa

Currently Tarawa is separated into two distinct zones (Figure 1). South Tarawa (including Buota) is a highly urbanised area whose population growth rate over the past 25 years has been well above the national average growth rate, augmented by inward migration from rural areas and outer islands. North Tarawa (excluding Buota), in contrast, remains largely rural. While its population growth rate over the past 25 years is above the national average, it is less than South Tarawa.

The estimated sustainable yields of safe freshwater sources in South Tarawa are inadequate for its current population and this situation will worsen over the next 20 years. North Tarawa, in sharp contrast, has more than sufficient water for its communities now and will have adequate supplies in the future, provided population growth rates remain at the average rate there over the past 25 years. If the available water resources in North Tarawa were shared with South Tarawa, the reasonable water demands of all of Tarawa could be met until almost 2020 provided the water losses from the reticulation are reduced to reasonable rates (25% or less).

The GoK's plans for both zones in Tarawa are unclear. If the aim is to progressively urbanise North Tarawa, then it is reasonable to suggest that North Tarawa should share its groundwater resources with South Tarawa. That, however, will be a politically difficult decision, involving lengthy consultations with communities in North Tarawa. If successful, under present arrangements, it will involve major land rental payments to land owners and will change the character of North Tarawa since it will involve the installation of a power station, pipelines and associated infrastructure. If the aim is to retain North Tarawa as a rural area with its own island-based freshwater resources, which will be adequate for North Tarawa for the next 20 years, then alternate water sources will need to be found for South Tarawa.

6.2 Leakage Reduction

Before any options for augmenting water supplies are considered leakage reduction and the causes of leakage must be addressed as a matter of highest priority. The ADB Sanitation, Public Health and Environment Improvement Project (SAPHE) 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 (Pipeline Network Analysis, 2010). This leakage is unacceptable in a water-scarce island. It 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 at least the 25% target identified as one of the possible targets in the PUB (2004) business plan. In addition, the behavioural factors contributing to water losses must be addressed.

As an interim step in the current drought, consideration should be given to isolating and shutting off excessively leaking parts of the reticulation system. Instead water could be supplied from fixed distribution points, such as existing village head tanks, or installed standpipes, or installed supply tanks throughout villages, or by tanker from main storages. This will require the provision of at least ten working water tankers in South Tarawa. The estimated annual cost of such a distribution system, is around $A2.2 million. Assuming no losses, and a daily delivery of 2,000 kL, the unit production cost of this interim step is about $A2.90/kL which has to be added to the unit production costs from Bonriki and Buota groundwater reserves of about $A3.60 (excluding capital costs).

While shutting down parts of the reticulation system is a backward step for South Tarawa's urban water supply, it will cut dramatically waste and the cost of supplying water that cannot be used. It may also improve cost recovery by charging for water supplied from fixed distribution points or by tanker, and would send a clear message that tampering with domestic water supply pipelines has consequences for all. It is emphasised, there is no point in increasing the amount of freshwater introduced into the reticulated water supply in South Tarawa if leakages remain at their current rate.

6.3 Extra Freshwater Sources in South Tarawa

The groundwater sources in South Tarawa itself are the current sources in Bonriki and Buota, together with potential increase in yield from these two islands and extra yield from other potential source locations in Betio, Buariki, and Bikenibeu (White, 2010b). These last three locations have relatively low estimated yields, totally 110 kL/day and require careful investigation of their yield and water quality as they are close to densely populated areas. They will not be considered here.

6.3.1 Improved rainwater harvesting

The 1995 and 2005 Census data shows that there was an 87% increase in the percentage of households with rainwater tanks in 10 years, with the SAPHE revolving fund for the purchase of rainwater tanks, and perhaps the 1998-2001 drought, making significant contributions. The TWMP study of rainwater harvesting in Tarawa was hampered by the lack of information on the characteristics of rainwater harvesting systems in use. None-the-less it was shown that almost all rainwater harvesting systems in Tarawa will fail in Tarawa's frequent severe droughts. This is because of the large number of people per household, and the generally limited roof catchment areas and rain tank storage volumes available and the lack of training on conservative rainwater use. The potential for increasing the household harvesting of rainwater in Tarawa is limited by the use of traditional thatched roofs in an estimated 40% of houses. The estimated potential increase in sustainable rainwater production is about 60 KL/day and the unit production cost of household rainwater harvesting in Tarawa for a 20 year amortisation period is over $8.20/KL.

Rainwater harvesting remains an important and relatively safe source for meeting potable water needs in wetter periods. Rainwater harvesting and storage bye-laws and building codes need to be enforced. Extensive community education and training are required in the judicious and careful use of rainwater from harvesting and storage systems, as well as in their installation and proper maintenance. There is a significant opportunity for community rainwater harvesting schemes from the many large public buildings in Tarawa. Thirty years ago, South Tarawa had a system of rainwater collection, storage and distribution from communal cisterns and tanks. In order for this to be re-established, an equitable management system and a major community training and participation program would need to be developed and put into practice.

6.3.2 Option 1: Tree removal at Bonriki

Deep rooted trees transpire about 150 L/day of shallow groundwater from the water reserves. Removal of 1,700 deep rooted trees from the central portion of the island will increase the sustainable yield of Bonriki by 250 kL/day. Under this option, negotiations with landowners over tree removal and compensation payments will be required. Only minor modification of the existing infrastructure is required. Sports fields could be created on the cleared portion of the water reserve to give a benefit to Bonriki villages and especially young people. The advantages and disadvantages of this option and indicative costs are summarised in Table 12.

Table 12. Advantages, disadvantages and indicative costs of the options for supply water to South Tarawa

Option	Description	Advantages	Disadvantages	Indicative Costs ($A1,000)
1	Increased groundwater production at Bonriki from tree removal	• An extra **250 kL/day** of water available for South Tarawa (0% losses) • Sports fields generated for eastern end of South Tarawa • May increase participation of Bonriki landowners in the protection, care and management of reserves • Local, temporary work generated by tree removal • No extra reticulation pipelines or treatment works required.	• Lengthy negotiations with Bonriki landowners over the cutting down of trees • Potential disputes with landowners and communities • One-off compensation costs for cutting down of trees • Environmental Impact Statement (EIS) may be required	**272**
2	Increased groundwater production at Bonriki from infilling ponds & constructing more galleries	• An extra **250 kL/day** of water available (0% losses) • May increase participation of Bonriki landowners in the protection, care and management of reserves • Local, temporary work generated by cleaning and infilling ponds • No extra reticulation pipelines or treatment works required.	• Lengthy negotiations with landowners over the in-filling of the ponds • Potential disputes with landowners and communities • Possible on-going land rental costs for in-filling ponds • EIS may be required • Small increase in PUB staff required	**2,270**
3	Groundwater production from Abatao and Tabiteuea	• An extra **220 kL/day** of water available (0% losses) • Treated water supply available for Abatao and Tabiteuea • Close to the South Tarawa distribution system • May increase participation of landowners in the protection, care and management of reserves • Local, temporary work generated by installation of galleries and pipelines • Local, permanent work for plant operation and maintenance • Increased development	• May require legislation • Lengthy negotiations with landowners and communities over new water reserves • Potential disputes with landowners and communities • On-going land rental costs for reserves • EIS may be required • Increase in PUB staff required • New cross-channel pipeline and possible treatment plant required • Change in character of these islands • Relatively expensive	**4,490**
4	Groundwater production from Buariki & Taratai	• An extra **1,530 kL/day** available (0% losses) • Treated water supply available for North Tarawa • Power station for North Tarawa • May increase participation of landowners in the protection, care and management of reserves • Local, temporary work generated by installation of galleries and pipelines • Local, permanent work for plant operation and maintenance • Increased development for North Tarawa	• May require legislation • Lengthy negotiations with landowners and communities over new water reserves • Expensive on-going land rental costs for reserves • EIS may be required • Major Increase in PUB staff required • New Storage tank, cross-lagoon pipeline and treatment plant required • Change in character of North Tarawa • Expensive	**20,900**

5A	RO Desalination production (using published data for two 1,000 kL/day units)	• An extra **2,000 kL/day** available (0% losses) • RO removes pathogens from product water • Only small land area required • Minimal land rental and compensation payments • Minimal negotiations with landowners • No new legislation required • Units can be located in areas of highest demand • Can be installed and started quickly • Connects directly into existing water supply pipeline • Energy recovery systems available	• Poor track record of RO in Pacific Island Nations and Kiribati in particular • Requires well trained operators • Requires regular maintenance and monitoring • Energy intensive (6 to 18.8 MWh) • Environmental impacts of rejected brine • Very expensive if operational life is short	**8,600**
5B	RO Desalination production (based on cost estimates from Veolia for 4x552 KL/day containerized units)	• An extra **2,200 kL/day** available (0% losses) • RO removes pathogens from product water • Only small land area required • Minimal land rental and compensation payments • Minimal negotiations with landowners • No new legislation required • Units can be located in areas of highest demand • Can be installed and started quickly • Connects directly into existing water supply pipeline • Energy recovery systems available • Maintenance and training contracts available	• Poor track record of RO in Pacific Island Nations and Kiribati in particular • Requires trained operators • Requires regular maintenance and monitoring • Energy intensive (5.8 MWh) • Environmental impacts of rejected brine • Requires well trained operators • Very expensive if operational life is short	**7,200**
6	Large scale constructed rainwater collection and storage	• Can be located in areas of highest demand • Simple technology • Minimal energy requirements • Connects directly into existing water supply pipeline • Past experience in Tarawa with communal rainwater collection and storage • Economic, provided system lasts 50 years	• Massive constructed roof areas and storage capacities needed in order to safeguard against failure during droughts. • Occupies too large an area for limited space in Tarawa • Would require negotiations with landowners • Would incur land rental costs • Very expensive if lifetime less than 50 years	**126,000 to 160,000**
7	Constructed island for groundwater production	• New government-owned land • No requirement to pay rental to land owners, • Much easier to protect and manage than the Bonriki and Buota water reserves. • Land created could be used for high value use such as location of photo-voltaics for power generation	• Very expensive • Time to build up a fresh groundwater lens to supplement water supply is too long to meet immediate water needs • Possibility of major environmental and social impacts from dredging sediment from the lagoon has been raised as a significant concern • Could be subject to land ownership claims	**31,500 to 45,000**

6.3.3 Option 2: Infilling the ponds at the western end of Bonriki

During construction of the airport runway at Bonriki, borrow pits were excavated at the western, lagoon end of Bonriki. These become brackish during drier periods and contribute salinity to the freshwater lens. If the bottom of these ponds were cleaned of organic matter and infilled with clean, dredged sand, the area and sustainable yield of Bonriki reserve could be increased by a further 250 kL/day. This option would require negotiations with landowners and the Bonriki community who use the ponds for soaking pandanus fronds for thatching, the installation of three new galleries in the reclaimed area and may involve possible increased land rental payments. The advantages and disadvantages of this option together with indicative costs are summarised in Table 12.

6.4 Freshwater Sources in North Tarawa

The main freshwater sources in North Tarawa are the shallow groundwater lenses in major islands (Table 8). Rainwater harvesting can contribute to potable household use but because North Tarawa is a rural area, the number of buildings with suitable roofs for rainwater collection is limited.

Previous suggestions for providing adequate water supply for South Tarawa included the progressive use of groundwater from islands north of Buota with the pumped groundwater being pumped across the channel between Abatao and Tabiteuea (see e.g. Falkland, 2003). The gradual development of all of the islands in North Tarawa would be a lengthy process and not able to meet the immediate needs in South Tarawa. While the background groundwater report has considered all islands in North Tarawa (White, 2010b), here only two will be considered: development of groundwater resources in Abatao and Tabiteuea, islands immediately north of Buota; and the large islands of Buariki and Taratai in the far north of North Tarawa (Figure 3)

6.4.1 Option 3: Groundwater production from Abatao and Tabiteuea

In this option, a total of 8 infiltration galleries would be constructed in already surveyed areas in Abatao and Tabiteuea (Falkland *et al.*, 2003) together with a water treatment plant for each island, a cross-channel pipeline to connect with the South Tarawa and reticulation systems in each island to supply local household needs. This would increase the sustainable water supply by a modest 220 KL/day (Table 8). Under this option, lengthy negotiations with landowners together with compensation payments and continuing land-rental payments will be required. New legislation may also be needed for the declaration of water reserves in Abatao and Tabiteuea.

The advantages and disadvantages of this option and indicative costs are summarised in Table 12.

6.4.2 Option 4: Groundwater production from Buariki and Taratai

In this option, a total of 18 infiltration galleries would be constructed in yet-to-be surveyed areas in the northern islands of Buariki and Taratai together with a power station to supply energy for pumping for the galleries and cross-lagoon transfer, one major water treatment plant, a major water storage tank, a cross-lagoon pipeline to connect with the South Tarawa reticulation system at Ambo (Figure 3) and reticulation systems for islands in North Tarawa to supply local household needs. This would increase the sustainable water supply by a substantial 1,530 KL/day (Table 8). Under this option, lengthy negotiations with landowners together with compensation payments and continuing, expensive land-rental payments will be required. New legislation may also be needed for the declaration of water reserves in Buariki and Taratai. This option would substantially change the character of North Tarawa.

The background report on groundwater (White, 2010b), considered the use of solar voltaic cells to produce the energy for pumping. Because of the demand for water in South Tarawa, pumping needs to be continuous and a battery-backed solar system was considered too expensive. In addition, the size of the required solar array to produce the necessary power may be too large for North Tarawa.

The advantages and disadvantages of this option and indicative costs are summarised in Table 12.

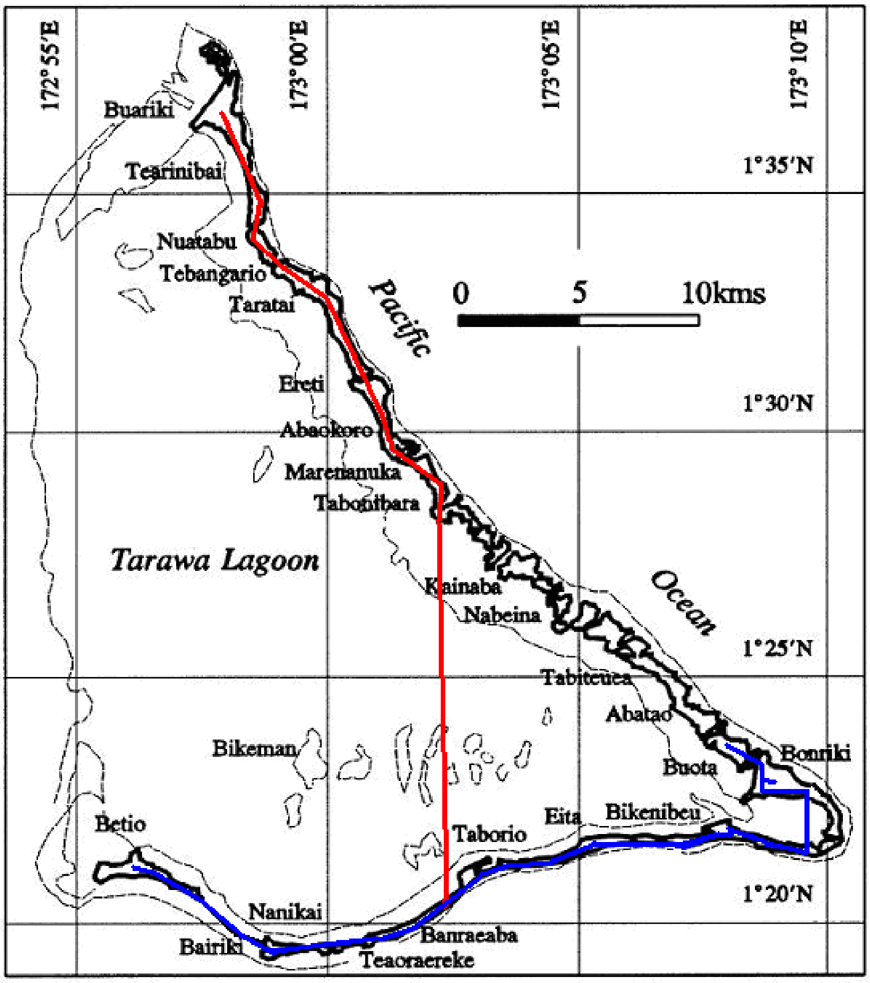

Figure 3 Option 4, development of the groundwater lenses at Buariki and Taratai with a cross-lagoon pipeline from Tabonibara to Ambo (red line) to connect with the Bonriki to Betio pipeline (blue line)

6.5 Additional Rain and Groundwater Sources in South and North Tarawa

The combined potential freshwater resources in South and North Tarawa in options 1 to 4 above plus increased rainwater harvesting give a potential increase in water supply of 2,310 KL/day. The estimated total capital outlay for the increased groundwater component of this is over $A27.8 million.

6.6 Other Freshwater Sources

The TWMP report on other water sources (White, 2011) summarises a range of other potential freshwater sources for Tarawa. The three principal options with the potential to meet Tarawa's projected future needs are seawater RO desalination, specially constructed rainwater catchments and an island constructed in the lagoon specifically for groundwater production.

6.6.1 Option 5: Seawater RO desalination

Previous water supply projects for South Tarawa rejected the use of seawater RO desalination to supplement water supply because of its cost, energy consumption (Metutera, 2002), and complexity, as well as the short lifetime of many RO units in the Pacific and in Tarawa. The raised island of Nauru has successfully run a seawater RO plant for 10 years, supplying a major proportion of its potable water needs. One of the strategies used there is to contract out maintenance and technical services for their RO plant.

Two cases have been examined here to estimate the applicability of RO to meet the water needs of Tarawa. In the first, option 5A in Table 12, published data was used to estimate the costs and suitability of two 1,000 kL/day seawater RO plants, which could be position close to areas of maximum demand in Betio and Bairiki. In the second, option 5B in Table 12, information was obtained from a commercial supplier, who proposed a system of four 20 foot shipping containers each containing three 184 kL/day modules (each container producing 552 kL/day)[5] with a total production of 2,200 kL/day. The advantages and disadvantages of these two systems together with indicative costs are listed in Table 12**.** Here it is suggested that maintenance, training of staff and technical advice be contracted out to the supplier of the RO systems. In the case considered, although RO plants sterilise the water produced, the water then moves through pipelines and into storage tanks that may be contaminated. Because of that, treatment plants have been included downstream of the storage tanks.

The great strengths of the RO systems is they can be installed and started quickly, are of small size, do not require lengthy negotiations with communities or excessive land rental payments, and can be installed close to areas of most need.

6.6.2 Option 6: Large scale, constructed rainwater harvesting and collection

The rainwater catchment analysis performed as part of the rainwater component of this plan (White, 2009c) reconfirmed previous studies (Shalev, 1992) that rainwater harvesting in Tarawa is only able to supplement a small component of water supply, due to the frequent, severe, ENSO related droughts in Tarawa. In order to sustainably supply 2,000 kL/day with zero risk of failure, using the historic rainfall data, a constructed roof catchment area of 5 km^2 is required coupled to storage tanks with total capacity of a massive 200,000 kL. Both are almost impossibly large in a small island situation.

If a 5% risk of failure is accepted, then the required roof area is reduced to 1.4 km^2 for the total storage capacity of 200,000 kL and a supply rate of 2,000 kL/day. The advantages and disadvantages of large scale constructed rainwater catchments are summarised in Table 12 together with the massive indicative costs.

6.6.3 Option 7: Constructed island for groundwater production

In this option, it is proposed to construct an island 1.3 km in diameter by dredging up lagoon sediments and natural accretion to the west of the islands of Tabiang and Marenanuka in North Tarawa (Figure 3). The island would be government-owned and would eventually produce, when a freshwater lens developed, approximately 2,100 kL/day from 25 installed infiltration galleries. The advantages and disadvantages of large scale constructed rainwater catchments are summarised in Table 12 together with the massive indicative costs.

6.7 Cost of Land Rental Payments for Water Reserves

The current water reserves in South Tarawa were declared over land that was privately owned. This has been highly controversial and has generated long standing disputes between authorities and land holders and their communities. Although the PUB regulations allow the compulsory purchase of land for water reserves, this has never been used by the GoK because of the fundamental importance of land ownership in Kiribati. Instead, the GoK currently pays impacted landowners a land rental of $A5,000/ha. For the existing Bonriki and Buota water reserves the total annual payment is $A575,550. If the groundwater options in the North Tarawa islands of Abatao, Tabiteuea, Buariki and Taratai are pursued, the estimated land rentals there would be $A550,000 which would bring the total land rental up to over $A1.1 million/year. This is a major cost imposition on the water supply system and the GoK.

The unit production costs of the above water supply options will now be compared.

[5] The help of Mr P. Battey of Veolia Melbourne, Vic, is gratefully acknowledged.

7. Comparison of Unit Production Costs of Options

In order to compare the cost effectiveness of the water supply options in section 6, their unit production costs will be compared using the Capital Recovery Factor (CRF)[6] to estimate annual capital costs, A ($/year), from total capital costs, P ($), over a period of n years with an interest rate, i.

$$A = P \times CRF \qquad [1]$$

where $$CRF = \frac{i \times (1+i)^n}{(1+1)^n - 1} \qquad [2]$$

The unit production cost, UPC ($/kL), for a water supply option producing W_a kL/year is

$$UPC = \frac{A + OM + R}{W_a} \qquad [3]$$

where OM is the estimated annual operations and maintenance costs and R is other annual expenses including, where applicable, land rental, assumed her constant at $A5,000/ha. In estimating the CRF, the TWMP has assumed an interest rate of 8% ($i = 0.08$) and has taken the period n to be the assumed lifetime, or amortisation time, of the option.

The UPC for the water supply options in section 6 are compared in Table 13 with the current UPC for the existing operations, maintenance and rental costs of water production from the Bonriki and Buota. This cost, however, is artificially low since it does not include the capital costs of the existing system.

Several features are evident in Table 13. UPCs for the groundwater options have been calculated for different water loss rates for water delivered to consumers. It is clear that the estimated current rate of leakage imposes major cost penalties on supplying water. This emphasises the importance of lowering water losses as the highest priority. It is also evident from the table and from equations [1] to [3] that the lifetime, or amortisation time, of the option makes a major impact on its UPC, particularly for RO desalination. Maximising the lifetime of infrastructure is difficult in harsh tropical environments, but it should be a key management objective.

7.1 Conclusions from the Comparison of UPCs

The comparison of unit production costs in Table 13 shows that seawater RO desalination is the most cost effective option, provided that it remains operational for 10 years. The experience in the Pacific and in Kiribati suggests that this is difficult. Contracting out the training of operators, maintenance of units and the provision of technical advice to system manufacturers significantly increase their lifetime.

The other significant advantages of seawater RO desalination over the groundwater options are that: they can be installed and operated rapidly; they can be located close to areas of highest demand; there small size means that negotiations with land owners and communities as well as land rental payments are minimised; an EIS may not be required; and they produce pathogen-free water.

The major disadvantage of seawater RO desalination is the energy cost. Other governments around the world have offset the energy costs by installing renewable sources of equivalent energy, such as wind generators. In Kiribati, there is also the potential to use coconut oil as a direct diesel substitute.

Its is re-emphasised that before any new sources of water are introduced in South Tarawa, the rate of water loss from the reticulation system and the factors contributing to those losses need to be addressed.

Table 13 Comparison of unit production costs (UPC) for Tarawa water supply options

[6] The estimates of CRF and UPC were kindly supplied by Mr A Falkand.

Option	Description	Production (kL/day)	Assumed Lifetime (yr)	Other details	UPC ($/kL)	Comments
	Current GW production from Bonriki and Buota	2,010	Not specified, assume 20	Current system, no capital costs included, no losses assumed	3.60	Metutera (2002) needs to be updated with capital costs
1	Increased GW production at Bonriki from tree removal	250	20	No losses assumed	2.98	Lowest cost option but limited increase in production
				25% losses assumed	3.97	
				50% losses assumed	5.95	
2	Increased GW production at Bonriki from infilling ponds & constructing more galleries	250	20	No losses assumed	5.74	Considerably more costly than clearing trees but still less than North Tarawa groundwater options
				25% losses assumed	7.65	
				50% losses assumed	11.48	
3	Groundwater production from Abatao and Tabiteuea	220	20	No losses assumed	7.39	
				25% losses assumed	9.86	
				50% losses assumed	14.78	
4	Groundwater production from Buariki & Taratai	1,530	20	No losses assumed	7.72	Generally similar unit costs to those for Abatao and Tabiteuea
				25% losses assumed	10.30	
				50% losses assumed	15.45	
5A	Desalination (RO) production (using published data)	2,000	2	Only production costs and no distribution costs	18.88	Cost very dependent on assumed lifetime
			5		8.43	
			10		5.02	
			2	Distribution costs using existing system added in. No losses assumed; use "no losses" sub-options above to compare with this & other options below	21.66	
			5		11.22	
			10		7.80	
			2	Distribution costs using main pipes & tanks + tankers. No losses assumed	21.79	
			5		11.34	
			10		7.93	
5B	Desalination (RO) production (based on cost estimates from Veolia)	2,200	2	Only production costs and no distribution costs	6.10	Cost very dependent on assumed lifetime, but best option if life time is 10 years
			5		3.32	
			10		2.41	
			2	Distribution costs using existing system added in. No losses assumed	8.89	
			5		6.10	
			10		5.19	
			2	Distribution costs using main pipes & tanks + tankers. No losses assumed	9.01	
			5		6.23	
			10		5.32	
6	Large scale rainwater collection and storage	2,000	20	No losses assumed	22.67	Most expensive option
			50		18.26	
7	Constructed island	2,100	20	Lower limit cost for fill; no losses	8.15	Costs would be less if at least some of the island was constructed by natural accretion
				Upper limit cost for fill; no losses	9.94	
			50	Lower limit cost for fill; no losses	7.32	
				Upper limit cost for fill; no losses	8.76	

Legend

Green	UPC < $5.00
Cyan	$5.01 < UPC < $10.00
Yellow	$10.01 < UPC < $20.00
Red	UPC > $20.01

8. Sustainable Management of Tarawa's Freshwater Resources

The background documents for the TWMP (White *et al.*, 2008; White 2010a,b; 2011a,b) have identified a range of management issues which need to be addressed to sustainably manage Tarawa's freshwater resources into the future. Recommendations are made in the following on these issues.

8.1 Water Legislation

Although various water laws and regulations exist, there is no unified and comprehensive fresh water resources law. The rights and responsibilities of water users and management agencies are not fully legally defined and there are questions as to the adequacy of protection of freshwater sources. As part of the UNDP/UNCDF Outer Island Water Supply Project, the UN Interregional Advisor on Water Legislation, Mr. Miguel Solanes, developed a draft Kiribati Water Resource Management Act in 1992 and submitted it to Attorney Generals. It has never been submitted to Cabinet or to the Maneaba-ni-Mangatabu for adoption.

As a matter of urgency, the 1992 draft national water legislation should be reviewed together with all relevant water legislation, necessary revisions completed and the revised draft legislation submitted to Cabinet.

8.2 Whole-of-Government Approach to Water Management

The *Directions Assigning Ministerial Responsibility* (5 August 2003) specify the following line Ministerial key responsibilities in water:

- Minister for Public Works and Utilities – water management; sewerage systems
- Minister for Health and Medical Services – health inspectorate services and environmental health
- Minister for the Environment, Lands and Agricultural Development – environment and conservation; waste and pollution management.

Water resource management in Tarawa however involves other important government bodies such as the Kiribati Meteorology Service and the National Economic Planning Office, Ministry of Finance and Economic Development. The National Water and Sanitation Coordination Committee, NWSCC, was set up to provide a systematic, whole-of-government coupled to non-government community organisations approach to water resource management. Its aim is: to share information; to develop a whole-of-government approach to water issues; to monitor progress of the NWRP and the NWRIP; to assess the availability and condition of water resources; and to report regularly to government. To date, there has been limited progress on these functions.

It is recommended that the NWSCC develop and implement a work plan. Because of the fundamental, national importance of water and the fact that it is a whole-of-government issue, it is also recommended that the NWSCC be placed under the control of Office Te Beretitenti to improve reporting to Cabinet and to ensure progress of the NWRIP.

8.3 Vision for Tarawa

Tarawa is separated into two distinct zones. South Tarawa (including Buota) is a highly urbanised area whose population growth rate over the past 25 years has been well above the national average growth rate, augmented by inward migration from rural areas and outer islands. North Tarawa (excluding Buota), although growing at greater that the national rate, remains largely rural. The greatest and most immediate threat to the availability and safety of water supplies in South Tarawa is its growing population.

The estimated sustainable yields of safe freshwater sources in South Tarawa are inadequate for its current population. This situation will worsen over the next 20 years as the population grows. North Tarawa, in sharp contrast, has more than sufficient water for its communities now and will have adequate supplies in the future, provided population growth rates remain at the average rate there over the past 25 years. If the available water resources in North Tarawa were shared with South Tarawa, then the reasonable water demands of all of Tarawa could be met until almost 2020, provided the water losses from the reticulation are reduced to reasonable rates. Development of groundwater sources in North Tarawa, however will change the character of North Tarawa and may not be welcomed by communities there. Much of the future needs will be dependent of whether there will be plans to limit the population growth in South Tarawa.

It is recommended that the GoK clearly articulate its vision for the future development of Tarawa and develop plans to work towards the realisation of that vision.

8.4 Protection of Groundwater Reserves

The Laws of the Gilbert Islands, 1977 declared water reserves on South Tarawa in Betio, Tearoraereke, Nawerewere to the east of Bikenibeu and Bonriki for the purpose of public water supply from the groundwater lenses in these islands. Buota, in North Tarawa, was subsequently declared a water reserve. Increased settlement at Betio forced the early abandonment of this reserve and Tearoraereke (Figure 1) was similarly abandoned by 1987. The site east of Bikenibeu was relinquished for construction of the Tungaru Central Hospital, completed in 1991.

The Public Utilities Ordinance, 1977, under the Public Utilities Board (PUB) Act, 1978, prohibit settlement on water reserves and allow eviction of existing dwellers and land owners from the declared reserves by the PUB. This regulation is highly contentious, since land is the principal form of wealth, sustenance and identity in Kiribati, and is a continuing source of tension and disputes between affected land owners and the Government, which sometimes leads to vandalism of infrastructure. The regulations under the PUB Act allow for the compulsory purchase of land on water reserves. Compulsory purchase is an anathema and has never been used for water reserves. Instead the GoK, through MELAD, pays commercial rents to land owners in Bonriki and Buota for the use of land in water reserves.

The abandonment of the water reserves in Betio and Tearoraereke emphasises the contentious nature of the water reserve regulations, the general reticence to enforce them and the scarcity of available land for settlement in South Tarawa. Encroachment by settlers and squatters on the existing water reserves at Bonriki and Buota is accelerating, despite the regulations, because of South Tarawa's ever-increasing population and scarcity of land. Abandonment of these water reserves, the main sources of safe, treated water in Tarawa is not an option. Continued settlement greatly increases the risk of a severe disease outbreak, such as the 1977 cholera outbreak. One significant problem in addressing the problem of settlement on the reserves is that there are several agencies, such as PUB, WEU in MPWU, Lands and Environment and Conservation Division in MELAD and MHMS who have some responsibility for management. The lack of a clear definition of responsibility is a recipe for inaction.

It is strongly recommended that: the protection of groundwater reserves be recognised as being of high priority in maintaining and improving the public health and safety of communities in South Tarawa; that a single agency be given the responsibility of preventing encroachment, inappropriate use and improving management of water reserves; that settlements be removed from water reserves; and that only land uses which do not pose a risk to groundwater quality be allowed.

8.5 Monitoring of Water Resources

The water resources of Tarawa are scarce and vulnerable to both human and natural impacts. The improved management of the fragile water resources in Tarawa is complex and requires accurate information on the quantity and quality of rainwater and groundwater in Tarawa, on the rates of extraction and use, on the impacts of climate variability and land use, and on the public health and environmental impacts of the water supply system. Monitoring of the resource, its use and impacts and the analysis of data and the regular reporting of that analysis to GoK are critical to improving management of water in Kiribati.

It is recommended that a comprehensive water resources monitoring and reporting plan be developed along with the resource requirements and organisational responsibilities for ensuring that good quality information, necessary for managing water in Tarawa is available

8.6 Payment of Land Rental in Groundwater Reserves

The TWMP has shown that the current land rentals paid to owners of lands in water reserves impose a major financial burden on the GoK and distorts the operational cost of water supply in South Tarawa. Despite these payments, increased settlements on and misuse of reserves, and vandalism of infrastructure continues.

It has long been suggested that rental payments be tied to reserve management objectives, so that the landowners be paid as custodians of water reserves with responsibilities for managing and protecting water reserves and infrastructure. In this model, failure to meet land management objectives would result in decreased payment. This provides incentives for landowners to participate in management of reserves and improve protection of reserves.

It is recommended that the payment of land rentals to land owners in water reserves be linked to land management criteria

8.7 Committee for the Management and Protection of Water Reserves

In order to control encroachment of settlers onto water reserves a community-government Committee for the Management and Protection of Water Reserves was established in 2000 as a lead-in to the SAPHE project. This Committee had community representatives from Bonriki and Buota villages, from Tarawa *unimwane* and representatives of government agencies. It appears that the Committee never met and has certainly been defunct for some time.

It is recommended that the community-government Committee for the Management and Protection of Water Reserves be re-established and supported.

8.8 Sustainable Groundwater Pumping Rates

Accurate estimates of the sustainable pumping rates from Bonriki and Buota have been established for the historic rainfall record. These permit continuous groundwater pumping without seriously depleting the groundwater resource. Pumping at greater than the sustainable rate during long droughts has the potential to salinise the groundwater lens at a time when freshwater is most in demand. Since 2004, following the SAPHE project, pumping at Bonriki has been significantly above the sustainable rate and some evidence of increases in salinity have been observed (White and Falkland, 2010). The failure of the pipeline from Buota in June 2008, has meant that there were pressures to continue the higher rate of pumping from Bonriki

It is recommended that the groundwater pumping rate from Bonriki be reduced to the sustainable rate as soon as practical.

8.9 Control of Water Losses

The total water lost from the supply system in South Tarawa is unknown but it is believed to be as high as 50%. The major portion of losses appears to occur in the domestic supply system to households. This involves enormous daily waste of a precious resource, doubles unit production costs, incurs costs of around $A1.3 million/year, diminishes the supply of water available to communities along South Tarawa and means that the supply system can only be operated intermittently. There is no point in augmenting the water supply in South Tarawa through introduction of new water sources if the current leakages are allowed to persist.

It is recommended as matter of highest priority that the water losses from the reticulation system be reduced to the target level of 25% or less. As a contingency plan, excessively leaky portions of the system should be isolated with water needed by households being supplied by bulk distribution.

8.10 Demand Management

There are long-standing cultural and social customs in Kiribati that make demand management a difficult issue. These, however, have led to a situation in water supply where the distribution of water in South Tarawa is inequitable, where wastage is encouraged and anti-social and even illegal actions are condoned, and where the water supply system is not financially sustainable.

The only mechanism presently available to the PUB to control demand is to supply piped water intermittently to various regions in South Tarawa for a brief time every two or three days. This has three disadvantages: households leave taps open to collect water in containers, so losses are high; customers are very reluctant to pay for an intermittent water supply; and intermittent supplies are prone to bacterial build-up in supply lines.

One problem faced in introducing water tariffs in Tarawa is the number of households with limited capacity to pay for water. Metering consumption of water and tiered charging appear the only sensible and equitable means of controlling excessive demand provided that it is well managed and contains measures to provide for the disadvantaged.

It is recommended that installation of water meters should be considered in any upgrading of the domestic distribution system and that a system for discouraging wasteful use of water be introduced.

8.11 Cost Recovery

The public freshwater supply system in South Tarawa is financially unsustainable with operations and maintenance costs far exceeding revenue. This means that people in South Tarawa are being subsidised at the expense of communities in rural areas and that those who pay for bulk water deliveries are subsidising the majority who do not. This subsidisation of urban communities is one of the key drivers of the in-ward migration to South Tarawa. The metering of water supplied to householders and a tiered system of charging for water coupled with a transparent scheme for subsidising the disadvantage is one way of improving cost recovery.

It is recommended that a more equitable and financially robust method of cost recovery for water supply be developed and introduced.

8.12 Drought Contingency Plan

Long ENSO-related severe droughts, in which rain tank storages fail and many household wells in narrower islands become to saline to use, occur frequently in Tarawa. Despite their frequency, each drought is considered to be an exceptional emergency. A drought contingency plan should have the following elements:

- An effective early drought warning system (KMS currently has SCOPIC)
- A method of reporting drought risk to water Ministries, the PUB and Cabinet
- An effective public communication strategy about drought risk
- An effective public communication strategy about water conservation
- A strategy to isolate excessively leaking parts of the South Tarawa reticulation system and to supply water from fixed distribution points or by tanker
- A strategy to increase monitoring of groundwater and rainwater
- Ensuring that there are sufficient, well maintained water tankers to deliver water Increased frequency of monitoring of groundwater sources
- Ensure there is adequate legislative basis for emergency interventions

It is recommended that a drought contingency plan be developed and approved by the NWSCC and submitted to Cabinet for consideration

8.13 Improved Rainwater Use

The TWMP attempt to estimate current and potential use of rainwater was hampered by the lack of information on the characteristics of rainwater systems in Tarawa. In South Tarawa, over the past decade there has been a major increase in the installation and use of rainwater collection and storage systems, partly due to the increase in buildings with suitable roofs and partly to the SAPHE revolving fund for the purchase of rain tanks. There is a need for community education of the maintenance and operation of rainwater systems. Large public buildings, many financed by aid donors, continue to be build with, either inadequate rainwater collection and harvesting, or none at all. The building codes and regulation mandate the installation of appropriate rainwater collection in new buildings, but they are not enforced. Over thirty five years ago in South Tarawa there was a system of distribution rainwater collected from large government and community buildings which has long been defunct.

It is recommended that: a database be established and maintained on the location and characteristics of rainwater harvesting systems in Tarawa; a community education program on the installation, operation and maintenance of rainwater systems be developed[7]; a system for ensuring that the existing building regulation and codes detailing the installation of adequate rainwater systems in new buildings are enforced; and the potential and rules for communal rainwater distribution from large public buildings be explored and developed.

8.14 Safety of Household Wells

The TWMP was hampered by the lack of systematic information on the water quality of household wells in Tarawa. Because of that it was assumed that, except for toilet flushing, all household water used in South Tarawa has to come from treated reticulated water or rainwater. It is believed that polluted household wells may be responsible for the poor public health data in South Tarawa. *."* Shalev (1992), nineteen years ago, concluded "*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."* Monitoring of the quality of water currently being used from open or closed household wells is essential for reducing public health risk.

It is recommended as a matter of urgency that the water quality of representative household wells in Tarawa be monitored and reported.

8.15 Behavioural Change

South Tarawa is a highly urbanised society whose needs differ from the practices and traditions of lower-density, subsistence rural areas. Some of the problems evident in the water sector stem from this mismatch of practices. The activities of individuals, such as gravel mining on water reserves, can threaten the public health of entire communities. A gradual behavioural change is required. Short duration community awareness campaigns appear to have very limited effectiveness. What is needed is a long-term coordinated and continuing program, starting with the earliest aged school children and involving the church and community groups to bring about behavioural change and the recognition that all will benefit from cooperative, community-focussed actions. It is suggested that the following could be useful indicators for a behavioural change program:

1. Widespread recognition that fresh water is a scarce resource in Tarawa that must be conserved and used wisely
2. Widespread recognition that groundwater is easily polluted so that the community is involved in protecting sources of fresh water from contamination and misuse.
3. Widespread recognition of the rights of others to have equal access to good quality water so that our actions do not diminish the access to or quality of our neighbour's water.
4. Evidence that the next generation is being trained in these values

It is recommended that a long-term coordinated and continuing program be established to bring about behavioural change in the use and sharing of water, and in its protection and conservation. This program must include a comprehensive water education program for schools.

8.16 Training and Succession Planning

The issues faced in managing water in Tarawa are complex, wide-ranging and diverse, but there are very few adequately trained people to deal with them. In addition, the GoK policy on retirement at age 50 means that expertise is soon lost. It is important that a whole-of-government plan be developed for the training of staff in the water sector and a plan be developed for planning for their replacement.

It is recommended that a whole-of-government plan be developed for the training of staff in the water sector and a succession plan developed for ensuring passing on of expertise.

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[7] SOPAC has excellent educational materials on rainwater harvesting

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