Government of the Republic of Kiribati

Tarawa Water Master Plan:

Te Ran-Maitira ae Kainanoaki, Future Water Demand

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

Acronyms and Abbreviations

ADB	Asian Development Bank
AGDHC	Australian Government Department of Housing and Construction
AIDAB	Australian International Development Assistance Bureau
AusAID	Australian Agency for International Development
℃	degrees Celsius
GoK	Government of Kiribati
hh	household
ICI	institutional, commercial and industrial
IPCC	Intergovernmentall Panel on Climate Change
KAP	Kiribati Adaptation Program (Phases I, II & III)
KHC	Kiribati Housing Corporation
km	kilometre
km^2	square kilometre
kL	kilolitre (one thousand litres = 1,000 L = 1 m^3)
kL/day	Kilolitres per day
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^3	cubic metre
ML	mega litre (one million litres = 1,000 kL =1,000 m^3)
ML/day	mega litre per day
MLPID	Ministry of Line and Phoenix Island Development
MPWU	Ministry of Public Works and Utilities
NASC	National Adaptation Steering Committee
NGO	non-government organisation
NSO	National Statistics Office
NWRIP	National Water Resources Implementation Plan
NWRP	National Water Resources Policy
NZAID	New Zealand International Aid and Development Agency
NWSCC	National Water and Sanitation Coordination Committee
OB	Office Te Beretitenti (the President)
OEC	Original Engineering Consultants Co. Ltd. (Japan)
OICWSP	Outer Islands Community Water Supply Project
pers	person
pers/km^2	persons per square kilometre
PUB	Public Utilities Board (within MPWU)
RDI	Richards and Dumbleton International
RO	reverse osmosis
SAPHE	Sanitation, Public Health and Environment Improvement Project
SOPAC	Pacific Islands Applied Geoscience Commission
ToR	terms of reference
TWSP	Tarawa Water Supply Project
TWMP	Tarawa Water Master Plan
UNEP	United Nations Environment Programme
UNDTCD	United Nations Department of Technical Corporation for Development
UNICEF	United Nations Children’s Fund
WB	World Bank
WEU	Water Engineering Unit (within MPWU)
WHO	World Health Organisation
WMO	World Meteorological Organisation

Summary

The Tarwa Water Master Plan, TWMP, is a direct response to the Government of Kiribati's National Water Resources Policy and its accompanying Implementation Plan. This component of the TWMP focuses on estimating future demand for water in Tarawa over the next 10 to 20 years. Tarawa is an island in transition from largely subsistence, rural lifestyles, still followed in North Tarawa, to high-density, urban living in South Tarawa. Over the last 50 years, demographic and socio-economic factors have changed dramatically. This means that the traditional adaptation strategies developed over 4,000 years of subsistence in small islands are largely ineffective in coping with the demands of a modern densely-populated urban society and Tarawa's highly variable climate.

Water sources

Examination of water sources used by people in Tarawa shows a wide variety of sources of water in current use: local groundwater in shallow, vertical household wells or bores, close to the household; piped or reticulated water, treated and supplied by the PUB from groundwater reserves at Bonriki and Buota; rainwater mostly stored in household raintanks; bottled water both imported and produced locally, and seawater for bathing and toilet flushing. The 2005 Census data shows that households use multiple sources of water to supply their needs with currently only two thirds accessing the treated PUB supply. Over 50% of households in South Tarawa still use open household water wells for drinking water, despite the risks of health impacts due to overcrowding. In North Tarawa that percentage is over 80%, close to other Gilbert Group islands.

An analysis of the trends of water source usage from 1990 to 2005 revealed that there has been a decrease in the percentage of households using the PUB piped treated water and an increase in the percentage of houses using open household wells in South Tarawa. Since the risk of contamination of domestic wells is high, these trends indicate increased risks of adverse health impacts. The percentage of households using rainwater has increased significantly since 2000. This appears to be due to the SAPHE Project revolving fund for the purchase of raintanks and also possible due to the impacts of the 1998 to 2001 drought.

Estimating water demand

Past estimates of design demands used in previous water supply projects in South Tarawa, based on assumptions about the quantity of water required to meet domestic and other needs, were examined. It is very difficult to estimate the total fresh water demand in Tarawa due to the following factors:

- little reliable data on the actual freshwater use by households
- very little quantitative data on use of household well water
- no database on extent of rainwater collection and use
- no metered household consumption figures
- almost no published information on ICI water use
- no flow monitoring at connections in the piped water systems, and
- high but unmeasured leakage in piped systems, particularly the urban distribution systems in South Tarawa.

Faced with this difficulty, the approach adopted in the past by a range of water supply projects over the past 36 years has been to assume a design target per capita demand in line with assumed estimates of minimum quantities required for consumption, cooking and hygiene. These estimates have ranged from about 6 to 100 L/pers/day and some have involved estimates of water requirements depending on the type of house being supplied and the availability of rainwater tanks. The SAPHE Project, completed in 2005, even assumed that only a fraction of households were to be supplied with treated piped water. Many estimates have been based simply on how much water is currently available without considering actual household needs. The earliest estimates in Tarawa are small and irrelevant to modern Tarawa.

Actual household use and design demand

Only three separate estimates of the actual amount of water consumed by households in Kiribati were found: an early set of measurements in Betio; more recent estimates in the outer island of Nonouti and in the rural, semi-urban and urban villages in Kiritimati. The Betio estimates are discounted because the situation in Tarawa has changed dramatically since then. The Nonouti and Kiritimati data were then used to estimate the domestic per capita demands in North and South Tarawa. Previous studies have pointed out that it is extremely risky to continue to use household wells for water supplies in South Tarawa, due to overcrowding and sanitation practices. It was therefore assumed that all household water needs in South Tarawa except toilet flushing would be met from the piped water system. To these

estimates were added assumed water requirements for ICI uses which were assumed to be 10% of domestic demand. No piped water was assigned to irrigation or toilet flushing in South Tarawa.

Estimated future populations

Three population growth models were used to estimate future populations. The first, exponential model assumed that the exponential growth rates for North and South Tarawa between the 2000 Census and the 2005 Census[1], using 2005 as the base year, would continue into the future. In this model South Tarawa grows very slightly faster (1.9%) than the total Kiribati population (1.8%) while North Tarawa continues to grow much faster (4.8%) than the national rate. By 2030, the population in South Tarawa plus Buota is 69,400 and in North Tarawa minus Buota the population is 14,300. The second linear percentage model assumes that there will be limits to the continued growth in South and North Tarawa. This assumes that the percentage of the total population living in South and North Tarawa grows linearly at the rate between 2000 and 2005 but that the total population of Kiribati continues to grow exponentially. In this model, by 2030, the population in South Tarawa plus Buota is 66,300 and in North Tarawa minus Buota is 11,000.In the third, conservative estimate the “South Tarawa Full” model, it is assumed that South Tarawa is so overcrowded that it no longer attracts outer islanders or local residents. In this model, the population slowly increases linearly from 2005 to only 52,000 people in 2030 while North Tarawa continues to grow exponentially with a projected population of 9,900.

Estimated required future water production

With these three population growth models and an assumed water loss rate of 50% it is estimated that the water production required to meet the assumed demand and pipe water losses in South Tarawa in 2030 will range from between 7.1 and 9.4 ML/day. The last rates are 3.5 and 4.7 times the sustainable yield of the current treated water sources in Bonriki and Buota (2.0 ML/day). If the water losses can be reduced to 25%, the estimated water production range needed to meet the assumed demand and water losses in South Tarawa by 2030 will range from 4.7 to 6.2 ML/day. The required production rates are 2.4 to 3.1 times the sustainable yield of the current treated water sources in Bonriki and Buota. The importance of reducing leakage as a high priority is clearly evident.

Sustainable South Tarawa population

Using the sustainable yield for the combined Bonriki and Buota water reserves and the estimated water requirements in South Tarawa and Buota an estimate was made of the population that can be sustained safely by the current water sources. For 50% water loss rates the population is 14,700 while for 25% loss rate the population is 22,000. These are about a third and a half respectively of the current population in South Tarawa. The biggest threat to sustaining the population in South Tarawa through variations in climate is the number of people in South Tarawa. That threat will only intensify if the expected population growth occurs in the next 20 years. North Tarawa, in contrast has adequate groundwater for the foreseeable future, provided resources are protected from contamination.

Controlling demand

Tarawa is a freshwater-scarce atoll yet it has almost no equitable ways to control water demand. At present, the only means available to control demand is through the intermittent supply of free water. This is less than satisfactory. It encourages waste and does not control profligate use so there are great inequities in water availability. Metering consumption of water and tiered charging appears the only sensible means of controlling excessive demand provided that it is well managed and contains measures to provide for the disadvantaged. By far the most profligate consumption of water is through leakages from the reticulation system, particularly the domestic reticulation system. Minimising excessive leakage from local piped distribution systems is the highest priority task. Until leakage can be better controlled, consideration should be given to closing down excessively leaking sections of domestic reticulation systems and reverting to distribution from centrally-located storages or tankers for which a charge is made. The possibility of imposing a Tarawa household tax to pay for the extra services provided there and to act as a disincentive for further migration to Tarawa could also be considered. In addition, the legislative basis for managing water in Kiribati should be reviewed and strengthend or replaced.

[1] At the time of finalising this report (Decembet 2010), population returns from the 2010 national census for North and South Tarawa were unavailable.

Information Gaps

This component of the TWMP has estimated the future water demand in Tarawa. The estimates here have been hampered by a lack of knowledge in key areas including:

1. There is no information on the current average amounts of household use of water from various sources in Tarawa.
2. There is very little information on the quality of household well water in Tarawa.
3. There is no information on total pipeline water losses from the urban piped distribution systems in South Tarawa.
4. Although the National Statistic office (NSO) has projected future population numbers for Kiribati as a whole for a number of assumptions there appear to be no published projected population numbers for South and North Tarawa
5. The impact of climate change on future demographics and water demand are unknown.

This lack of information makes the development of a soundly-based Tarawa Water Master Plan difficult.

Assumptions

The main assumptions underpinning this component of the TWMP are outlined below

Half the household wells in South Tarawa have groundwater that is too polluted for use
Previous studies in South Tarawa have identified the risk in crowded areas of using local wells for general use. There is currently no systematic monitoring of local, domestic well water quality. It has been assumed that 50% of local household wells are unsafe for general use. This does not preclude local well water from being used for toilet flushing and, where not too saline, for irrigation.

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.

No piped freshwater is 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 watse water sources from the piped supply.

No piped freshwater is 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.

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.

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, 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 PUB Business Plan 2004-6.

Summary of the components of water demand used in the TWMP

Component	Demand (L/pers/day)		Comments
	South Tarawa	North Tarawa	
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 sewater 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
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%	

Estimated ranges of populations using water from the South Tarawa (including Buota) water supply system and wells in North Tarawa (without Buota)

Year	Lower Bound Population for Water Supply			Upper Bound Population for Water Supply		
	South Tarawa*	North Tarawa†	Tarawa	South Tarawa*	North Tarawa†	Tarawa
2005	**41,684**	**4,305**	**45,989**	**41,684**	**4,305**	**45,989**
2010	43,800	5,160	48,960	46,040	5,460	51,500
2020	47,850	7,470	55,320	56,130	8,770	64,900
2030	52,000	9,930	61,930	68,870	14,030	82,900

* Includes Buota † Does not include Buota

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1 Introduction

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 in a highly variable climate.

The geographical, hydrologic, climatic, and current demographic and socio-economic factors in Tarawa combine to make water issues amongst the most complex in the world. Droughts related to La Niña events are common and safe freshwater is often scarce so water resources have to be protected and used carefully. Increasing impacts of human settlement and particularly sanitation, the vulnerability of freshwater sources in low, small islands to climate change, variability, and storm surges coupled to the links between development, poverty alleviation, health and safe water availability require continued leadership by the government and commitment by government agencies and the community to protect, conserve and use wisely the nation's water resources. The endorsement in January 2009, of the National Water Resources Policy (NWRP) and its accompanying 10-year National Water Resources Implementation Plan (NWRIP) by Cabinet of the Government of Kiribati (GoK) is an important response to wide-spread concerns over freshwater.

1.1 Freshwater, a major concern for I-Kiribati

A lead-up study to the Asian Development Bank (ADB) Sanitation, Public Health and Environment (SAPHE) project, carried out an extensive household survey in South Tarawa on water supply, sanitation, and waste collection as well as a number of additional socio-economic in Tarawa (ADB, 2000). The survey, undertaken in 2000, covered 68% of all households. In one question, the survey asked households to identify problems that were affecting them. While the top ranked problems changed depending on location[2], the top five overall, priority problems were: insufficient clean water (35%); sanitation (31%); too many people (31%); health/access clinics (29%); and transport (29%). Economic issues, such as not enough jobs (17%), were of much lower priority.

When asked about whether the quality of piped water supplied by the PUB should be improved, 89% of all households surveyed responded yes, 7% no and 3% did not know[3]. The responses to this survey highlight the fundamental concerns about water and health in Kiribati generally and in South Tarawa particularly.

As part of the National Adaptation Program of Action conducted during the Kiribati Adaptation Project Phase I, extensive consultations were held throughout the Gilbert Group in 2002-3 to determine priority strategies for adapting to the predicted consequences of climate change (World Bank 2006). What emerged from these consultations were not so much adaptation strategies but a prioritised list of major concerns of I-Kiribati. In the top ten identified priorities, seven were water and sanitation related:

- Water pumps/pipes to get water from good sources to settlements and homes
- Protect water wells
- Assess and locate available water on the islands
- Water conservation at home (including awareness raising)
- Improve sanitation, construct toilets
- Water conservation in piping systems
- Install rainwater tanks

[2] The survey split South Tarawa up into Betio, Bairiki, Bikenibeu and rural Tarawa. Comparing South Tarawa with North Tarawa, none of South Tarawa could now, or then, be considered rural.

[3] Care must be taken in interpreting survey results in Kiribati as I-Kiribati tend to believe that it is impolite to give an answer to a question which they perceive may not make the surveyor happy.

These strategies fall into three categories: make use of a variety of safe water sources; protect freshwater sources particularly from human and animal wastes; and conservation of water by the community, industry and government agencies. They reflect widespread concern throughout Kiribati over freshwater.

1.2 Demand Component of the Tarawa Water Master Plan

The World Health Organisation (WHO, 2006) Guidelines for Drinking-water Quality emphasise that "*the quantity of water collected and used by households has an important influence on health. There is a basic human physiological requirement for water to maintain adequate hydration and an additional requirement for food preparation. There is a further requirement for water to support hygiene, which is necessary for health."* This fundamental need is the basis for the NWRP and NWRIP.

The TWMP is a direct response to the NWRP and NWRIP. It aims to provide a strategic plan for the development of water resources in Tarawa over the next 10 to 20 years. Its scope is the development, management, protection and monitoring of fresh water resources in Tarawa taking account of all available water resources (primarily groundwater and rainwater) and possible additional sources. Somel information necessary to develop a soundly-based Plan is not available at the time of writing. It will therefore be necessary to update this Plan once information becomes available.

This component of the TWMP examines the difficult issue of the projected future demand for freshwater in Tarawa.

2 Components of Water Demand

It was recogised over 35 years ago that the limited quantity of freshwater in South Tarawa meant that potable water could not be used for toilet flushing. Instead systems were developed which used seawater or local household well water. That is still the case and this component of the TWMP assumes that potable water will not be used for tolet flushing in Tarawa in the future.

There are five main components to water demand in Tarawa: household demand; and demand from institutional, commercial, and industrial, ICI, users and unaccounted for water losses from the distribution system.

Household demand depends on:

- Number of people per household, and
- Demand per person or per capita demand.

While the number of people and the population growth rate in Tarawa is available from the 2005 Census results published by the National Statistics Office (NSO, 2007a; b) the per capita demand is not.

The ICI users consist of:

- Schools
- Hospitals and clinics
- Government ministries and local government
- Maneabas
- Churches
- Hotels and guesthouses (tourism)
- Commercial premises
- Industries

Again there is very little information available on the amount of water used by these ICI sectors. The average supply to Tungaru Central Hospital over the period 2004-8 was 39.2kL.day (White *et al.,* 2008). It is, however, clear from previous water supply projects that the largest component of freshwater use in Tarawa is household consumption.

It is very difficult to estimate the expected total freshwater demand in Tarawa due to the following factors:

- little reliable data on the actual freshwater use by households
- very little quantitative data on use of household well water
- no database on extent of rainwater collection and use
- no metered household consumption figures
- almost no published information on ICI water use
- no flow monitoring at domestic connections in the piped water systems, and
- high but unmeasured leakage in piped systems, particularly the urban piped water distribution systems in South Tarawa.

Faced with these difficulties, the approach adopted by a range of water supply projects over the last 35 years has been to assume a design target per capita demand in line with assumed estimates of minimum quantities required for consumption, cooking and hygiene. These estimates have ranged from about 6 to 100 L/pers/day . Some have involved estimates of water requirements depending on the type of house being supplied and the availability of harvested rainwater.

The total water requirements have then been estimated from the chosen per capita demands and the expected total population with an allowance added for ICI water use and the estimated water losses from the system. Many of the previous estimations have been largely based on what the available water supply systems could supply rather than what the population needed.

Before examining previous estimates of demand, the sources of water used in Tarawa will be examined in the following section.

3 Current Sources of Water in Tarawa

3.1 General Water Sources

The current sources of water used in Tarawa are:

- Local fresh and brackish groundwater in shallow, vertical household wells or bores, close to the household
- Piped or reticulated fresh groundwater treated and supplied by the Public Utilities Board (PUB) in South Tarawa from groundwater reserves at Bonriki and Buota
- Rainwater harvested from roofs and mostly stored in household and institutional rain tanks
- Bottled water both imported and produced locally by desalination, and
- Seawater

Seawater is used both for bathing and washing and also as flushing water in the piped sewerage systems at Betio, Bairiki and Bikenibeu, which are accessed by about a third of South Tarawa's households in 2005 (NSO 2007a). The following concentrates on sources of freshwater. Desalination of seawater by reverse osmosis (RO) has been used in the past in Tarawa and elsewhere in Kiribati. There are currently no publically-owned, operating RO plants in Tarawa.

3.2 Sources of Household Drinking Water

The 2005 Census (NSO, 2007a, Table H36) provides details of the sources of drinking water used by households in North and South Tarawa and in Kiribati as a whole (Table 1). The percentages of households accessing different sources of drinking water in North and South Tarawa compared with those in other Gilbert Group islands(Tarawa excluded) are listed in * Closed wells are genered raised wells with a cover

Table 2 and also shown graphically in Figure 1.

Firstly, from Table 1 and * Closed wells are genered raised wells with a cover

Table 2 it is obvious that households use multiple sources for drinking water, even in urban South Tarawa since the percentages add up to more than 100%. Secondly it is also apparent from Figure 1 that the water use pattern in urban South Tarawa is quite different to rural North Tarawa and to other Gilbert Group islands, which are similar to North Tarawa. In South Tarawa, 54% use open household wells as a drinking water source, despite 67% of households accessing PUB piped water, indicating that the piped water system is insufficient to meet demand. In North Tarawa, 87% of households used open household wells while only 1.6% of households in North Tarawa use piped water, and this presumably is only in Buota.

Table 1 Sources of drinking water in Tarawa compared with all of Kiribati (NSO, 2007a)

Location	Number of Households	Rainwater	Piped Water	Open Wells	Closed* Wells	Bottled Water
South Tarawa	5,245	2,243	3,512	2835	949	199
North Tarawa	867	105	14	757	170	8
Total Tarawa	**6,112**	**2,384**	**3,526**	**3,592**	**1,119**	**207**
Total Kiribati	**13,999**	**3,483**	**4,299**	**9,763**	**2,988**	**269**

* Closed wells are genered raised wells with a cover

Table 2 Percentage of households in Tarawa using different sources of drinking water compared with other Gilbert Group islands for the 2005 Census

Location	Number Households	Percentage of Households (%)				
		Rainwater	Piped Water	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

Approximately the same percentage of households in North Tarawa (20%) and South Tawara (18%) use closed household wells as sources of drinking water. These closed wells have been classified as "*improved drinking water sources"* (WHO/UNICEF, 2008). While closed wells prevent direct introduction of contaminants into the well, this classification fails to recognise that the high permeability of atoll soils means that pollutants are transmitted rapidly through the soil with little retention or absorption. The high population density in South Tarawa (2,558/km^2 in 2005, NSO, 2007b) coupled with the 7% of households there and the 27% of households in North Tarawa (population density 373/km^2 in 2005, NSO, 2007b) that practice bush defecation, together with the number of free-ranging pigs and other domestic animals mean that both closed and open household wells have a high risk of faecal contamination. According to the 2005 Census (NSO, 2007a, Tables H6, H7, H9), South Tarawa has on average over 2.5 pigs/household and North Tarawa has nearly 2.9 pigs/household, together with other free ranging domestic animals, such as dogs, cats and chickens, as well as family burials beside the home. According to the household survey conducted during the Sanitation, Public Health and Environment (SAPHE) Project in 2000 the average was 3.53 pigs/household. There is consequently a high risk of faecal contamination of household wells in South Tarawa and in villages in North Tarawa.

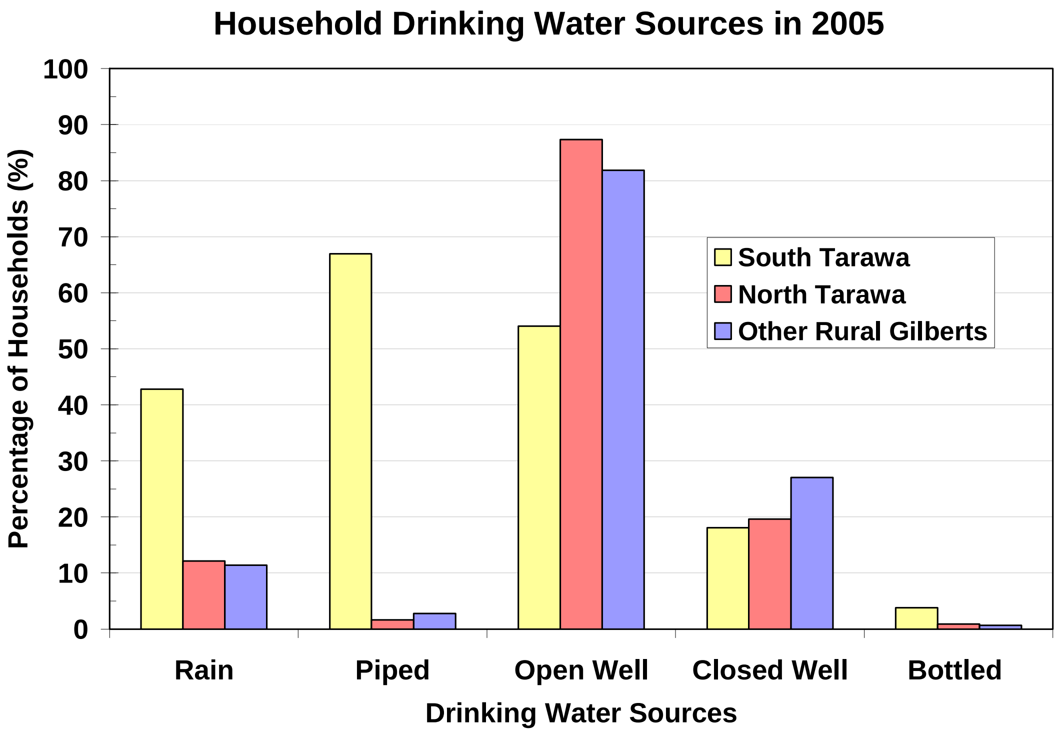

Figure 1 **Comparison of the percentage of households in 2005 using different sources of drinking water for urban South Tarawa, rural North Tarawa and other Gilbert Group islands**

Nearly 43% of households in South Tarawa in 2005 used rainwater to augment drinking water supply but in North Tarawa, only 12% of households used rainwater, similar to the 11% of households in other Gilbert Group islands. The last two are probably a reflection on the predominance of thatched roofs in North Tarawa and the outer islands, which greatly increases the difficulty of rainwater harvesting. The much larger percentage of households using rainwater for drinking in South Tarawa is partly a reflection of the roofing materials used there and partly a result of the SAPHE Project, completed in 2005. The SAPHE Project established a revolving fund for household loans to purchase rainwater tanks, guttering, pumps and improved sanitation by public servants in South Tarawa. Table 3 lists the number of rainwater tanks purchased with this scheme administered by the Kiribati Housing Corporation (KHC).

Bottled water is a minor component of household water use, with 3.8% of households using this source in South Tarawa, compared with 0.9% in North Tarawa. 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.

Table 3 Details of loans from the revolving fund, set up under the SAPHE Project in South Tarawa, for improved rainwater use and sanitation (from KHC data supplied August 2008)

Year	Water tank	Flush toilet	Compost toilet	Water pump	Guttering
2002	207	50	0	0	0
2003	242	12	0	0	0
2004	261	11	2	9	0
2005	124	10	0	41	0
2006	105	12	0	35	0
2007	87	1	0	12	1
2008(June)	49	3	0	14	0
Total	**1075**	**99**	**2**	**117**	**1**

The SAPHE Project, completed in 2005, upgraded some of the household water supplies with 500 L trickle-fed household tanks. Unfortunately not all households in South Tarawa were connected. Table 4 shows that less than 62 % of households were connected to the piped distribution system and less than 43% of total households had improved SAPHE connections. Disturbingly, 15.6% of all households had open pipe connections contributing to the large urban distribution losses in South Tarawa.

Table 4 Household connections to the reticulated water system in South Tarawa following the SAPHE Project

Item	No. of Households
Total number of households in South Tarawa from 2005 census	5238
Households connected to piped distribution system	3,224
Households with new SAPHE 500 L tank connections	2,229
Households with low level taps	178
Households with open pipes	817

Unfortunately there is almost no information on how much of the three main sources of freshwater (piped water, household wells and rainwater) are used by households in South Tarawa. The PUB production figures from Bonriki and Buota water reserves cannot be used since the losses from the system are unknown. Also at many connections there are no household water meters.

3.3 Changes Sources of Household Drinking Water

In order to estimate the contribution of different water sources to meeting future demands it is useful to examine the changes in the contribution of different water sources that have occurred in the past. The NSO has assembled data on sources of household drinking water in its past census data for 1990 (table H15), 1995 (table H 16) and 2000 (table H27) (NSO, 2007a). The changes in the percentages of household water sources between 1990 and 2005 in South and North Tarawa and in the rest of the Gilbert Group of islands is listed in Table 5. These results are also plotted in Figure 2 [4]. The data for the piped water in Table 5 include both piped and tanker-delivered water supplied by the PUB.

Again it is noticeable in both Table 5 and Figure 2 that the characteristics of household water use in North Tarawa are very similar to those in the remaining Gilbert Group islands. Both of these, however, are quite different to household water use in South Tarawa. Table 5 shows that there was almost a decrease of 10% in households in South Tarawa using rainwater between 1990 and 2000. This may be due to two factors. The first is that ferro-cement household tanks installed

[4] Data for 1995 has been omitted from Figure 2 since it as only one entry for water wells. Questions have also been raised about some of the statistics in the 1995 census (Demke *et al.,* 1998).

during earlier water projects may have started to fail. The second is that when the 2000 census was taken, Tarawa was still in the grip of the 1998-2001 drought and the data may reflect a decrease in the use of rainwater tanks and also in domestic wells in North Tarawa and in the other Gilbert Group islands in that period.

Table 5 Change in percentages of households in Tarawa using different sources of drinking water compared with other Gilbert Group islans from 1990 to 2005 (from NSO census data)

Year	Location	Total House-holds	Percentage of Households (%)				
			Rain water	Piped water	Open Well	Closed Well	Other
1990	South Tarawa	3297	35.2	74.9	34.6	14.0	4.5
	North Tarawa	551	4.7	14.2	82.9	3.4	6.5
	Other Gilbert Group	6697	7.5	14.5	78.0	16.8	8.5
1995	South Tarawa	3520	23.3	55.3	58.4*		
	North Tarawa	618	5.8	24.9	87.2*		
	Other Gilbert Group	6890	5.4	30.3	84.8*		
2000	South Tarawa	4529	24.4	69.5	32.8	17.7	
	North Tarawa	693	4.9	16.5	68.5	18.3	
	Other Gilbert Group	6469	7.2	29.5	68.3	29.3	
2005	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 Gilbert Group	7407	11.4	2.8	81.9	27.0	0.7[†]

* Only one value for wells is given for wells in the 1995 census results

[†] These values for bottled water in the 2005 census (NSO, 2007a)

Between 2000 and 2005 there was a dramatic increase of 19% (a factor of almost 1.8 times) in the household use of rainwater in South Tarawa. This is approximately equivalent to an extra 1,400 houses having rainwater tanks. In Table 3, 1075 rainwater tanks were purchased under the SAPHE revolving fund scheme. It is tempting to conclude that a large portion of the increase in the use of rain water tanks between 1995 and 2005 is due to the SAPHE revolving fund scheme. Between 1990 and 2005 household use of rainwater also increased in both North Tarawa (by a factor of almost 2.6 times) and other Gilbert Group islands (a factor of over 1.5 times). The increase in the use of rainwater in these locations cannot be attributed to the SAPHE revolving fund since it did not operate in outer islands. It may be that the 1998-2001 drought helped convince some householders that it was necessary to increase rainwater harvesting.

Between 1990 and 2005, there was an 8% decrease in the percentage of houses being supplied by the PUB piped water system in South Tarawa. This may reflect the inadequacy of the piped service to meet demand, the number of squatter settlements in South Tarawa and household developments around Temaiku, where piped water is unavailable. This is reflected in the growth in rainwater use and in the 19% increase in the use of open wells in South Tarawa.

The use of piped water in both North Tarawa and other Gilbert Group islands decreased dramatically between 1990 and 2005. This is due to the failure of small water supply systems installed under the United Nations Department of Technical Cooperation for Development (UNDTCD) Outer Island Community Water Supply Project (OICWSP).

The results in Table 5 and Figure 2 presents some disturbing trends for GoK. The decrease in the percentage of households receiving treaed piped water and the increase in the use of household wells as sources of drinking water indicate that more people in Tarawa are relying on potentially polluted local groundwater. If this continues health statistics are expected to worsen, contrary to the goals of the NWRP and NWRIP.

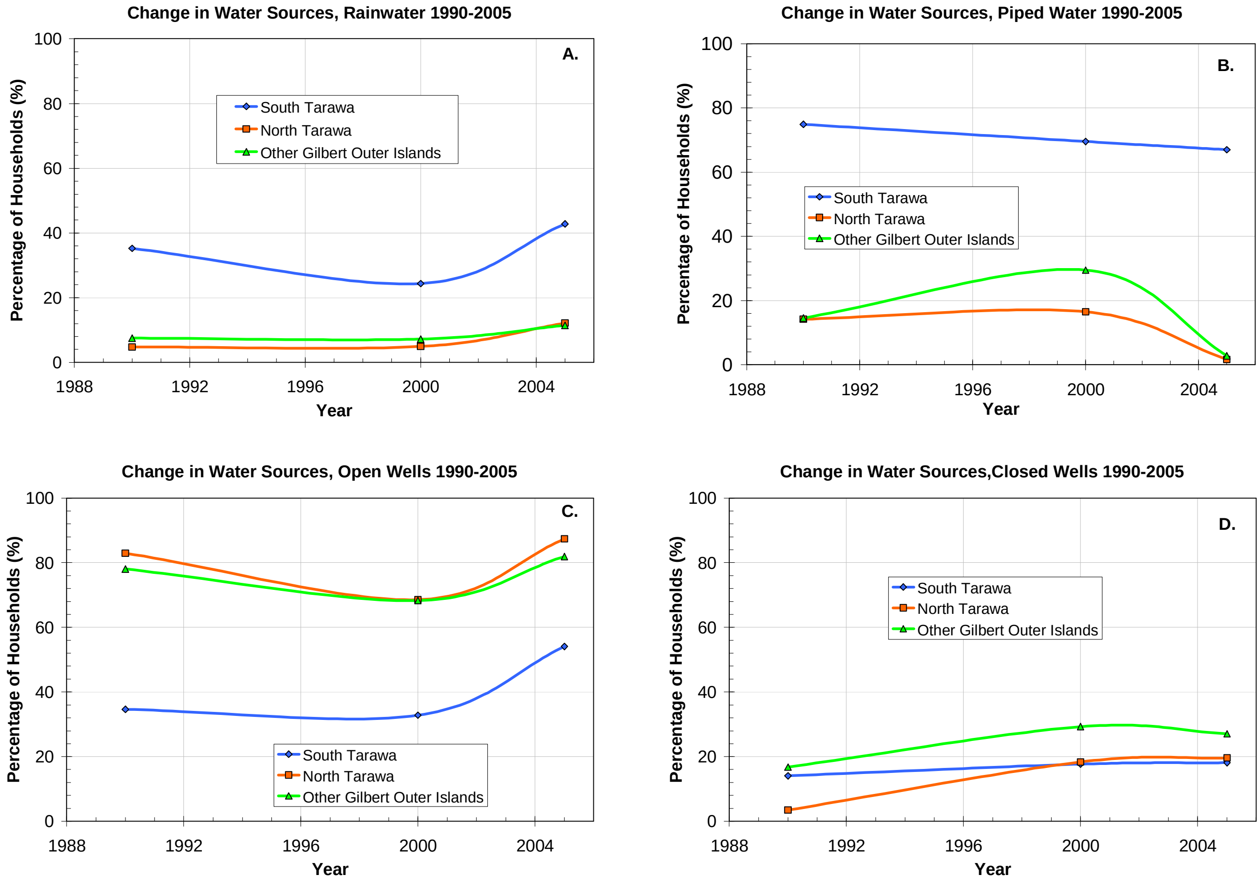

Figure 2 Changes in water sources used in South (blue lines) and North Tarawa (brown lines) and other Gilbert Group islands (green lines) for: A. rainwater; B. piped water; C. open wells; and D. closed wells

3.4 Geographic Differences in Sources of Household Drinking Water

The values in * Closed wells are genered raised wells with a cover

Table 2 and Table 5 show the results for South Tarawa as a whole. The SAPHE household survey (ADB, 2000) showed that water sources vary with location in South Tarawa (Table 6).

Table 6 Geographic distribution of household use of water sources in South Tarawa (ADB, 2000, Table 15)

Water Source	Area			
	"Rural" South Tarawa	Bikenibeu	Bairiki	Betio
PUB piped supply	54%	76%	96%	83%
PUB tanker	1%	5%	2%	19%
Shallow well - buckets	63%	51%	25%	25%
Shallow well – hand pump	3%	2%	0%	1%
Shallow well - elec pump	4%	1%	2%	3%
Rainwater tank -own	11%	6%	15%	14%
Rainwater tank -other's	3%	2%	0%	8%
Other	1%	1%	1%	1%
Total. Households	1,386	649	323	787

Table 6 shows that households in the high-density areas of Bairiki and Betio in 2000 relied heavily on treated, water supplied by PUB and much less on local household wells. In Bikenibeu, reliance on PUB-supplied water is less and use of household wells is more than in Bairiki and Betio. In areas outside these population centres, use of household wells is higher and reliance on PUB water is lower. It should be noted that this SAPHE 2000 water use survey suggested that on average 70% of households in South Tarawa used PUB water, which is higher than that found in both the previous 1995 Census and the following 2005 Census. This raises some doubts about the accuracy of the survey but suggests that a “one-size-fits-all” design for South Tarawa may not be appropriate.

The Sustainable Towns Project (STP, 2010) surveyed sources of water used in 420 households in redevelopment districts in Betio (293) and Bairiki (127) (Table 7).

Table 7 Percentage of households in redevelopment districts in Bairiki and Betio using different water sources for drinking cooking and bathing (STP, 2000, Tables 10, 11 and 13)

Water Source	%Drinking		%Cooking		%Bathing	
	Bairiki	Betio	Bairiki	Betio	Bairiki	Betio
PUB water into household	73	44	76	51	54	12
PUB water from neighbour	25	25	24	22	13	0.7
Rainwater tank	1.6	25	0.8	12	1	0.3
Protected Well (own)	-	3.1	-	11	11	53
Unprotected well (own)	-	-	-	0.3	1.6	12
Protected well (elsewhere)	-	1.7	-	2.0	14	14
Unprotected well (elsewhere)	-	-	-	0.7	5.5	7.8
Bottled water	-	0.7	-	0.3	-	-
From private vendor	-	0.3	-	0.3	-	-
Other	-	0.7	-	0.3	-	-
Total No. households	127	293	127	293	127	293

As with the ADB (2000) survey (Table 6), the STP survey found nearly 98% of the development households surveyed in Bairiki accessed water for cooking and drinking from the PUB supply compared with a lower percentage, 69%, in Betio. Again this is probably due to the high salinity of groundwater in Bairiki and the lack of space for rainwater tanks. Unlike the ADB survey, however, the STP (2010) survey appears to have failed to recognise that households in Tarawa use multiple sources of water for individual uses so the results in Table 7 are of limited value. It does, however, reinforce the fact that there are spatial variations in the use of water sources in urban South Tarawa.

The STP survey does supply some useful information about the PUB water supply in turns of the frequency of supply (Table 8), sufficiency of supply (Table 9), occurrence of bad taste of PUB supplied water (Table 10), payments (Table 11) and willingness to pay for improved water supply (Table 12).

Table 8 Frequency of supply of PUB piped water to households in redevelopment districts in Bairiki and Betio (STP, 2010, Table 14)

Supply Frequency	%Total	%Bairiki	%Betio
Less than once every 3 days	23	18	25
Every third day only	10	20	5
Every second day only	28	37	24
1-4 hours per day	2	-	3
5-12 hours per day	-	-	-
>12 hours per day	1	-	2
Unlimited access	9	-	13
Don't Know	24	21	26
Not Applicable	3	4	2
Total households	420	127	293

Table 9 Sufficiency of water supply in households in redevelopment districts in Bairiki and Betio (STP, 2010, Table 15)

Sufficient water when needed	%Total	%Bairiki	%Betio
Always	28	26	29
Usually	8.6	5.5	10
Sometimes	33	42	29
Rarely	6.2	0.8	8.6
Never	6.4	11	4.5
Don't Know	16	13	18
Not Applicable	1.0	2.4	0.3
Total households	419	127	292

Table 10 Occurrence of bad taste in PUB supplied water to households in redevelopment districts in Bairiki and Betio (STP, 2010, Table 16)

Location	Total	Yes	No	Don't Know
Bairiki	126	70	18	12
Betio	293	53	27	19
Total households	419	58	25	17

Table 11 Payment for PUB supplied water to households in redevelopment districts in Bairiki and Betio (STP, 2010, Table 20)

Payment	%Total	%Bairiki	%Betio
Yes	43	28	49
No	41	55	35
No Fee	3.3	7.9	1.4
Don't Know	10	7.1	11
Not Applicable	2.9	2.4	3.1
Total households	420	127	293

Table 12 Willingness to pay for improved water suppy (quality and quantity) inhouseholds in redevelopment districts in Bairiki and Betio (STP, 2010, Table 20)

Willingness to pay	%Total	%Bairiki	%Betio
Yes	66	61	68
No	21	20	22
Don't Know	10	12	8
Not Applicable	4	6	2
Total Households	241	93	148

The STP survey of the redevelopment districts in the Bairiki and Betio reveals an infrequent, inadequate PUB piped water supply and one where the water periodically has taste problems. It is known that bacterial build-up is a key problem with intermittent water supply systems (AGDHC, 1986). Of considerable interest is the fact that nearly 49% of the households in Betio claim they pay the bulk charge for the PUB water supplied, while only 28% claim so in Bairiki (Table 11). At first glance it appears that a large (66%) of households are prepared to pay for an improved water supply. However it is noted that only 57% of the households chose to answer this question. This is perhaps a reflection that many I-Kiibati in Tarawa believe that water supply should be free.

3.5 Other Water Sources

In addition to shallow groundwater and rainwater (White and Falkland, 2009b) there are other sources of water that are used or have the potential for use in Tarawa. There is little information on the volume used of these other sources.

3.5.1 Bottled Water

Both imported and locally produced bottled water is in limited use for drinking water in Tarawa. About 3.8% of households use this source in South Tarawa, compared with 0.9% in North Tarawa. It is clear that the cost of bottled water, currently about $1.50/L for either local or imported bottled water is a significant constraint on its use. Total imports of bottled water are between about 300 to 500 m^3/year of which about 93% is used in South Tarawa, or 280 to 470 m^3/year.

3.5.2 Desalination

Desalination of seawater or brackish water appears an attractive alternate freshwater source for small Pacific islands and there are or have been both public and private reverse osmosis (RO) desalination plants in Tarawa. Neither the Betio desalination plant, supplied during the 1998-2001 drought and connected to the public reticulation system, nor any of the other public RO plants in Tarawa are currently working. Difficulties encountered in many Pacific Island countries are the initial high cost of the plant, the expensive power consumption of ROplants, and problems with upkeep and maintenance. At its maximum production, the Betio reverse osmosis desalination plant supplied 0.1 ML/day to the reticulation system in Betio. Much of this was lost through leakage in the domestic reticulation system.

3.5.3 Bulk Importation of Water

During the phosphate mining period, bulk water was shipped into Banaba to supplement rainater harvested from buildings and stored in large tanks. Banaba was a special case where the water was imported as ballast on ships transporting phosphate from Banaba. Bulk shipping of water is very expensive (Falkland, 1983) and is normally only considered in emergencies.

3.5.4 Seawater

Seawater is widely used in Tarawa for washing, bathing and for flushing the sewerage systems at Betio, Bairiki and Bikenibeu, which are accessed about by a third of the households in Tarawa (National Statistics Office, 2007a, Table H37).

A summary will now be given of previous design targets for water demand used by water supply projects in Tarawa and other relevant areas in Kiribati.

4 Previous Water Demand Estimates

4.1 Major Water Supply Projects in South Tarawa

There have been three major water supply infrastructure projects implemented in South Tarawa in the past 35 years. These are:

- South Tarawa Piped Water Supply Project, 1974-1975
- Tarawa Water Supply Project, TWSP,1983-1987
- SAPHE Project, 1999-2005.

Design reports for these projects (AGDOW, 1973; AGDHC, 1975; RDI, 1978; AGDHC, 1972; AGDHC, 1986; Royds Consulting Limited, 1996; OEC, 2000; ADB, 2000) have used a variety of methods and assumptions to estimate per capita design demands for South Tarawa's water supply. Additional relevant estimates have been made for a water master plan for Kiribati (Shalev, 1992) and a recent water supply planning report for Kiritimati (ADB, 2007a).

These reports are discussed in turn in this section.

4.2 Betio piped water supply system investigation report, 1973

An investigation report into supplying reticulated freshwater to Betio, South Tarawa in 1973 (AGDOW, 1973) estimated per capita demands for a typical family of 10 people (six adults and four children). The estimated freshwater per capita demand was equivalent to 18 L/pers/day (4 gallons/pers/day) to cover the uses of drinking, cooking, washing dishes, laundry and ablutions. The estimated non-potable water demand for flushing toilets was 45 L/pers/day (10 gallons/pers/day).

Over 36 years ago this report noted that the *"water being presently obtained from the Betio, Bairiki and Bikenibeu pumps is unsuitable for drinking because of its high pollution and frequently high salinities. It is distributed by road tanker mainly to the low density housing for ablutionary purposes and the flusing of septic toilets" (AGDOW, 1973).* At that time, short galleries equipped with pumps were operational in the major population centres of Betio, Bairiki and Bikenibeu.

4.3 South Tarawa Piped Water Supply System Manual 1975

The South Tarawa Water Supply System was installed by the Australian Government in 1974-1975 (AGDHC (1975). When commissioned, the public potable water supply system included both groundwater piped from galleries at Bonriki, Buota, Temaiku and Teaoraereke, and rainwater harvesting into communal tanks at Betio, Bairiki, Nanikai and Bikenibeu. Potable water was distributed to consumers on Betio to communal tanks via a piped distribution system. At Bairiki and Bikenibeu, water was distributed by tankers. Consumers at Nanikai and other villages on South Tarawa obtained water from communal tanks supplied from the main pipeline and from rainwater tanks. In addition, many households in Betio, Bairiki and Bikenibeu had rainwater tanks and received non-potable water from local galleries delivered by tanker.

To provide the necessary information and instructions to operate the South Tarawa Water Supply system, estimates were made of the daily allowance of water that could be supplied in 1975 and 1980 (AGDHC, 1975). Using population data from the 1973 census, estimated allocations of potable water for all population centres on South Tarawa was about 20 L/pers/day in a "good season" and about 12 L/pers/day in a "drought period" (AGDHC, 1975, section 3).

More detailed allowance estimates were made for Betio for three "seasons", severe drought, average rainfall and very wet, which, because of the extensive use of rainwater harvesting, depended on rainfall (AGDHC, 1975, section 5). These estimates or possible supply rates are shown in Table 13 for estimated populations in 1975 and 1980.

Table 13 Possible per capita supply rates for Betio, South Tarawa Water Supply (AGDHC, 1975)

Rainfall Conditions	Year	Estimated Population	Pop'n using piped water	Allowance (L/pers/day)	Year	Estimated Population	Pop'n using piped water	Allowance (L/pers/day)
Severe Drought	1975	8,000	8,000	9.6	1980	12,000	12,00	6.5
Average Rainfall			6,000	22.9			9,000	15.3
Very Wet			4,000	36.6			8,000	18.3

Based on the amount of water available, AGDHC (1975, para 5.06) recommended a nominal supply rate of 10 L/per/day for Betio. It is also important to note that 35 years ago and with a estimated population of 8,000 in Betio, AGDHC (1975, para 4.03) also noted that *"water from the wells on Betio… is not of good quality and further drinking of it is to be discouraged."*

4.4 Richards and Dumbleton International Feasibility Study, 1978

The British Ministry of Overseas Development contracted Richards and Dumbleton International, RDI, to advise the then Gilbert Islands Colonial Administration on the development of their water resources. RDI estimated the per capita consumption of water in South Tarawa by dividing the production capacity of the then operating galleries by the number of people in South Tarawa and Buota to arrive at a design demand of 11.4 L/pers/day[5] in 1978 (RDI, 1978). For estimates of consumption in 1983 and 1988, RDI increased the per capita design demand to 15.9 and 22.7 L/pers/day. RDI's report is of particular interest since it also estimated, fairly arbitrarily, water demand in commerce, industry, tourism and public institutions for 1978, 1983 and 1988 (Table 14).

The estimated demand for water for domestic consumption increased from 79% of total consumption in 1978 to 84% in 1988. The design demand for education was based on an assumed fixed allocation of 2.3 L/pers/day for children and teachers. For the Tungaru Hospital, RDI used a figure of 45.4 L/pers/day in 1978 rising to 90.8 L/pers/day by1988 for both staff and patients. If the design demand figures in Table 14 are expressed as overall per capita demand, then the estimated per capita total demands for 1978, 1983 and 1988 were about 14, 20 and 27 L/pers/day, which are considerable increases on the recommended supply rate of AGDHC (1975) for Betio. Figure 3 shows that RDI progressively overestimated the growth of South Tarawa's population. In addition, RDI did not include water losses from the system.

4.5 Pre-Design Study, Tarawa Water Supply Project, 1982

A pre-design report for the Australian Agency for International Development (AIDAB) TWSP (AGDHC, 1982) allocated differing per capita demands to different grades of houses in South Tarawa. The reason for this was that larger houses, with roof areas greater than 130 m^2, were meant to be relativly self-sufficient by using harvested rainwater stored in rainwater tanks of total capacity 27 kL for droughts less severe than 1 in 10 years. In addition, it was planned that 25% of the population in housing constructed of local materials and some in barracks would receive water from communal standpipes at a lower rate of 20 L/pers/day. Projections of demand were made to the year 2000 based on three estimates of population growth: a high no-outer island growth model, assuming outer islander migration to South Tarawa; a medium, partial reduction model assuming redued urban migration as other growth centres developed; and a low proportionate growth model in which South Tarawa grew at the same rate as the rest of Kiribati. Figure 3 shows that only the medium model came close to predicting the actual census data. Only predictions based on the medium population estimates will therefore be discussed here.

[5] RDI (1978) used units of imperial gallons for volume measurements

Table 14 Estimated sectoral demand for water for 1978, 1983 and 1988 from RDI (1978)

Year	1978	1983	1988
Population	18,583	22,976	28,415
Sector	**Design Demand (kL/day)**		
Domestic	210.9	365.1	645.0
Tourism	12.3	23.5	38.6
Commerce	5.4	6.6	7.7
Industry	2.3	2.3	4.5
Education	9.3	11.5	14.0
Health	8.2	18.2	28.1
Port	14.5	15.9	18.2
Airport	0.5	0.7	0.9
Government	4.5	5.9	7.7
Total	**268**	**450**	**765**
Domestic/Total (%)	78.7	81.2	84.3
Per Capita (L/pers/day)	**14.4**	**19.6**	**26.9**

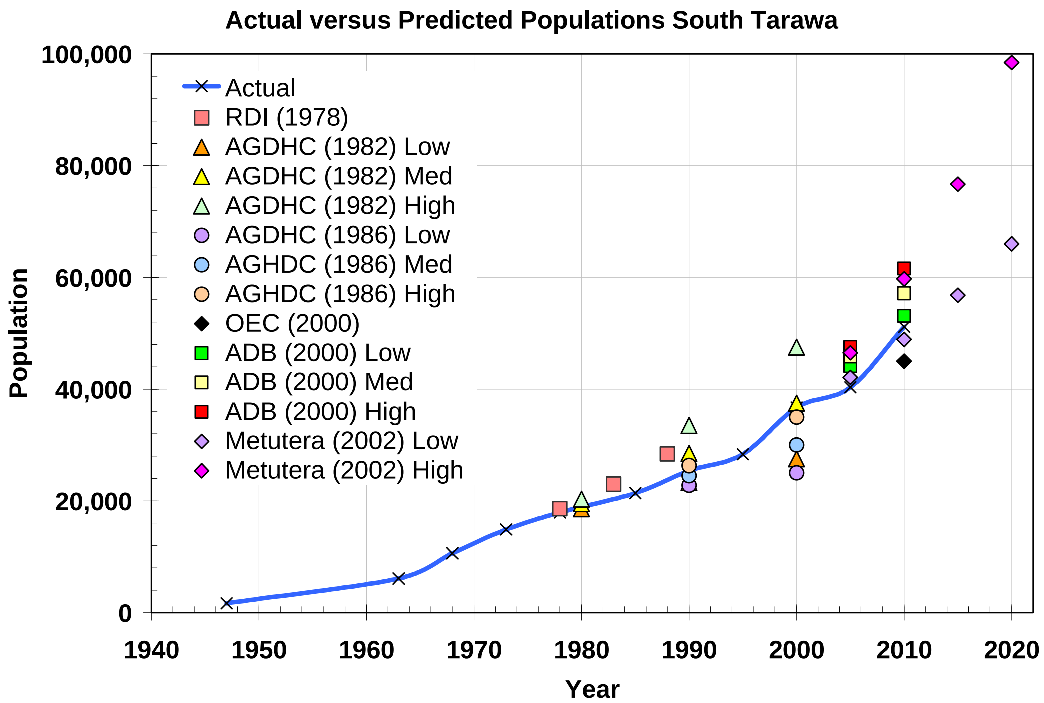

Figure 3 Actual (NSO, 2007a) versus projected population numbers for South Tarawa from RDI (1978), AGDHC (1982), AGHDC (1986), OEC (2000), ADB (2000) and Metutera (2002)

AGDHC (1982) assumed that a rapidly increasing marginal water tariff would limit water use for drinking, washing, cooking and bathing to 40 L/pers/day. The estimated graded design demand was:

Category I	A, B & C Housing	10%	7.7 L/pers/day
Category II	D, E, F Housing & Barracks	65%	36 L/pers/day
Category III	Local Housing	25%	20 L/pers/day

With the percentage distribution of total population in the various houses, this gave an average per capita domestic demand of about 29 L/pers/day. The estimated total water demands in 1990 and 2000 from AGDHC (1982) are given in Table 15 and includes a 10% allowance for lost water.

Table 15 Estimated sectoral demand for water in South Tarawa for 1990 and 2000 from AGDHC (1982)

Year	**1990**	**2000**
Population	28,500	37,500
Sector	**Design Demand (kL/day)**	
Domestic	831	1,093
Commercial*	15	30
Industry	30	50
Institutional	15	30
Lost water (10%)	89	120
Total	**980**	**1,323**
Domestic/Total (%)†	93	91
Per Capita (L/pers/day)	**34**	**35**

* Includes hotel, airport, port, and Government offices
† Total in this ratio does not include lost water

The estimated per capita total demands in AGDHC (1982) are higher than those in RDI (1978) and are equivalent to 34 to 35 L/pers/day. Not including losses, domestic water demand was assumed to be 93 to 91% of total demand. In 1990, the AGDHC (1982) estimate of non-domestic water use is 54 kL/day (excluding water losses) whereas RDI's estimate for 1988 is 120 kL/day.

4.6 AGHDC Review of Pre-Design Study, 1986

Due to a number of changes in the TWSP, AGDHC (1986) reviewed the pre-design study (AGDHC, 1982). Changes included the results of the 1985 census and the GoK's decision to abandon standpipes and connect all houses directly to the water supply system. Only the AGDHC (1986) high growth population estimate for 1990 and 2000 agrees with the actual census data (Figure 3) and the high estimate only will be used in assessing design demand. Using the same household breakdown as AGHDC (1982) but without Category III since the standpipe option had been removed, AGHDC arrived at an average per capita domestic demand of 37 L/pers/day. They did not alter the estimated ICI uses and did not include their estimated 20% losses in their estimates of total demand, which are now included in Table 16.

Table 16 Estimated sectoral demand for water for 1990 and 2000 from AGDHC (1986)

Year	**1990**	**2000**
Population	26,300	37,500
Sector	**Design Demand (kL/day)**	
Domestic	967	1,378
Commercial*	15	30
Industry	30	50
Institutional	9.3	11
Lost water (20%)	204	294
Total	**1,225**	**1,763**
Domestic/Total (%)*	95	94
Per Capita (L/pers/day)†	47	47

* Includes hotel, airport, port, and Government offices
† Total in this ratio does not include lost water

With the estimated higher loss rate and higher demands than ADGHC (1982), the average total per capita requirement for water increases to nearly 47 kL/day. By 2000, this already exceeded the capacity of the water supply system at that time.

A particularly notable feature of AGDHC (1986) is its list of recommendations:

- *Future monitoring of the lens is essential. The monitoring program must be designed as an integral part of the operation of the lenses.*
- *Consumption figures for existing metered houses and future metered connections should be collected to establish actual rates of water consumption. This data should be collected for the full range of domestic, business and industrial users. This information is vital for planning of water supply alterations and augmentation.*
- *Loss rates for stage one of the system should be measured. … Action should be taken to trace the source of losses if the figure exceeds 10-20% of total water produced.*
- *The whole issue of the financial management of the water supply system needs to be reviewed to ensure long-term success of the scheme.*
- *Australia (should) accept some ongoing professional level responsibility for system operation by reviewing the system performance, including the freshwater lens, initially on an annual basis.*

These tasks still are largely incomplete, 24 years after they were recommended.

4.7 Draft 10 Year National Water Master Plan, 1992

Shalev (1992) in the Draft 10 Year National Water Master Plan[6] proposed that the entire urban population should be assured the supply of 50 L/pers/day. For outer island rural populations, such as North Tarawa, the Plan assumed 30 L/pers/day as a design demand. There was no allowance made for ICI water use or for water losses from pipelines.

It is notable that in regard to household water wells, Shalev (1992) commented "…*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*." The water use statistics in Table 1 and * Closed wells are genered raised wells with a cover

Table 2 show this health hazard remains.

4.8 AIDAB's Pacific Regional Team, 1993

The very high incidence of diarrhoeal diseases, particularly amongst young children on South Tarawa, led to the GOK requesting Australian assistance in upgrading the sanitation and water supply systems on South Tarawa. AIDAB's Pacific Regional Team conducted a field appraisal of the proposal in 1993 (AIDAB, 1993).

While the team made no estimates of demand, their identification of the key issues and ways of addressing them are still relevant. The team concluded that the problem in South Tarawa was critical and that it should be addressed in as comprehensive manner as possible if sustainable and effective development is to be achieved. It recommended a multi-disciplinary, coordinated, long term (at least 10 years) program with multiple components being conducted in parallel rather than by implementing individual components and with annual budgets of several million (1990) dollars. The report was ignored until the SAPHE Project.

4.9 Precursor to the ADB SAPHE Project, 1996

As a precursor to the ADB SAPHE Project, an ADB Technical Assistance study prepared a prioritised program of improvements in water supply, sewerage disposal and solid waste management in South Tarawa (Royds Consulting Limited, 1996). In estimating the future water demand, it was assumed that by 2000 the design demand would increase to 40 L/pers/day and that the percentage of the population in South Tarawa supplied by the scheme would increase from 70 to 80%[7]. In addition, it was assumed

[6] The draft plan was never endorsed by GoK.
[7] The 2005 Census data suggests about 67% of households has access to piped water

that water losses would decrease from 50% in 2000 to 30% in 2003. With these assumptions, it was estimated that total water demand would be 1,750 kL/day by 2000. This is quite close to the AGDHC (1986) estimate for 2010 (Table 16). Royds (1996) estimated demand would increase to 2,125 kL/day by 2010, about 0.1 kL/day higher than the current sustainable yield estimate of Bonriki and Buota water reserves but the report made no allowance for ICI water use.

4.10 ADB SAPHE Living Conditions Report, 2000

A lead-up study to the ADB SAPHE Project, carried out an extensive household survey in South Tarawa on water supply, sanitation, and waste collection as well as a number of additional socio-economic factors (ADB, 2000). The objectives of this "client survey" were to enable the SAPHE Project agency to evaluate the then present situation on water supply, sanitation, and waste collection as well as a number of additional socio-economic factors. The survey, undertaken in 2000, covered 68% of all households and divided South Tarawa into four regions: Betio; Bairiki; Bikenibeu; and "rural Tarawa" (only in South Tarawa). It is useful as it shows geographic differences in water use (Table 6) but unfortunately, the survey did not canvas the amount of water used in households.

The survey attempted to estimate future populations in South Tarawa to 2010 using three population growth models. In the high growth model, it was assumed that population would continue to grow from 2000 at the rate found for the years 1995 to 2000, 5.31%. In the medium growth rate model, it was assumed that the actual total population in Kiribati was 80,800 instead of the 1995 Census value of 77,658 (Demke *et al.*, 1998) and the share of the population of South Tarawa related to the total population of Kiribati remained the same, giving a growth rate of 4.51%. In the low growth model, the results of the 1995 Census were disregarded, and the population for 1995 was replaced with an interpolation value between the figures of 1990 and 2000, giving a growth rate of 3.76%. Table 17 shows the projected populations for South Tarawa from ADB (2000) based on these three growth models and compares it with the 2005 Census value. The projected populations are also plotted in Figure 3

Table 17 Projected populations in South Tarawa from ADB (2000) compared with the 2005 Census value.

Scenario	Year			Census 2005
	2000	2005	2010	
Population High	36,722	47,566	61,613	40,311 (1.9%)
Growth rate	5.31%			
Population Medium	36,772	45,841	57,147	
Growth rate	4.51%			
Population Low	36,722	44,164	53,116	
Growth rate	3.76%			

It is clear form Figure 3 and Table 17 that the even the low growth rate estimate greatly overestimated the population in 2005 and so that the value for 2010 can be expected to be signifcantly too high. This emphasises the difficulty in projecting populations out to 10 years ahead. This TWMP has been requested to project the population and water demand by 20 years.

4.11 Water Supply Design for the ADB SAPHE Project 2000

The design population and estimated water demands for piped water for the SAPHE Project (OEC, 2000) 2000) were based on Royds Consulting Limited (1996) which assumed a demand of 40 L/pers/day for only 80% of South Tarawa's population supplied with water. These estimates are summarised in
Table 18.

Table 18 Population and demand estimates used in the design of the SAPHE Project (OEC, 2000)

Year	2010
Population	45,000
Sector	**Design Demand (kL/day)**
Domestic (80% population 40L/pers/day)	1,440
Commercial/Institutional (10% Domestic)	140
Lost water (30% Total)	670
Total	**2,250**
Domestic/Total (%)	91
Total per Capita (L/pers/day)	50

Neither Royds (1996) nor OEC (2000) provide any justification for these figures, particularly the assumption that the supply was designed for only 80% of the population of South Tarawa. In discussing future demand and water sources, OEC (2000) acknowledged that: "…*a supply of 40 litres per person per day to 80% of the population is not sufficient to meet the community's long term expectations of a piped water supply.*" OEC (2000) then provides a summary of the minimum long-term water requirements considered to be necessary to achieve an acceptable supply (Table 19). Again, no references or justification for the values listed were supplied.

Table 19 Suggested minimum long term domestic and total water requirements (OEC, 2000)

Water usage component	Demand (L/pers/day)
Drinking and cooking (potable)	10
Dishwashing (non potable)	10
Laundry, cleaning (non potable)	22
Bathing, shower (non potable)	20
Hand basin (non potable)	7
Others (non potable)	4
Subtotal (non potable)	73
ICI demand (10% of domestic)	7
Total Demand	80
Leakage/losses (20% of total production)	20
Total potable & non potable demand	100
Seawater for toilet flushing - piped system	45

OEC (2000) suggested that part of the potable water needs could come from rainwater harvesting as well as piped water and that the non potable water required could be supplied from shallow household wells, rainwater or piped water. As is pointed out in White and Falkland, (2009a) the ability of household rainwater harvesting systems in Tarawa to supply more than 5 L/pers/day through the most severe drought on record is severely limited by the available roof areas, storage tank volumes and demand of large households in Tarawa. In addition, as was pointed out over 36 years ago (AGDOW, 1973; RDI, 1975) the quality of groundwater in parts of South Tarawa is poor and has become increasingly so over the intervening years (White and Falkland, 2009b, 2009c). In the absence of a thorough monitoring program of well water quality, there is considerable risk in recommending the wide-scale use of local groundwater in parts of Tarawa. The total demand in 2010 predicted by OEC (2000), who used an unrealistically low 20% lost water assumption was 4,500 kL/day, about 2,500 kL/day more than the sustainable yield of the Bonriki and Buota water reserves.

4.12 Pacific Regional Consultation 2002

An invited case study of water management in Kiribati for the Pacific Regional Consultation Meeting on Water in Small Island Countries in Sigatoka, Fiji, 29 July - 3 August 2002 (Metutera, 2002) contained projections of both future populations and expected water demand until 2020 (Table 20)

Table 20 Projected population and demand for South Tarawa from the Kiribati country paper (Metutera, 2002)

Year	Population		Demand (ML/day)	
	Low	High	Low	High
2000	36227		1159	
2005	42,090	46,516	1,347	1,489
2010	48,901	59,728	1,565	1,911
2015	56,815	76,693	1,818	2,454
2020	66,010	98,475	2,112	3,151

The projected low and high populations used as the base year the population for South Tarawa in the 2000 census and assumed growth rates of 3 and 5% respectively. The projected demands were based on the same assumptions as those used in the design of the SAPHE Project; a per capital demand rate of 40 L/pers/day and only 80% of the population being supplied. The remaining 20% were expected to source water from rainwater or local groundwater. It was also assumed that major water users such as hotels, hospitals, schools and Industries would rely on desalination.

A basic assumption in this Master Plan is that water should be distributed equitably so that all households, institutions and businesses have access to the public water supply system.

4.13 SAPHE Mid Term Review. 2003

A review of groundwater resources management for Tarawa (Falkland, 2003) was completed as a contribution to the SAPHE mid-term review and included a reassessment of the SAPHE design estimates estimates for South Tarawa. It adopted the the capita demand estimates of OEC (2000) in

Table 18 including the aim to supply only 80% of the population and an assumed 30% water loss rate. Using the results of the 2000 census and assumed annual population growth rates of 3 and 5% to estimate the population in 2010 of beween 49,000 and 59,000 people, it estimated that production required by 2010 would be 2.25 to 2.7 ML/day, greater than the sustainable combined yield of Bonriki and Buota even with these modest supply rates.

4.14 Recommended Water Supply in Kiritimati 2007

While geographically and climatically different to Tarawa, Kiritimati has some similarities in terms of water supply. It has an urban centre (London), lower density semi-urban area (Tabwakea and Main Camp) and two rural villages (Banana and Poland). After considering an actual stratified survey of household water use in Kiritimati (ADB, 2007b), the design demands selected were 60 L/pers/day for households in semi-urban and rural areas, where it was assumed that 30 L/pers/day could be sourced from local groundwater for toilet flushing, and for the urban area of London, 90 L/pers/day, where the groundwater is too polluted to be used even for toilet flushing.

4.15 Sustainable Towns Survey of Bonriki and Betio, February 2010

The Sustainable Towns Project (STP, 2010), which seeks to relocate squatters from Betio and Bairiki to Temaiku, conducted a community census and profile survey of Betio and Bairiki redevelopment districts of about 423 households in those two locations. The survey asked detailed questions concerning the sources and condition of water supplied but failed to ask how much water was being used.

4.16 Concluding Comments on Previous Design Demands

A summary of the total per capita demands suggested by the above reports is shown in Table 21.

Almost all the design estimates for South Tarawa, discussed above have been based on how much water is available for distribution, rather than on any survey of how much water households use in Tarawa. The earlier estimates of design demand must be discounted. They were made in an era when South Tarawa had just over a third of its current population, when parts of South Tarawa were still rural and when there was a lower risk of pollution of local groundwater. In addition, there were few demands for water using devices. In the now highly urbanised South Tarawa, conditions are totally different, and subsistence demand estimates are no longer appropriate.

Table 21 Summary of the estimated per capita water demand in South Tarawa from previous studies

Year	Total per Capita Demand (L/pers/day)	Reference
1973	18	AGDOW (1973)
1975	10-37	AGDHC (1975)
1978	14-27	RDI (1978)
1982	34-35	AGDHC (1982)
1986	47	AGDHC (1986)
1992	30-50*	Shalev (1992)
1996	40[†]	Royds (1996)
2000	50[†‡]	OEC (2000)
2002	40[†]	Metutera (2002)
2003	40[†]	Falkand (2003)

* Lower value for outer islands, upper value for urban areas
[†] Assumes only 80% of all households supplied with piped water
[‡] Includes ICI demand and 30% assumed losses

One of the issues, identified here in Figure 3 is the difficulty of projecting future populations in Tarawa. Past demographic trends and changes in inward migration complicate the issue of predicting future populations on which estimates of future water demand critically depend.

In Tarawa, the lack of quantitative data on how much water households actually use from various sources, makes selecting reasonable demand figures extremely difficult. OEC (2000) attempted to define reasonable demand figures for an urban population with its suggested 100 L/pers/day. ADB (2007c) based their estimate of 60 L/pers/day for rural and semi-urban areas, without toilet flushing, on an actual survey of water use in Kiritimati. The following section examines reported values of actual household water use in Kiribati.

5 Household Water Use in Kiribati

5.1 South Tarawa, Early Water Use

There is very limited data on actual daily household water use in Kiribati. As far as can be determined, only one survey has been conducted of household water use in Tarawa. As a precursor to upgrading the water supply in South Tarawa, Harrison (1980) conducted a survey of household consumption in 73 households in Betio, Bairiki, Eita and Bikenibeu in early 1980. It appears as though 36 households responded. The results range from 2.6 L/pers/day to greater than 27 to 45 L/pers/day[8]. For some curious reason, Harrison discounted children's consumption to half that of an adult. He concluded that the normal consumption rate for cooking and drinking was just under 6 L/pers/day with a further 7 L/pers/day for washing bringing the total demand to about 12.5 L/pers/day. The survey did not include any of the bigger government houses.

It must be remembered that the survey, conducted 30 years ago, when water sourcing was significantly different to modern times and when parts of South Tarawa were still rural. It is not particularly relevant to Tarawa of the 21st century.

Two studies conducted by the ADB provide further insight into household water use. Unfortunately neither study was conducted in Tarawa.

5.2 Nonouti, Outer Island Water Use

ADB (2004, Appendix A) provides information on household interviews conducted in Rotima village on the island of Nonouti[9]. From those interviewed, estimates of the daily amount of household water use from household wells can be extracted and are shown in Table 22.

Table 22 Estimated per capita daily consumption of water in Rotima village, Nonouti (estimated from ADB, 2004)

Household (hh)	Number of People	Total Daily Volume of Water Used (L/hh)	Daily Volume Used for Irrigation (L/hh)	Total daily per capita use (L/pers/day)	Total daily per capita use excluding irrigation (L/pers/day)
Katirongo	6	200	n/a	33	33
Beta	3	200	40	67	53
Nabuti	4	280	40	70	60
Tokomawa	9	100	n/a	11	11
Teranga	8	260	n/a	33	33
Biromima	12	400	100	33	25
Kautoa	7	460	140	66	46
Moiwa	8	175	n/a	22	22
Mean	**7.1**	**259**	**80**	**42**	**35**
Minimum	3	100	40	11	11
Maximum	12	460	140	70	60

It can be seen in Table 22 that there is a wide range in the estimated total per capita daily use from 11 to 70 L/pers/day with a mean of 42 L/pers/day. Where information was provided, the amount of water used for irrigation could be estimated giving a mean of about 80 L/household/day. When the amount

[8] Harrison also reported consumption figures in imperial gallons.

[9] These interviews were not conducted with the aim of assessing average per capita consumption and the figures must be considered as rough estimates.

of water used for irrigation is excluded, mean daily per capita use reduces to 35 L/pers/day. None of the design estimates in section 4 included irrigation in design demand.

5.3 Kiritimati, Urban, Semi-Urban and Rural Water Use

In one of the most comprehensive studies undertaken to date, ADB (2007b) conducted a survey of household water use in Kiritimati. The stratified survey selected 87 households (13% of island households) in all villages in Kiritimati and was conducted from October to December, 2007. Households surveyed used a mixture of reticulated water, local household well water and rainwater sources. The mixture of sources used depended on location since local groundwater in urban London is too polluted to use while that in rural Poland is generally too saline to consume. In Kiritimati, reticulated household water use is metered and read by the Water and Sanitation Division, Public Works Department, Ministry of Line and Phoenix Island Development (MLPID). ADB (2007b, Table A1) compared the average per capita household water consumption estimated from MLPID data with that collected by the ADB survey. The comparison is reproduced in Table 23. It should be noted that this data is strictly for domestic water use.

Table 23 Comparison of average per capita water use in Kiritimati villages from metered water use (MLPID) and from the ADB (2007b) household survey.

Village	Water Use (L/pers/day)	
	MLPID Records	Household Survey
London/ Tennessee	42	53*
Tabwakea/ Terawanbakoa	29	52
Banana/ Main Camp/ New Banana	27	49
Poland	26	55
Mean	**31**	**52**
Maximum	42	53
Minimum	26	49

* This includes 4 L/per/day of water from delivered to London by tanker from groundwater reserves.

Estimated water use from MLPID records, which does not include water losses (estimated to be 50% or higher) is about 60% of that from the household survey. An explanation for this is that the MLPID data only accounts for reticulated water use while the household survey data includes water from all sources. In London, where groundwater is heavily polluted, reticulated water use is closer to total water use recorded in the household survey. In semi-urban Tabwakea and rural Banana, local groundwater is used more due to its better quality and could account for the bigger difference between reticulated water use and water use from all sources. ADB (2007a,c,d) recommended that the design demand for London should be 90 L/pers/day while that for the other settlements, Tabwakea Main Camp, Banana and Poland should be 60 L/pers/day (see section 4.14).

5.4 Implications for Tarawa Water Demand

The mean total daily water use for Rotima in Nonouti (Table 22) is for a rural outer island and may be relevant to rural North Tarawa but not applicable to urban South Tarawa. The mean daily water use for London in Kiritimati (Table 23) is probably much more applicable to South Tarawa, since it is an urban environment with polluted groundwater. Using the data for urban London and semi-urban Tabwakea in Kiritimati, a range for domestic daily per capita demand for South Tarawa can be estimated to be between 60 to 90 L/pers/day. Similarly using the data for Nonouti and the rural villages in Kiritimati, the estimated range for daily per capita demand for North Tarawa ranges from 35 to 60 L/pers/day.

5.5 Households Receiving Piped Water

The 2005 census suggests that only two thirds of households receive treated PUB water in South Tarawa. Previous studies have assumed significant numbers of households were to be mostly independent of the piped water supply system except for droughts more severe that 1 in 10 years, depending on the area of house roofs. Given the size of rainwater tanks available in Tarawa, the roof areas and the number of people per household, the demand that can be met from rainwater is very limited (While and Falkland, 2009a, 2009d). The most recent design study for South Tarawa (OEC, 2000) assumed that only 80% of households would be supplied with treated water.

This TWMP rejects the notion of partial supply of treated freshwater for South Tarawa residents, or differentiation of water supply on size of house roofs. Instead the assumption is used here that 100% of households in urban South Tarawa will be supplied with treated water from the PUB distribution system.

5.6 Concluding Comments

The data presented in this section provide at least some guidance for estimating per capita household demand in Tarawa in the 21st Century. For rural areas about 40-60 L/pers/day is required for domestic and irrigation needs. It can be argued that London in Kiritimati is not as highly urbanised as South Tarawa where actual average household water use may be higher. For South Tarawa, where piped freshwater is not used for toilet flushing, it is assumed that a minimum of about 60 L/pers/day is required for domestic consumption alone.

6 Other Water Demands

Thus far the demands for the important domestic sector in South Tarawa have been the main focus. The need for complementary water development for people in North Tarawa has not been considered in previous design studies apart from ADB (2004) which excluded South Tarawa. There are other, non-domestic water demands which need to be taken into account to estimate the total water requirements of Tarawa, both now and in the future. These are analysed in this section.

6.1 Institutional, Commercial and Industrial, ICI, Uses

If there is limited information on domestic water use in Tarawa, there is even less information on ICI[10] uses. As mentioned previously in section 2, Tungaru Central Hospital is one of the few government institutions for which the average water supply over the period 2004-8, 39.2kL/day is available (White *et al.,* 2008). Faced with the difficulty of determining a demand for this sector with almost no data, previous design studies have either assumed values for components of the sector or taken the demand for the sector as a fixed percentage of the domestic design demand. Keeping the water demand for ICI as a constant percentage allows it to grow with the population. It does not, however, allow for any increased percentage use by these sectors. Table 24 summarises the assumed ICI demand percentages used in previous design studies.

Table 24 The percentage of domestic demand assigned to ICI uses by previous South Tarawa water supply design studies

Reference	ICI demand/domestic demand (%)	Design Year
RDI (1978)	21	1978
	19	1983
	16	1988
AGDHC (1982)	6	1990
	8	2000
AGDHC (1986)	5	1990
	6	2000
OEC (2000)	10	2010

The assumed sector percentages in Table 24 range from 5 to 21%. RDI (1978) estimated a small per capita allowances for domestic consumption so the assumed ICI demand appears as a higher percentage.

The ICI demands in rural North Tarawa are expected to be less than those in South Tarawa and remain so into the future. Faced with the absence of data it is assumed here that the ICI demand will be 10% of the daily domestic per capita demand in South Tarawa and 5% in North Tarawa. It is noted that these assumptions allow the sectors to grow with the population but make no allowance for the introduction of water-intensive industries, or growth in government organisations or commercial operations.

6.2 Toilet Flushing

Approximately 33% of households in South Tarawa in 2005 were serviced by the PUB seawater-flushed sewerage system and 27% of households had flushed toilets connected to septic tank systems. In North Tarawa almost 19% of households also had flush septic tank systems. The spatial distribution of different sanitation systems in use varies in South Tarawa (ADB, 2000) as shown in

[10] Institutional demand has sometimes been termed social demand. Since here institutional use includes government buildings as well as schools, hospitals, churches, and maneabas, the term institutional is preferred.

Table 25. There is a much higher percentage of flushed toilets in Bairiki and Betio than in the rest of South Tarawa.

Table 25 Spatial distribution of sanitation systems in South Tarawa found by ADB (2000) compared to the 1995 and 2005 results for all of South Tarawa.

<table>
<tr><th rowspan="2">Sanitation System</th><th colspan="5">Area (ADB, 2000)</th><th>Census 1995</th><th>Census 2005</th></tr>
<tr><th>Rural S.Tarawa</th><th>Bikenibeu</th><th>Bairiki</th><th>Betio</th><th>Total</th><th colspan="2">All South Tarawa</th></tr>
<tr><td>water sealed latrine</td><td>38%</td><td>44%</td><td>3%</td><td>18%</td><td>30%</td><td>20%</td><td>34%</td></tr>
<tr><td>composting toilet</td><td>2%</td><td>11%</td><td>2%</td><td>2%</td><td>4%</td><td></td><td>3.7%</td></tr>
<tr><td>toilet/sewerage</td><td>4%</td><td>23%</td><td>58%</td><td>57%</td><td>27%</td><td rowspan="2">48%</td><td>33.3%</td></tr>
<tr><td>toilet/septic tank</td><td>10%</td><td>22%</td><td>19%</td><td>6%</td><td>12%</td><td>27.3%</td></tr>
<tr><td>beach - seaside</td><td>55%</td><td>20%</td><td>20%</td><td>24%</td><td>36%</td><td>33%</td><td>20.0%</td></tr>
<tr><td>beach - lagoon side</td><td>38%</td><td>24%</td><td>18%</td><td>25%</td><td>30%</td><td>32%</td><td>29.1%</td></tr>
<tr><td>other (bush)</td><td>9%</td><td>2%</td><td></td><td>8%</td><td>6%</td><td>12%</td><td>6.8%</td></tr>
<tr><td>Number households</td><td>1,387</td><td>662</td><td>324</td><td>786</td><td>3,159</td><td>3,520</td><td>5,245</td></tr>
</table>

The source of water used to flush septic tank systems is unrecorded but in many instances comes from household wells. Because of the large population in South Tarawa and the scarcity of treated fresh water, it is assumed here that water for flushing toilets will be either seawater or water from household wells. It is therefore assumed that no water for toilet flushing will be supplied from the piped water supply system.

6.3 Irrigation and Livestock Water

Many households in Tarawa use fresh groundwater for irrigating vegetables and fruit trees either for domestic consumption or as cash crops. It is assumed here that most irrigation water needs in South Tarawa will be sourced from household or other local groundwater wells. In addition, it is assumed that recycled "grey water" from washing, bathing and kitchen waste water from the piped water supply in South Tarawa will continue to be used for irrigating plants (ADB, 2000). This could amount to as much as 40 L/pers/day. North Tarawa, particularly Abatao, at present produces fresh produce for South Tarawa and it is envisaged that this is likely to continue into the future. It is assumed that irrigation needs in North Tarawa will be met from wells with recycled "grey" water being a possiblity when future piped systems are installed there.

It is assumed that water for domestic animals and livestock will continue to be sourced from local groundwater wells, where suitable, and from recycled "grey" water.

6.4 Water Losses[11]

While estimates for water losses from the main transmission pipeline on South Tarawa between Bonriki and Teaoraereke, replaced under the SAPHE scheme have been estimated to be 22% of total production (White *et al.*, 2008), none are available for the complete urban distribution systems that feed water from headtanks to households. Based on the difficulty of maintaining supply in South Tarawa (PUB, 2004) and on similar systems in other Pacific island countries, these losses have been estimated as in excess of 50%. In the absence of actual measurement of losses, various assumptions about water losses from the total piped distribution system have been made in previous design studies and are summarised in Table 26.

[11] 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..

AGDHC (1986) considered that the 10% losses assumed in AGDHC (1982) were unrealistic, citing losses in Indonesia of between 20 and 65%. It recommended that "… *a leak detection survey and any rectifications be considered for the water supply system before the scheme is handed over to the PUB."* That was not done then nor has been systematically addressed subsequently. Water lost from the system is good quality, treated water wasted and revenure foregone. It is strongly recommended that the PUB form a dedicated leak detection and control team to decrease the rate of water losses. Since some of the losses are due to inappropriate tampering by households with the pipelines, a major community education and awareness campaign would also need to be launched to bring about behavioural change.

Table 26 Percentages of total water production assumed lost from the piped distribution system in previous design studies.

Reference	Percentage Losses of Production (%)	Design Year
RDI (1978)	Not assessed	1978 1983 1988
AGDHC (1982)	10	1990 2000
AGDHC (1986)	20	1990 2000
OEC (2000)	30	2010

The PUB Business Plan, 2004-2006 (PUB, 2004) aimed to reduce water losses to 25% by 2006 with further reductions to 20% by 2009. While losses from the main pipeline from Bonriki appear to be about 22% (White *et al.,* 2008), losses from the urban pipeline distributions systems are very large and have not been decreased to date.

Information on water losses was supposed to have been collected by another KAPII Freshwater Component pilot projects. Because of delays to the project no data is available, and so two values of water losses will be assumed here. Since the urban piped distribution systems were not rehabilitated during the SAPHE Project or subsequently, it can be assumed that 50% losses of total production occur currently from the piped distribution system. It is also assumed that management of the system and leakage control will improve so that total losses will be reduced to 25%.

6.5 Impact of Climate Change on Water Demand

The rise in atmospheric temperatures above the current accompanying climate change (Ali *et al.* 2001), which may be as high as 1℃ by 2050 (Metutera, 2002), may 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, it is difficult to estimate any increase in per capita water demand due to climate change. It is assumed that the maximum increase in water consumption due to climate change will be 2 L/pers/day.

6.6 Summary of Assumed Demand Components in This Study

It is assumed in the TWMP that the minimum per capita demand recommended by ADB (2007a;c;d) of 60 L/pers/day, where toilet flushing is not supplied by the piped fresh water system, is appropriate for South Tarawa where household wells are still suitable for non-potable uses. Where groundwater is too polluted to risk any use, such as where it is contaminated with hydrocarbons, it is assumed that the minimum per capita demand should be increased to 90 L/pers/day. The absence of any systematic information on the quality of local groundwater in South Tarawa, means that it is not possible to assess the percentage of local groundwater in South Tarawa that is safe for non-potable use. It is strongly suggested that systematic surveys of the quality of local groundwater in household wells be carried out in Tarawa.

The assumed components of the total water demand that are used as the basis of the Master Plan are listed in Table 27.

Table 27 Summary of the water demand components for the Tarawa Water Master Plan

Component	Demand (L/pers/day)		Comments
	South Tarawa	North Tarawa	
Per capita household demand, excluding toilet flushing	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	30	30	Provided from sewater for piped sewage system or well water not contaminated with hydrocarbons.
Institutional, Commercial & Industrial use	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	2	2	Allowance for 1℃ rise in atmospheric temperature
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 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%	

Having estimated the daily per capita total water demands, the next step in estimating future water demand is to project the future population of Tarawa.

7 Future Population Growth in Tarawa

7.1 Planning Horizons and Methodology

The ToR for the Tarawa Water Master Plan require planning horizons of 10 and 20 years. Given the inaccuracies of past projections of populations (see Figure 3) over only 10 years into the future, it must be recognised that future population projections involve a number of assumptions on key factors infuencing population growth. These include: mortality rates, fertility rates, inward migration rates, external migration rates, and the absence of catastrophic disease outbreaks and natural disasters. Some of these factors are impossible to forecast. The following analysis uses published census data (NSO, 2007a; 2007b) to estimate reasonable projections of future populations from which the future water requirements for Tarawa can be estimated.

7.2 Exponential Population Growth in Tarawa

The 2005 Census (NSO, 2007a, Table A, p12) lists the island population for South Tarawa since 1921 and for North Tarawa since 1931. Population growth since 1963 is plotted in Figure 4. Kiribati has adopted an exponential growth rate model for population projectons:

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

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 cenus yearsand t is the time in years since the census or base year.

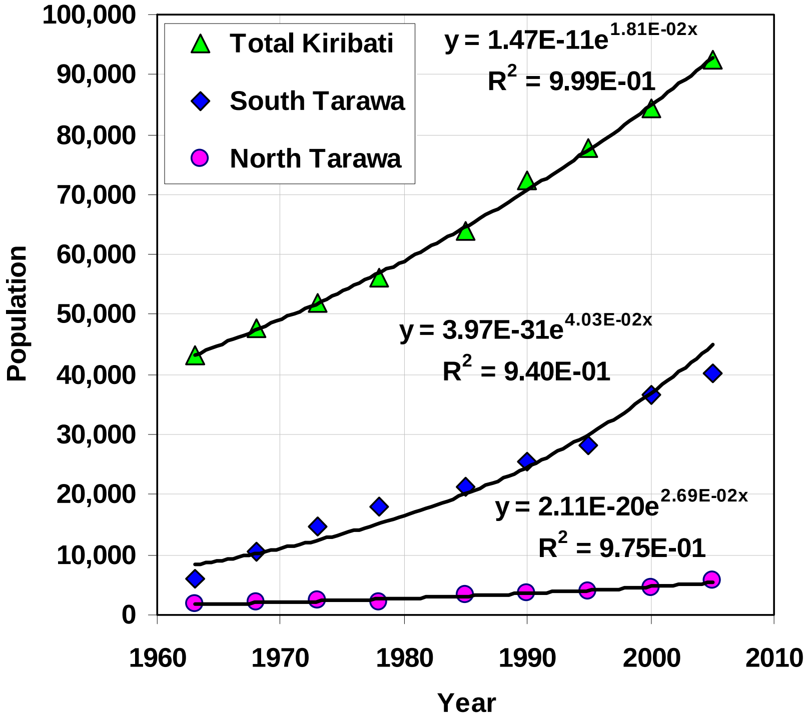

Figure 4 Growth rates of population in North and South Tarawa since 1963. The solid lines are the exponential growth rate model (eqn 1) fitted to the data for 1963 to 2005.

Census data from different base years give different projected populations. Here, growth rates are estimated from 5 year periods 1985-90, 1990-1995, 1995-2000, 2000-2005 and for the whole period 1985-2005 (Table 28) using the census data (NSO, 2007a, Table A) and are compared with the growth rates for all of Kiribati. Demke *et al.*, (1998) dispute the census data for 1995 and claim that the total populaion of Kiribat was 3,140 more than that recorded in the census. If correct the growth rate for total Kirinati for 1990-1995 would be 2.2% but it would be an implausibe 0.9% for 1995-2000.

The much higher population growth rates in South Tarawa than Kiribati as a whole clearly reflect the inward migration from outer islands to the population centre in South Tarawa with its better services. Between 2000 and 2005, a remarkable change occurred in the growth rates with South Tarawa only growing at a rate very slightly greater than Kiribati as a whole, while the growth rate in North Tarawa accelerated. One possible explanation advanced for this is that South Tarawa is “full” (NSO, 2007b). Another is that strategies to make outer island living more attractive, such as the establishment of local junior secondary schools, are bearing fruit.

Table 28 Estimated exponential growth rates fitted to the population data in South Tarawa and North Tarawa from different years compared with growth rates for Kiribati

Location	Exponential Growth Rate (%) for different years				
	1985-90	1990-95	1995-2000	2000-05	1985-2005
South Tarawa	3.42	2.21	5.17	1.87	3.17
North Tarawa	2.59	1.86	2.23	4.75	2.86
Total Kiribati	2.49	1.42	1.69	1.82	1.85

Several population trends are noticeable in Figure 4. There was a very rapid increase in growth in South Tarawa from 1963 to 1973 due to inward migration. From 1973 to 1985 growth slowed as Tuvaluans left Tarawa following the split up of the former Gilbert and Ellice Island Colony and the independence of Tuvalu in 1978 followed by Kiribati on 12 July 1979. The South Tarawa growth rate increased between 1985 and 1990 and again decreased between 1990 and 1995. There has been a significant growth rate decrease between 2000 and 2005 in South Tarawa following an apparent growth spurt in 1995 to 2000.

If it is assumed that these growth rates are maintained until 2030[12] then the expected populations in North and South Tarawa can be estimated using equation (1), the growth rates in Table 28 and starting with the 2005 census populations are shown in Table 29.

Table 29 Estimated populations in South and North Tarawa in the years 2010, 2020, 2030 using the five exponential growth rates in Table 28 starting from the 2005 populations: South Tarawa 40,311; North Tarawa 5,678

Year	Predicted from Exponential Growth Rate (%) for years									
	1985-90		1990-95		1995-2000		2000-05		1985-2005	
	South Tarawa	North Tarawa	South Tarawa	North Tarawa	South Tarawa	North Tarawa	South Tarawa	North Tarawa	South Tarawa	North Tarawa
2010	47,800	6,500	45,000	6,200	52,200	6,300	44,300	7,200	47,200	6,600
2020	67,300	8,400	56,200	7,500	87,600	7,900	53,300	11,600	64,800	8,700
2030	94,700	10,800	70,100	9,000	146,900	9,900	64,300	18,600	89,000	11,600

It can be seen that selection of the exponential growth rate selected has a major impact on the estimated populations in South and North Tarawa. By 2030, the past growth rates suggest that the South Tarawa population could be between 64,300 and 146,900 and the population for North Tarawa

[12] This assumes that inward migration will proceed at the same rate. The inward migration from Outer Islands to Tarawa will be limited by the total population growth of Kiribati and by migration from the Gilberts Islands to the Line and Phoenix Islands so it might be expected that these rates will decrease.

could range between 9,000 to 18,600. Using the growth rates from 1985 to 2005 tends to smooth out fluctuations between census results giving estimates in the medium range for both North and South Tarawa. The census data for 2005 reflects recent trends in internal migration within Kiribati, including a population shift from the Gilbert Group to the Line Islands Group (NSO, 2007b). Because of that, the growth rates for 2000-05 are important in estimating future population numbers.

A key question in estimating the future population trends in Tarawa and particularly South Tarawa is the expected future percentage of the total population of Kiribati that will live in Tarawa. Table 30 lists the projected populations for South and North Tarawa and Tarawa as a whole and the percentage of total population expected in South Tarwa, assuming that the exponential growth rates found in Table 28 for the period 2000 to 2005 continue into the future.

Table 30 Estimated populations for South and North Tarawa, Tarawa and Kiribati to 2030 based on the exponential growth rates for 2000-2005 (Table 28) and the 2005 census results.

Year	Projected Population Numbers				South Tarawa/Kiribati (%)
	South Tarawa	North Tarawa	Tarawa	Kiribati	
2005 Census	**40,311**	**5,678**	**45,989**	**92,533**	**43.6**
2010	44,300	7,200	51,500	101,500	43.6
2020	53,300	11,600	64,900	122,100	43.7
2030	64,300	18,600	82,900	147,000	43.7

Based on the census data from 2000 and 2005 the results in Table 30 suggest that there will not be a continued increase in the percentage of population living in South Tarawa. These estimated populations suggest that the inward migration from outer islands in Kiribati to South Tarawa will continue but at a very much slower rate than in the past and there will be an increased growth rate in North Tarawa. The values in Table 30 suggest that the percentage of the total population living in South Tarawa will not exceed 44% of the total Kiribati population by 2030. In section 7.4, possible limits to inward migration to Tarawa are examined. Firstly, however, a comparison is made between projections of the total population of Kiribati in Table 30 using the exponential growth rates for 2000-2005 with projections of the NSO (2007b).

7.3 Comparison with NSO population projections

The NSO (2007b, Appendix 8) has projected the total population of Kiribati from the 2005 census using a combination of 9 different cases, 3 assumed total fertility rates, and 3 assumed migration rates, but only one assumed mortality rate. The projections can be grouped into low, medium and high estimations of future population numbers for Kiribati (Table 31).

Table 31 Low, medium, and high projected future number of people in Kiribati (adapted from NSO, 2007b) compared with the estimated population from Table 30

Year	Number of People			
	Low	Medium	High	2000-2005 Exp*
2005	**92,533**			
2010	99,063	100,915	102,773	101,500
2015	106,050	110,499	114,999	111,400
2020	113,000	120,300	127,800	122,100
2025	119, 384	129,769	140,387	134,000
2030†	128,000	142,000	157,000	147,000

*From the growth rate for 2000-2005 from Table 28

† Statistics Office projections are only to 2025. Values for 2030 are estimated

The NSO suggests that population changes close to those for the medium population scenario using the medium fertility assumption, with the total fertility rate decreasing from its current level of 3.5 to 2.6/woman in 2025, and the medium migration assumption, with a total of 100 net annual outward migration leaving Kiribati, appears to be the most likely population outcome. The NSO has not published projections for Tarawa, so the NSO projections can only be compared with the estimates here for Kiribati (see Table 30)

The NSO (2007b) population projections in Table 31 have been extrapolated beyond their limit of 2025 to 2030 using exponential fits to the projections. The comparison in Table 31 shows that the simple exponential fit to data based on the 2005 census pollations and the growth rate for 2000-2005 of 1.85% for Kiribati Tarawa are slightly greater than the medium projections suggested by the NSO as the most likely population outcome. For this reason it is assumed here that the exponential growth predictions based on the growth rate for 2000-2005 are a likely upper limit for the population in North and South Tarawa.

While NSO (2007b) made no projections of future populations in South or North Tarawa, it did remark on the noticeable decrease in the rate of growth of South Tarawa population between 2000 and 2005 and the significant increase in the rate of growth of population in North Tarawa (Table 28).

7.4 Limits to Growth of South Tarawa

The 2005 Census (NSO, 2007a, Table A, p12) shows an increasing population shift in Kiribati from outer islands to the urban centre of South Tarawa between 1931 and 2000. The proportion of the total Kiribati population resident in Tarawa has increased from 10% in 1931 to just below 44% in 2005 (Figure 5). Two periods of rapid increases in the percentage of the Kiribati population living in South Tarawa are evident in Figure 5, from 1963 to 1973 and 1995 to 2000. It is, however, noticeable that, between 2000 and 2005, the rate of increase slowed for Tarawa as a whole and the percentage of total population remained almost constant for South Tarawa. This suggests a limit to population growth in Tarawa.

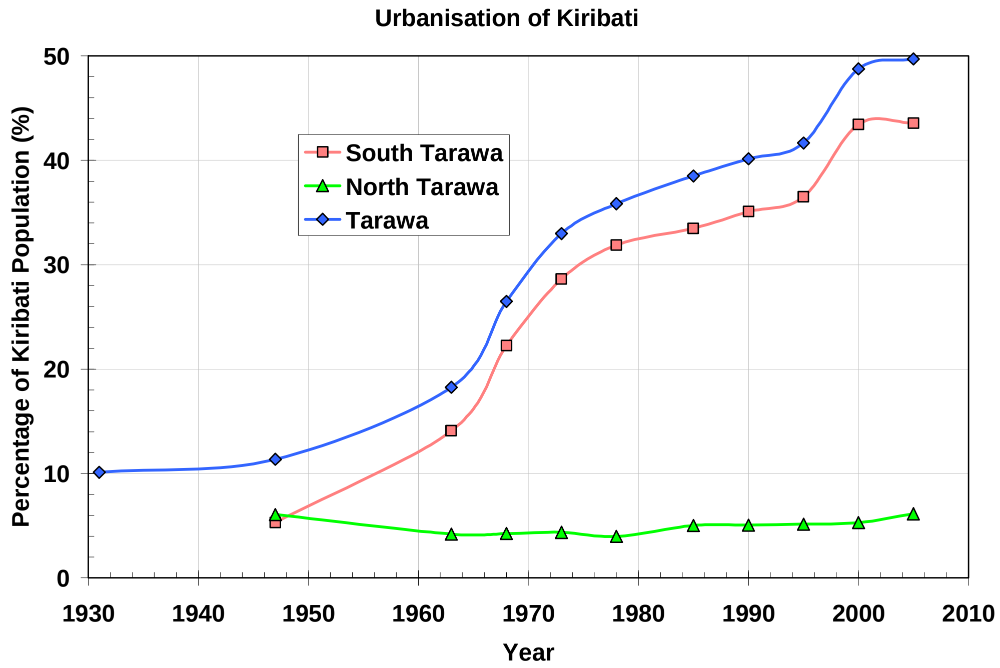

Figure 5 Change in percentage of total population living in Tarawa, North and South Tarawa.

The NSO (2007b) has commented on this trend. "*Until the year 2000 there was a strong trend of rural to urban migration in Kiribati. People left the Outer Islands and settled in South Tarawa. The population growth of South Tarawa therefore was significantly higher than the national average, resulting in high population densities and crowded households, especially in Betio[13]. The 2005 census data, however, show a different trend. Based on data of place of residence 5 years before the census, it can be concluded that there was a net-flow of people from the Gilbert Group islands (including South Tarawa) towards the Line Islands, in particular the islands Tabuaeran and Kiritimati showed very high population growth rates.*

Possible explanations for this trend are:

1. *South Tarawa and especially Betio is 'full', and there is only limited availability of land for additional housing construction or extension, therefore*
2. *North Tarawa has increasingly become the destination of Outer Islands migrants, and possibly even for former South Tarawa residents.*

New settlement developments in North Tarawa, and Tabuaeran and Kiritimati increase demands for land allocation, energy and water consumption, waste disposal, sewage connections and general infrastructure."

Unfortunately, the NSO did not attempt to predict the range of future populations that might be expected in South Tarawa. South Tarawa is clearly not full since, between 2000 and 2005, the population grew at a rate of 1.9%, slightly greater that the national rate of 1.8%.

In order to estimate the possible future shifts in population in South Tarawa, a linear trend was fitted to the percentage of total population data in Figure 5 for South and North Tarawa from 2000 to 2005. The projected percentages were then taken of the 'most probable' medium total population of Kiribati from NSO (2007b). The projected percentages of the total population living in Tarawa to 2030 are shown in Table 32 together with the estimated populations for Tarawa.

Table 32 Estimated percentages of the population of Kiribati living in Tarawa and possible population numbers for Tarawa from 2010 to 2030

Year	% of Kiribati Population			Estimated Populations			
	S. Tarawa	N. Tarawa	Tarawa	S. Tarawa	N. Tarawa	Tarawa	Kiribati*
2005	**43.6**	**6.1**	**49.7**	**40,311**	**5,678**	**45,989**	**92,533**
2010	43.8	6.9	50.7	44,200	6,900	51,100	100,900
2020	44.0	8.6	52.6	52,900	10,300	63,200	120,300
2030	44.2	10.2	54.4	62,800	14,500	77,300	142,000

*'Most probable' estimates, NSO (2007b).

The estimated populations for South Tarawa in Table 32 are only slightly less than those in Table 30, while for North Tarawa they are significantly less. This method uses the 'most probable' approximately exponential growth rate for Kiribati as a whole but assumes that the percentage of the population living in South and North Tarawa will increase only linearly, not proportionally. Since there is only a small difference between the estimated population for South Tarawa in Table 32 and that in Table 30 it is assumed that the values in Table 30 are a realistic upper bound of South Tarawa population. For North Tarawa it is assumed that the values in Table 32 provide a lower bound of the estimated population.

A third population model will also be considered. It assumes that overcrowding in South Tarawa will make conditions unattractive so that Outer Island migrants and residents in South Tarawa will move to

[13] Bairki is similarly overcrowded

other locations[14], possibly in the Line Islands. It will be assumed that the population of South Tarawa will only grow linearly to 50,000 in 2030. This is equivalent to an exponential growth rate between 2005 and 2030 of 0.9% only half the actual rate for 2000-2005 for South Tarawa This is the "South Tarawa Full" estimate and is expected to be a lower bound to the population in South Tarawa. It is noted that with this estimate there will be an expected significant migration of 13,000 to 15,000 people away from South Tarawa.

Table 33 gives the estimated upper and lower bounds of future population numbers in Tarawa that will be used in this work and these are also plotted in Figure 6.

Table 33 Estimated lower and upper bounds of future populations in Tarawa to 2030

Year	Lower Bound Population			Upper Bound Population		
	South Tarawa	North Tarawa	Tarawa	South Tarawa	North Tarawa	Tarawa
2005	**40,311**	**5,678**	**45,989**	**40,311**	**5,678**	**45,989**
2010	42,300	6,900	49,200	44,300	7,200	51,500
2020	46,100	10,300	56,400	53,300	11,600	64,900
2030	50,000	14,500	64,500	64,300	18,600	82,900

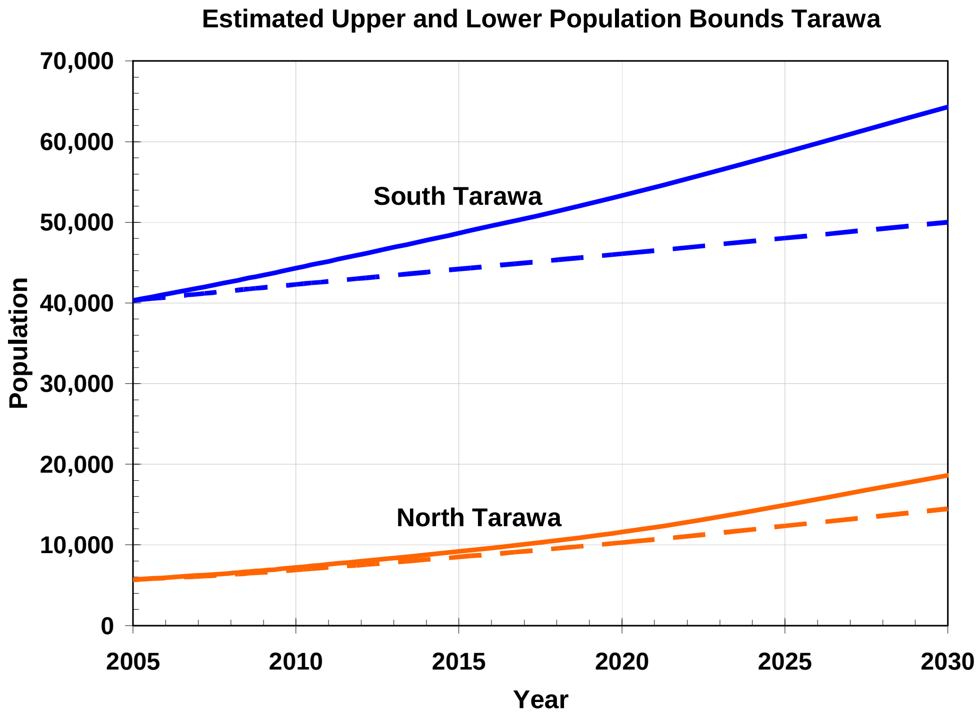

Figure 6 Estimated lower and upper bounds of future populations in North and South Tarawa, solid lines are upper bounds, dashed lines are lower bounds

[14] It is planned under the Sustainable Towns Project to relocate 15 to 20 thousand people from squatter areas in Betio, Bairiki and elsewhere to government land in Temaiku. This may attract more squatters.

7.5 Inclusion of Buota in South Tarawa Water Supply

The estimated population bounds in Table 33 are for the planning and local government zones of North and South Tarawa. For water supply, however, Buota, which is in the planning zone of North Tarawa, receives water from the South Tarawa (and Buota) water supply system. For water supply, the population being supplied is South Tarawa (Table 33) plus Buota while the relevant North Tarawa population is North Tarawa (Table 33) less Buota. The NSO published statistics do not give growth rates for individual villages. In order to estimate future population, it is assumed that the growth rates for Buota are identical to those for North Tarawa as a whole[15] for the period 2000 to 2005. The estimated populations are shown in Table 34. To compliment the South Tarawa Full estimate, it will be assumed that Buota is also reaching population limits and it will be assumed that Buota will only have 2,000 people by 2030 (this is equivalent to an exponential growth rate of 1.6% over 25 years).

Table 34 Estimation of the bounds of future populations in Buota

Year	Estimated populations in Buota	
	Lower*	Upper†
2005	**1,373**	
2010	1,500	1,740
2020	1,750	2,830
2030	2,000	4,570

The estimated range of populations for Buota can now be added to those for South Tarawa and subtracted from the range for North Tarawa to give the estimated range of populations for the South and North Tarawa water supply systems which are given in Table 35. These will be used in estimating demand for Tarawa's water supply systems.

Table 35 Estimated ranges of populations using water from the South Tarawa (including Buota) water supply system and wells in North Tarawa (without Buota)

Year	Lower Bound Population for Water Supply			Upper Bound Population for Water Supply		
	South Tarawa*	North Tarawa†	Tarawa	South Tarawa*	North Tarawa†	Tarawa
2005	**41,684**	**4,305**	**45,989**	**41,684**	**4,305**	**45,989**
2010	43,800	5,160	48,960	46,040	5,460	51,500
2020	47,850	7,470	55,320	56,130	8,770	64,900
2030	52,000	9,930	61,930	68,870	14,030	82,900

* Includes Buota
† Does not include Buota

7.6 Impact of Climate Change on Population Growth and Distribution

Climate change disturbances of physical systems and ecosystems could pose 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

[15] It is probable, since Buota is connected to the services in South Tarawa, that its population could even be growing at a faster rate than North Tarawa.

diseases such as malaria, dengue, and yellow fever are sensitive to factors such as temperature, rainfall, and humidity.

Since rainfall is generally expected to increase with increasing temperatures, in small island countries in the central Pacific, 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 further slowing of the population growth might also occur in Tarawa with increasing global temperatures. The lower bound South Tarawa Full estimate could be considered to be due to the impact of climate change. Rising sea-levels, however, could force an increase in inward migration from low-lying outer islands. Since there is no information on the magnitude of this impact, and since the time horizon for the TWMP is 2030, it is assumed here that the above range of estimated future populations in Tarawa given in Table 35 spans the plausible lower and upper bounds of future population numbers in Tarawa.

8 Future Water Demand

8.1 Design Water Demand

The absolute minimum requirement for good quality drinking and cooking water in temperate climates is about 7.5 L/pers/day (WHO, 2006), which for tropical climates should be increased to about 10 L/pers/day. As discussed in section 4, previous design targets of per capita water needs in Tarawa have ranged between 6.5 to 100 L/pers/day. WHO (2006) points out that there is a correlation between human health and the quantity of good quality water used in households. In the absence of measured data on the current actual household usage of freshwater in North and South Tarawa, the quantities adopted here to be supplied by the water distribution system are given in Table 27.

Several difficulties arise in adopting these values. It is uncertain whether they are realistic estimates of actual per capita domestic and ICI consumption in Tarawa. While some use has been made of estimated household use in Nonouti and Kiritimati, with situations similar to North and South Tarawa, the values adopted merely represent assumed future per capita water needs for treated water. There is very little potential in the adopted figures for radical increase in domestic or ICI water use.

Since there is no systematic information on the quality of local groundwater accessed via household wells by communities in North and South Tarawa, it is assumed that in densely-populated parts of South Tarawa, estimated to be 50% of households there, major household water needs will need to be met from treated water supplies. This is in part already reflected in the smaller percentage of households using well water in Betio and Bairiki (Table 6). In North Tarawa, it is assumed that household wells are less polluted than in South Tarawa and are available for use.

8.2 Water Demand for Tarawa to 2030

In order to estimate total future water requirements for Tarawa, the estimated range of future populations in Table 35 are used together with the per capita design demands for South and North Tarawa in Table 27 .The projected total actual daily demand in megalitres/day (ML/day) for South and North Tarawa and Tarawa as a whole are listed in Table 36. These estimates do not include losses.

Table 36 Estimated total daily design water demands (ML/day) for South, North and all of Tarawa to 2030 for lower and upper bound future population estimates

Year	Lower Bound Daily Demand (ML/day)			Upper Bound Daily Demand (ML/day)		
	South Tarawa	North Tarawa	Tarawa	South Tarawa	North Tarawa	Tarawa
2005	**2.8**	**0.28**	**3.1**	**2.8**	**0.28**	**3.1**
2010	3.0	0.34	3.3	3.1	0.35	3.5
2020	3.3	0.49	3.7	3.8	0.57	4.4
2030	3.5	0.65	4.2	4.7	0.91	5.6

A sobering conclusion from Table 36 is that even in 2005, the estimated demand for South Tarawa was 40% greater than the combined sustainable yields of the Bonriki and Buota water reserves without allowing for leakage. This partly explains the increased domestic uses of rainwater and household wells in South Tarawa found in section 3.3. By 2030 it is estimated that this demand in South Tarawa will have increased to between 3.5 to 4.7 ML/day.

The next task is to estimate total water supply that needs to be produced in order to meet the estimated total water demands and water losses from the distribution system.

8.3 Required Water Production to Meet Future Demand and Losses

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. The two design estimates of current (50%) and future loss rates (25%), discussed in section 6.4, will therefore be used.

The water production rates required to meet a 50% leakage rate and the future demand estimated in Table 36 are listed in Table 37, while the necessary production rate to satisfy demand and 25% losses are given in Table 38. It is assumed here that all water to meet demand will be sourced from leaky piped water systems. Under the 25% losses option, it is assumed that a new piped water system will be installed in villages in North Tarawa from 2015 onwards and will have 25% losses.

Table 37 Required water production rates needed to meet the estimated future demands in Tarawa and a water loss rate of 50%

Year	Lower Bound (ML/day)			Upper Bound (ML/day)		
	South Tarawa	North Tarawa	Tarawa	South Tarawa	North Tarawa	Tarawa
2005	**5.7**	**0.28**	**5.9**	**5.7**	**0.28**	**5.9**
2010	6.0	0.34	6.3	6.3	0.35	6.6
2020	6.5	0.49	7.0	7.6	0.57	8.2
2030	7.1	0.65	7.7	9.4	0.91	10.3

Table 38 Required water production rates needed to meet the estimated future demands in Tarawa and a water loss rate of 25%.

Year	Lower Bound (ML/day)			Upper Bound (ML/day)		
	South Tarawa	North Tarawa	Tarawa	South Tarawa	North Tarawa	Tarawa
2005	**3.8**	**0.28**	**4.1**	**3.8**	**0.28**	**4.1**
2010	4.0	0.34	4.3	4.2	0.35	4.5
2020	4.3	0.65*	5.0	5.1	0.76*	5.8
2030	4.7	0.86*	5.6	6.2	1.22*	7.5

* It is assumed from 2015 that villages in North Tarawa will be supplied with piped water with a 25% loss rate.

8.4 Required Water Production and Sustainable Yield in South Tarawa

The required water production for South Tarawa with 25% water losses is illustrated in Figure 7 where it is compared with the current sustainable groundwater production rate from Bonriki and Buota. With 50% water losses, the amount of water production needed to satisfy the estimated demand and losses in South Tarawa even in 2005 was over 2.8 times times the combined sustainable yields of the Bonriki and Buota groundwater reserves. With 25% losses, this reduces to 1.9 times the sustainable yields. By 2030, for 50% water losses, the production required for South Tarawa varies from 7.1 to 9.4 ML/day. If water losses can be reduced to 25%, this range for 2030 would be reduced to 4.7 to 6.2 M/day.

It is clear that 50% losses (Table 37) impose an enormous burden and cost on the water supply system. If these can be reduced to 25% (Table 38), the task of satisfying demand will be more efficient and more economic. The highest priority in improving water supply in South Tarawa is to identify water losses and to reduce them.

The South Tarawa Full population model, in which the population is assumed to be only 50,000 in 2030, obviously has a lower total water demand. Even with this somewhat unrealistic population projection, by 2030 estimated demand will be over 3.5 times the current combined sustainable yield of

Bonriki and Buota water reserves, if water losses continue at the estimated 50% losses. This could be reduced to less than 2.4 times the combined yield, if water losses are reduced to 25%.

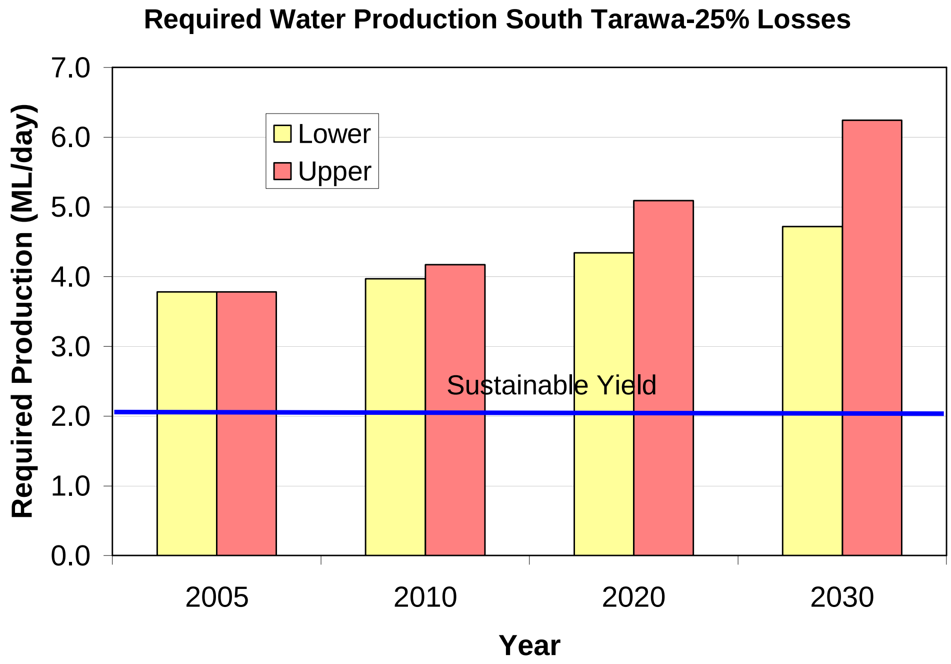

Figure 7 Estimated water production rates required to meet the projected future water demands in South Tarawa for lower and upper bound population growths with an assumed water loss rate of 25%. Solid blue line is the combined sustainable yield of Bonriki and Buota water reserves.

8.5 Water Demand in North Tarawa

In contrast to South Tarawa, North Tarawa appears to have more than adequate supplies of groundwater to meet its future needs. Even though these need to be confirmed by continued monitoring, it has been estimated that North Tarawa (excluding Buota) has groundwater with a sustainable yield of between 1.5 and 4.2 ML/day (White and Falkland, 2009b). Comparison with Table 37 and Table 38 shows that the lowest estimate in this range of yields is greater than the estimated upper bound of demand in North Tarawa with 25% water losses. Because North Tarawa is considered to have “excess” water over the needs of its local population, it has long been considered as a potential source of water to supplement supply for South Tarawa (see e.g. AGDHC, 1982). Metutera (2002), however, points out that the long-standing continuing problems over the creation of water reserves on privately owned land in Bonriki and Buota indicate that sourcing water from North Tarawa may be very problematic.

Since all the required water production rates for South Tarawa in Table 37 and Table 38 are greater than the sustainable groundwater yield from the four accurately assessed water lenses in neighbouring North and South Tarawa (Bonriki, Buota, Abatao and Tabiteuea), potential options for supplying the required future water production need to be found. This will be examined in separate components of the TWMP (White and Falkland, 2009c; 2009d; and 2009e).

In the final section of this component, the population in South Tarawa and Buota that can be sustained from current groundwater sources in Bonriki and Buota is examined.

8.6 Sustainable South Tarawa and Buota Population for Current Treated Water Supply

This section examines the South Tarawa and Buota population that the current treated groundwater sourced from Bonriki and Buota water reserves can sustainably support. The assumption here is that the required per capita total freshwater demands are as given in Table 27. The combined sustainable yield of Bonriki and Buota is taken to be 2.01 ML/day (Falkland, 2004). Again, two water loss rates are considered, 25% and 50% of total production. With these assumptions, the population in South Tarawa and Buota that can be supported by the current treated water sources is given in Table 39.

Table 39 Estimated populations in South Tarawa and Buota with the total water demands in Table 27 that can be sustainably supported by current treated water sources.

Water Losses	Sustainable Population
25%	22,000
50%	14,700

The information in Table 39 is very sobering. With the estimated current lloss rate, the population in South Tarawa and Buota that can be sustained at the per capita design demand by the current treated water sources at Bonriki and Buota is about one third of the current population in South Tarawa and Buota. Even if better management reduces the pipe loss rate to 25%, the sustainable population is about half the current population of South Tarawa and Buota. This clearly demonstrates that the main threat to providing adequate supplies of safe freshwater in South Tarawa and Buota is the large number of people there, not climate change.

9 Demand Management

A central problem in Tarawa is the strong linkage between rainfall and sea surface temperature. This means that Tarawa oscillates rapidly between having too much water and being in major drought (White and Falkland, 2009a; d). With too much water, there are few incentives to conserve water until the onset of drought when it is often too late for conservation.

The ability to control demand for water and to limit profligate use and wastage of Tarawa's precious water resources is a key factor in managing piped urban water supply systems. Demand management has long been recognised as a critical issue in conserving scarce water supplies in Kiribati and was one of the issues raised early in South Tarawa's transition from household well and communal tank water distribution systems to a piped water supply system (Harrison, 1980). Harrison noted cultural constraints to controlling demand, including the notion that because landowners traditionally owned underlying groundwater, there was an underlying belief that water should be free. Harrison observed: "…*the group of people using a tank in major urban areas do not share any sense of organization. The neighbourhood groups… have no mechanisms of social control related to themselves."*

Harrison's observations must be interpreted in terms of past practices. In the past and in rural areas currently, water management 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.

9.1 Behavioural Change

Previous reports have recommended public education campaigns aimed at conserving water (e.g. AGDHC, 1986; OEC, 2000) as a way of voluntarily controlling demand. The most recent were conducted as part of the SAPHE campaign. Such short duration 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 a recognition that all will benefit from cooperative, community-focussed actions. It is suggested that the following could be useful idicators 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

9.2 Demand Control Mechanisms

There appears to be currently no legal mechanism in place for controlling excessive water use in Tarawa. A single landowner in a narrow part of Tarawa could use a large electric pump in a vertical household well to pump excessive volumes of water from the island groundwater lens, resulting in the lens becoming saline and of no use to neighbours. There appear to be no legal restrictions preventing this, since there is no national water legislation specifying who owns groundwater resources. The draft National Water Resources Act 1994 has never been tabled in parliament or reviewed for current suitability.

The traditional way of controlling demand is to meter water use and to charge for the quantity of water used by the consumer. The design for the SAPHE Project (OEC, 2000) envisaged that every connection to the piped water system would be metered to enable charging based on consumption. Originally the PUB had envisaged a progressively increasing, three-tiered charging scheme that imposed increasing tariffs when threshold consumptions were exceeded. The PUB business Plan 2004-6 (PUB, 2004) planned a charging system based on metered use.

OEC (2000) also considered that the installation of 500 L trickle-fed water tanks, which took 24 to 48 hours to fill, at every household connection would restrict excessive use and allow a continuous water supply. As shown in Table 4, not all house connections were upgraded under SAPHE, and neither was there wide-scale installation of water meters. In the past, households in Tarawa have illegally by-passed water meters. After the installation of the trickle-fed tanks under SAPHE, many households removed the trickle feed control thereby removing one of the means for controlling demand at the household level. Consequently, the PUB (2004) has returned to the previous fixed monthly charge for household water use which does not control excess use[16]. Those households that are closer to the head supply tanks therefore access more water than household at the end of the distribution system and the system is clearly inequitable.

The only mechanism currently 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 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 (Table 12); and intermittent supplies are prone to bacterial build-up in supply lines (AGDHC, 1986).

One of the problems faced in tariff structures for water in Tarawa is the number of households with very limited capacity to pay for water (PUB, 2004). Metering consumption of water and tiered charging appears 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.

9.3 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.

One strategy often used to control leakage is to reduce the water supply pressure head. In the urban villages along South Tarawa, this head is set by the head tanks and ranges between 6 to 8 m of water. There seems almost no potential to lower this head further. In Betio, the head is about 15 m, and there may be some opportunity to reduce this head provided that the major leakages in the local distribution systems are minimised. Tungaru Central Hospital at Nawerewere has a high level pressure head tank which should be replaced with a lower level head tank to reduce leakage, pump maintenance and energy consumption.

9.4 Population Pressure

In section 8.6, it was suggested that the population that can be sustained by the current treated, piped water supply in South Tarawa with the present estimated leakage is about one third of the current population. The number of people in South Tarawa is a major factor in the growing demand for water. The census results (NSO, 2007b) indicate that population growth rates in South Tarawa decreased

[16] Tanker deliveries of water to households and businesses do charge for consumption. However, there is no extra penalty for excessive water use since repeated deliveries are at a flat rate.

significantly between 2000 and 2005 to almost the national growth rate. One interpreation for this offered by the NSO was that South Tarawa was “full” with people actually migrating from South Tarawa to both North Tarawa and the Line Islands. Here that has been used to estimate a lower bound projection of population of 50,000 by 2030. There is no guarantee that this will actually be the case.

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 subsidied by the rest of Kiribati. One possible disincentive to further increased settlement in South Tarawa could be a South Tarawa household tax to cover the costs of these services.

9.5 Drought Contingency Planning

Lengthy, severe droughts are common in Tarawa (White and Falkland, 2009d). 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.

9.6 Demand Management, Difficult but Necessary

It is recognised that 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.

10 Concluding Remarks

This component of the TWMP has estimated the future water needs for Tarawa. Tarawa is an island in transition from largely subsistence, rural lifestyles, still largely followed in North Tarawa, to high-density urban living in South Tarawa. Over the last 50 years, demographic and socio-economic factors have changed dramatically. This means that the traditional adaptation strategies developed over 4,000 years of subsistence in small islands are largely ineffective.

Examination of water sources used by people in Tarawa shows a wide variety of sources of water in current use: local groundwater in vertical shallow household wells or bores, close to the household; piped or reticulated water, treated and supplied by the PUB from groundwater reserves at Bonriki and Buota; rainwater mostly stored in household raintanks; bottled water both imported and produced locally; and seawater for bathing and toilet flushing. The 2005 Census data shows that households use multiple sources of water to supply their needs with currently only two thirds accessing the treated PUB supply. Over 50% of households in South Tarawa still use open household water wells for drinking water, despite the risks of health impacts due to overcrowding. In North Tarawa that percentage is over 80%, close to other Gilbert Group islands.

An analysis of the use trends of different water sources from 1990 to 2005 revealed that there has been a decrease in the percentage of households using the PUB piped and treated water and an increase in the percentage of houses using open household wells in South Tarawa. Since the risk of contamination of domestic wells is high, these trends indicate increased risks of adverse health impacts. The percentage of households using rainwater has increased significantly since 2000. This appears to be due to the SAPHE Project revolving fund for the purchase of raintanks and also possibly due to the impacts of the 1998 to 2001 drought.

Past estimates of design demands used in previous water supply projects in South Tarawa, based on assumptions about the quantity of water required to meet domestic and other needs, were examined. It is very difficult to estimate the total fresh water demand in Tarawa due to the following factors:

- little reliable data on the actual freshwater use by households
- very little quantitative data on use of household well water
- no database on extent of rainwater collection and use
- no metered household consumption figures
- almost no published information on ICI water use
- no flow monitoring at connections in the piped water systems, and
- high but unmeasured leakage in piped systems, particularly the urban distribution systems in South Tarawa.

Faced with this difficulty, the approach adopted in the past by a range of water supply projects over the past 36 years has been to assume a design target per capita demand in line with assumed estimates of minimum quantities required for consumption, cooking and hygiene. These estimates have ranged from about 6 to 100 L/pers/day and some have involved estimates of water requirements depending on the type of house being supplied and the availability of rainwater tanks. The SAPHE Project, completed in 2005, even assumed that only a fraction of households were to be supplied with treated piped water. Many estimates have been based simply on how much water is currently available without considering actual household needs. The earliest estimates in Tarawa are small and are largely irrelevant to modern Tarawa.

Only three separate estimates of the actual amount of water consumed by households in Kiribati were found: an early set of measurements in Betio; more recent estimates in the outer island of Nonouti and in the rural, semi-urban and urban villages in Kiritimati. The Betio estimates are discounted because the situation in Tarawa has changed dramatically since then. The Nonouti and Kiritimati data were then used to estimate the domestic per capita demands in North and South Tarawa. Previous studies have pointed out that it is extremely risky to continue to use household wells for water supplies in

South Tarawa, due to overcrowding and sanitation practices. It was therefore assumed that all household water needs in South Tarawa except toilet flushing would be met from the piped water system. To these estimates were added assumed water requirements for ICI uses which were assumed to be 10% of domestic demand. No piped water was assigned to irrigation or toilet flushing in South Tarawa.

It is assumed that irrigation needs can be met by local household wells and recycled grey water and that toilet flushing can either be supplied from household wells or possible future piped seawater sewerage system. A small fixed allowance was incorporated to allow for the impacts of global warming due to climate change. With these assumptions and the information from Nonouti and Kiritimati, the total combined per capita needs for South Tarawa were 68 L/pers/day and 65 L/pers/day in North Tarawa where ICI needs are smaller. Two water loss rates from the piped distribution system were assumed, 50% of total production, estimated to be approximately the current loss rate and a future design target of 25% of total water production

Two population models were used to estimate the bounds of possible future populations in Tarawa. The first (exponential) model assumed that the exponential growth rates for North and South Tarawa found between the 2000 Census and the 2005 Census, would continue from the populations in the 2005 census into the future. In this upper bound model, South Tarawa grows very slightly faster (0.1%) than the total Kiribati population while North Tarawa continues to grow much faster than the national rate (4.8%). The second model adopts a conservative estimate that South Tarawa is “full” (NSO, 2007b). It assume that South Tarawa is so overcrowded that it no longer attracts outer islanders or local residents. In the lower bound model, the population slowly increases linearly from its value in the 2005 Census to only 50,000 people in 2030.

With these two population models and an assumed water loss rate of 50% it is estimated that the water production needed to meet the assumed demand and pipe water losses in South Tarawa in 2030 will range from between 7.1 and 9.4 ML/day. The required rates are 3.5 and 4.7 times the sustainable yield of the current treated water sources in Bonriki and Buota (2.0 ML/day). If the water losses can be reduced to 25%, the estimated water production range needed to meet the assumed demand and water losses in South Tarawa by 2030 will range from 4.7 to 6.2 ML/day. The production rates are about 2.4 to 3.1 times the sustainable yield of the current treated water sources in Bonriki and Buota. The importance of reducing leakage as a high priority, first step is clearly evident.

Using the sustainable yield for the combined Bonriki and Buota water reserves and the estimated water requirements in South Tarawa and Buota (Table 27) an estimate was made of the population that can be sustained by the current water sources. For 50% water loss rates the population is 14,700 while for 25% loss rate the population is 22,000. These are about a third and a half, respectively, of the current population in South Tarawa. The biggest threat to sustaining the population in South Tarawa is not the impacts of climate change but the large number of people living in South Tarawa.

Tarawa is a freshwater-scarce atoll yet it has almost no equitable ways to control water demand. At present, the only means available to control demand is through the intermittent supply of free water. This is less than satisfactory. It encourages waste and does not control profligate use so there are great inequities in water availability. Metering consumption of water and tiered charging appears the only sensible means of controlling excessive demand provided that it is well managed and contains measures to provide for the disadvantaged. By far the most profligate consumption of water is through leakages from the reticulation system, particularly the domestic reticulation system. Minimising excessive leakage from local piped distribution systems is the highest priority task. Until leakage can be better controlled, consideration should be given to closing down excessively leaking sections of domestic reticulation systems and reverting to distribution from centrally-located storages or tankers for which a charge is made. The possibility of imposing a Tarawa household tax to pay for the extra services provided there and to act as a disincentive for further migration to Tarawa could also be considered. In addition, the legislative basis for managing water in Kiribati should be reviewed and strengthened or replaced.

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