Theme 1: Water Resources Management

Case Study:

Water Management in Kiribati With Special Emphasis On Groundwater Development Using Infiltration Galleries

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Background of Water Resources Development in Kiribati

South Tarawa is the capital of the Republic of Kiribati where all government institutions are located and where about 43% percent of the national population (2000 census) resides. Tarawa (see Figure 2) is administratively divided into North Tarawa (Buota to Buariki) as a rural area and South Tarawa (Betio to Bonriki) as an urban area. The total population of Kiribati according to the 2000 population census is 84,460 of which 36,227 lived on South Tarawa.

The major water sources in Kiribati and Tarawa in particular, are groundwater and rainwater. A study conducted in 1981 by the Australian government (AGDHC, 1982) concluded that groundwater offered the greatest potential for implementation of a reticulated water supply system. Based on that finding an extensive study was made of the freshwater lenses (also called 'water lenses') of Tarawa from Bonriki to Buariki in the north of the Tarawa atoll. The study recommended the use of infiltration galleries as the best method for water extraction from Bonriki and Buota water lenses.

Fresh ground water occurrence of significant extent is, in general, limited to larger islands, where lenses of freshwater 'floating' on seawater have developed in the underground (see Fig. 1). Generally, freshwater lenses occur on those parts of islands where the central area of coral sands and gravel is sufficiently wide (over 250-300 m approximately). The head of freshwater above sea level controls the thickness of the freshwater lens below sea level. According to the Ghyben-Herzberg theory, a freshwater table elevation of 1 m above sea level would correspond to freshwater depth of 40 m below sea level to the interface between fresh and seawater. This is due to the difference in specific weight between freshwater (1.000) and seawater (1.025). In practice, freshwater and seawater mix, largely due to the influence of ocean tides, forming a transition zone and not a sharp interface. The actual depth to the base of the transition zone is generally greater than, and the depth to the base of the freshwater zone is less than 40 m below sea level per 1 m above sea level. In practice, the elevation of the freshwater table is generally much less than 1 m and hence the depth of the transition zone is less than stated above.

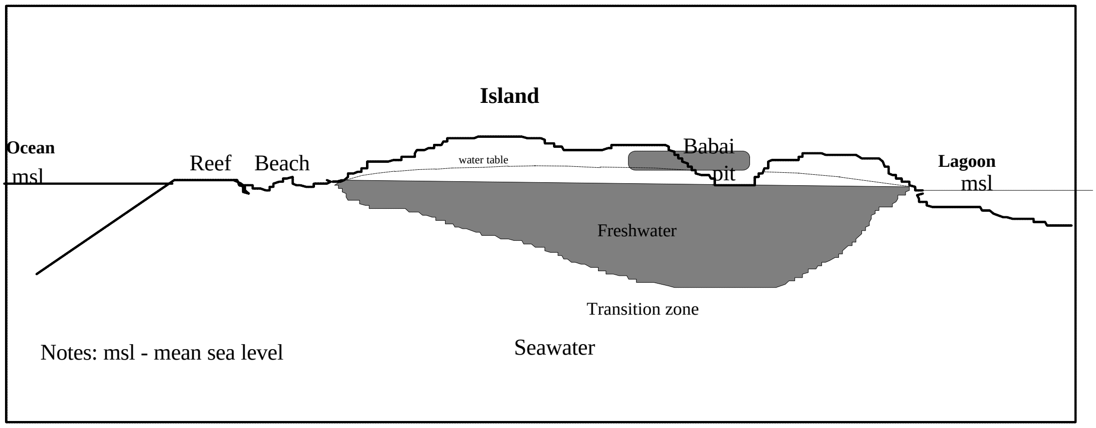


Figure. 1: Typical Cross-Section of Freshwater Lens on a Coral Island

The exclusive source of recharge of freshwater lenses in coral islands is local rainfall. The rate of infiltration is generally high in very permeable coral sands and gravels. Part of the infiltrating water is lost again through evapotranspiration, particularly in areas having coconut plantations and a thick cover of other vegetation. A movement of fresh groundwater towards the sea and the lagoon and mixing of freshwater with underlying saline water counterbalance the recharge of the freshwater lens by the remaining amount of infiltrating rainwater.

Open hand-dug wells have been the traditional method used by the I-Kiribati people to obtain freshwater for their basic needs. As the depth from the surface to the groundwater table is generally just a few meters and the soil is fairly easy to excavate by hand, open wells, or rather pits, 1-2 metres in diameter, are excavated to some 30 to 50 cm below groundwater table. The walls are usually supported by stones and the well is left uncovered, for everyone to scoop up water as needed. This method has the obvious drawback of being a health hazard, as the water is exposed to contamination. With the introduction of pit latrines in numerous villages in recent years, their proximity to the hand-dug wells is causing many wells to become unsafe for drinking, as contaminated groundwater can in a short time flow into the dug wells. In high-density housing areas such as South Tarawa all of the remaining old open dug wells are now a severe health hazard and are used now as second-class water.

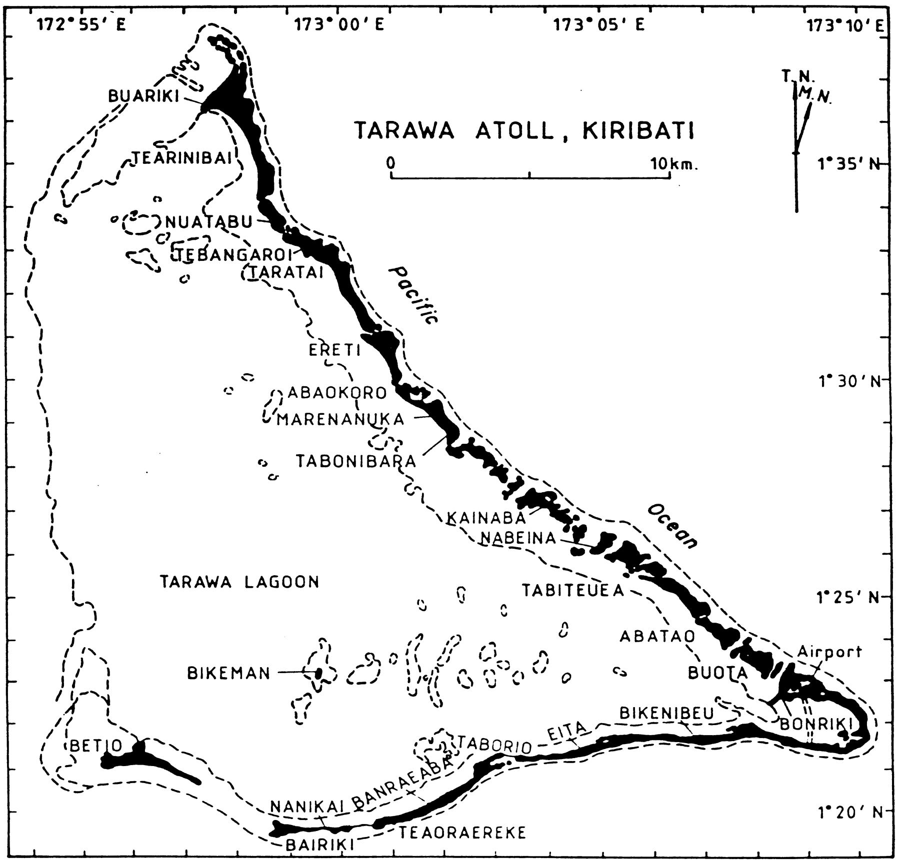


Figure 2. Map of Tarawa

Because of the high pollution level of groundwater wells in the villages, which is closely associated with high-density housings, the public water supply system was designed with the water source located away from populated areas on South Tarawa. The traditional method of water extraction from wells cannot be applied for the public system as it involves pumping a huge amount of water. The method of water extraction for the South Tarawa Water Supply System is via infiltration galleries, which have been used since the late 1960's. Infiltration galleries are used for the large scale pumping on some coral islands where water is scarce. The design of the original infiltration galleries was based on the use of concrete blocks as conduits. This was later modified with the use of perforated PVC pipe as conduit for the galleries.

In 1983, the South Tarawa Water Supply Project was implemented by the Australian Department of Housing and Construction using infiltration galleries as a method of large scale pumping. Construction work was completed in 1987 with most households in South Tarawa having individual metered house connections. Immediately after the commissioning of the South Tarawa Water Supply system it was found out that the system could not cope with the twenty-four hours supply. This was due to the limited water source, demand for water was greater than the design demand and the number of connections is more than anticipated in the design. Also the drought in 1989 increased demand further, thus making things worse.

The Public Utilities Board, a government owned corporation, was established on the 1st July 1977 with a mandate under the Public Utilities Ordinance to run the water supply, sewerage and electricity services to people on South Tarawa including government offices and the commercial sector. It is estimated that 60% of the people living on South Tarawa are relying solely on the PUB water, while the remaining still use well water and rainwater. During the drought from 1998 to 2000, more people relied on PUB while less than 10% relied on rainwater tanks and groundwater wells.

2. Technical Description of Infiltration Galleries.

The infiltration gallery method is used for groundwater extraction from lenses on some low-lying coral islands in the Pacific and the Indian Oceans. The infiltration gallery skims water off the surface of the lens, thus distributing the pumping over a wide area. This distributed pumping can avoid the problem of excessive drawdown and consequent up coning of saline water caused by localised pumping from individual wells.

In general, the infiltration galleries can be divided into two categories:

1. Open Trenches; and
2. Buried conduits (See Diagram below)

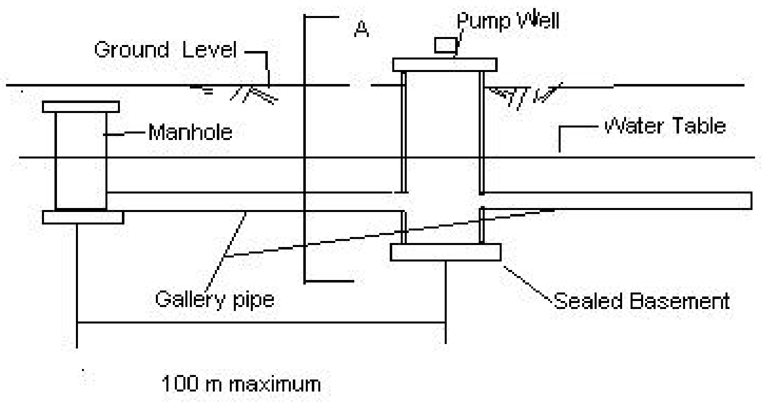
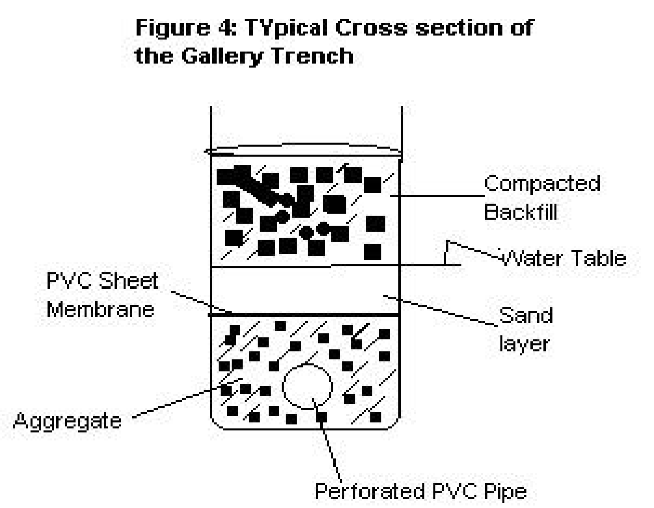


Figure 3: Typical Cross Section of infiltration gallery constructed from horizontal perforated pipe



The open trench type of gallery was formerly used on Kiritimati Island in the Northern Lines islands of Kiribati. These have been changed to the buried conduits under a current AusAID funded water supply and sanitation improvement project on the island.

The buried conduit type of infiltration gallery has been proved to be the most effective type. The ideal location for infiltration galleries is in open areas such as airfields, sport fields and recreational reserves. It is generally found that in such areas, the water lens is thick than elsewhere. A good example of this is the Bonriki water reserve, which has the thickest lens on South Tarawa and is located adjacent to the Bonriki International Airport. An open area such as the airport acts as a catchment that can rapidly recharge the aquifer after heavy rain. Also, evapotranspiration is lower as there are no trees.

The gallery should consist of some form of horizontally laid permeable conduit to allow water to infiltrate from the surrounding saturated zone. Slotted or perforated PVC pipes and porous concrete blocks made from fine aggregates have been found to be suitable conduits. Slotted PVC pipes conduits have the added advantage of being easy to clean, if required, and hence are preferred.

Generally, one pump per gallery is sufficient. Joints between the pump wells and incoming infiltration gallery pipes and the pump well basement slab should be sealed. This measure is important to ensure that the only water entering the pump well is through the slots in the conduit pipes and hence prevent local over pumping with consequent excessive drawdown and possible upconing of the transition zone.

Based on previous studies (Mather 1975, Peterson 1985, Falkland and Custodio, 1991) regarding the most appropriate gallery layout design, the layout should be parallel to the edges of the lens, and not perpendicular to them, except near the centre. The most appropriate layout of the gallery for the island of Tarawa, some of which have limited lateral extent and thin freshwater zones, is a linear system. The Bonriki lens is relatively thick compared with other atolls. The South Tarawa Water Supply Project adopted the linear system.

The water source for the South Tarawa water supply system comes from 24 infiltration galleries located on two islands namely Bonriki and Buota. There are six (6) infiltration galleries on Buota and seventeen (17) on Bonriki using a new design of infiltration gallery using perforated pipe as a conduit.

There is one old type of gallery still used on Bonriki making up the total of eighteen (18) galleries on Bonriki. Gallery layout plans of Buota and Bonriki are shown in Figures 5 and 6. The length of each of the 23 galleries using perforated pipes is approximately 300 m. Thus the total lengths of these galleries are 5,100 m for Bonriki and 1,800 m for Buota.

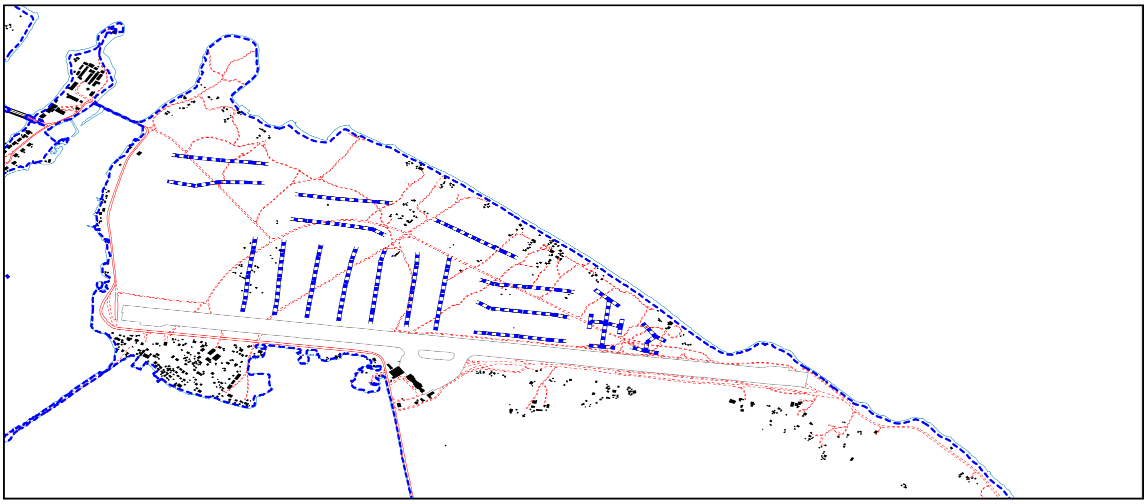


Figure 5: Map of Bonriki showing Gallery Layout

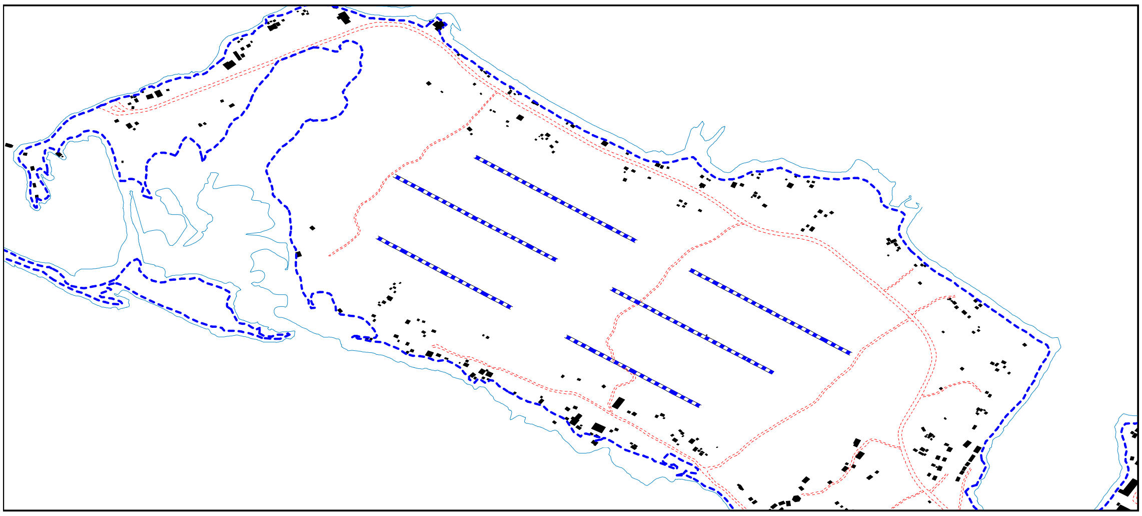


Figure 6: Map showing Gallery Layout on Buota

The amount of water extracted from the Bonriki and Buota galleries on a daily basis since 1989 has been about 1100 m^3/day. It was found this pumping rate was in theory exceeding the original estimate of sustainable (safe) yield of 950 m^3/day (AGDHC, 1982: refer Table 2). Because of this anomaly, the PUB requested the Australian government to conduct a review study of the sustainable yields for the Bonriki and Buota water lenses. A review was carried in 1992 (Falkland, 1992) and a revised sustainable yield of 1,300 m3/day was estimated. The revised sustainable yields estimates were 1000 m^3/day and 300 m^3/day for Bonriki and Buota, respectively.

Under the on-going Sanitation and Public Health Environment (SAPHE) project a further review of sustainable yields was carried out following a long drought of 1998-2000 when the total annual rainfall for Tarawa was well below average. The total annual rainfall during the drought was 629 mm, 646 mm and 902 mm in 1998, 1999 and 2000, respectively. The average annual rainfall for Tarawa is approximately 2000 mm.

The revised sustainable yield estimates for the areas of current infiltration galleries at Bonriki and Buota are 1350 m^3/day and 350 m^3/day, respectively (Alam et al, 2002). The review was based primarily on the performance of the water lenses during the 1998-2000 drought when not even a single gallery was shut down due to elevated salinity. The salinity (measured in electrical conductivity or EC units) of the water in each gallery never exceeded 2,000 ?S/cm.

3. Use of Infiltration Galleries to maximise Sustainable Yields

The use of infiltration galleries in Kiribati dates back from the 1960's. Six short infiltration galleries were constructed on Bonriki (3) and Buota (3). It was predicted during those days that the water lenses at Bonriki and Buota could be used at a constant pumping rate even during long droughts (AGDHC, 1975). Table 1 exhibits the estimated yields of the Bonriki and Buota galleries and other galleries at Temaiku and Teaoraereke during "good seasons" and "drought periods". It was estimated in AGDHC (1975) that the latter galleries could not be used during the drought periods.

Table 1: Sustainable Yield Estimates of early galleries.

	Yield	
Lenses	**Good Season**	**Drought Period**
	m^3/day	**m^3/day**
Buota	91	91
Bonriki	91	91
Temaiku	45	Nil
Teaoraereke	68	Nil
Totals	**295**	**182**

Source: Operation and Maintenance Manual for the South Tarawa Piped Water Supply System (AGDHC, 1975)

The first galleries at Bonriki and Buota consisted of flat-graded runs of hollow concrete building blocks dry butt-jointed, with inverts at or near mean sea level. These were constructed with large size gravel acting as a screen around the porous concrete block underdrain. The total lengths of the gallery arms ranged from 8 to 15 meters. There were four gallery arms arranged in radial or cruciform pattern. The water was pumped from a pit located at the centre of the four (4) arms. The pit was typically 1.5 m by 3.5 m in plan and made of concrete block wall.

In the outer islands of Kiribati, similar infiltration galleries were constructed on Nikunau, Arorae and Tabiteuea South to feed windmill-pumping systems. These systems were constructed in the early 1970's with funding assistance provided by the then South Pacific Commission with funds provided by the World Health Organisations. This was done in response to the 1972-1973 droughts, which struck the country, mainly the islands in the southern Gilbert group.

Using the new gallery design, using perforated PVC as conduits; the safe yields of the Bonriki and Buota lenses have been reviewed from time to time based on the performance of the lens during droughts. Table 2 below tabulates different safe yields of the Bonriki and Buota lenses, using different phases and methods of groundwater modelling. The 1981 estimates used a sharp interface model, utilising very limited groundwater monitoring data (AGDHC, 1982). The 1992 estimate was done again using a sharp interface model but was based on more than 10 years of groundwater monitoring data (Falkalnd, 1992). The 2002 estimate was modelled using a dispersion type of model SUTRA developed by the US Geological Survey (Alam et al, 2002). This model has also been used for freshwater lens modelling on small coral in the Pacific and Indian Oceans (e.g. Marshall Islands, Griggs and Peterson, 1989, and Cocos (Keeling) Islands: Alam and Falkland, 1998 and Tarawa, Alam and Falkland, 1997)

Table 2: Sustainable Yield Estimates of the current Bonriki and Buota infiltration galleries.

Water Lens	1981 Estimated Safe Yield [1]* (m^3/day)	1992 Estimated Safe Yield [2]** (m^3/day)	2002 Estimated Safe Yield [3]*** (m^3/day)
Bonriki	750	1000	1350
Buota	200	300	350
TOTAL	**950**	**1300**	**1700**

Note: [1] * AGDHC 1982, [2] ** Falkland 1992, [3] *** Falkland et al 2002.

4. Performance of the Infiltration Galleries during the drought.

The salinity (EC) of the individual gallery wells were regularly monitored during the 1998-2000 drought. The graphs in Figure 8 exhibit the conductivity readings of the a few galleries at Bonriki and Buota to show how these performed during the drought. The readings were taken during the 1998-2000 drought and another round of readings at the end of the drought in early 2002.

The best way to monitor the performance of the water lens is to measure the EC of the water lens at different depths. This was done using the special multi-level monitoring boreholes drilled to depths varying between 21 and 30m at Bonriki and Buota. For most boreholes the monitoring depths (depth of monitoring tubes) are 6m, 9 m, 12 m, 15 m, 21 m and, if drilled deeper than 21m, additional monitoring depths of 24 m, 27 m and 30 m.

Figure 7 exhibits the depth from groundwater surface to selected salinity (EC) values within the freshwater and transition zones of the water lens at Borehole BN16, which is located in the centre of the Bonriki lens. This borehole has a depth of 30 m. The base of the freshwater zone can be described by the 2,500 ?S/cm line while the mid-point of the transition zone can be described by the 25,000 ?S/cm line. From the graph it can be seen that at some stage between 1992 – 1994 the depth of the freshwater zone was about 25 m. During the 1998-2000 drought the depth of the freshwater zone was less, being in the range of 10 – 15 m. The exact depth of the freshwater zone could not be determined at this borehole during the 1998-2000 droughts due to the effects of vandalism of some of the monitoring tubes. However, comparison with other nearby boreholes, suggest that the minimum thickness of the freshwater zone in the centre of the island was approximately 10m

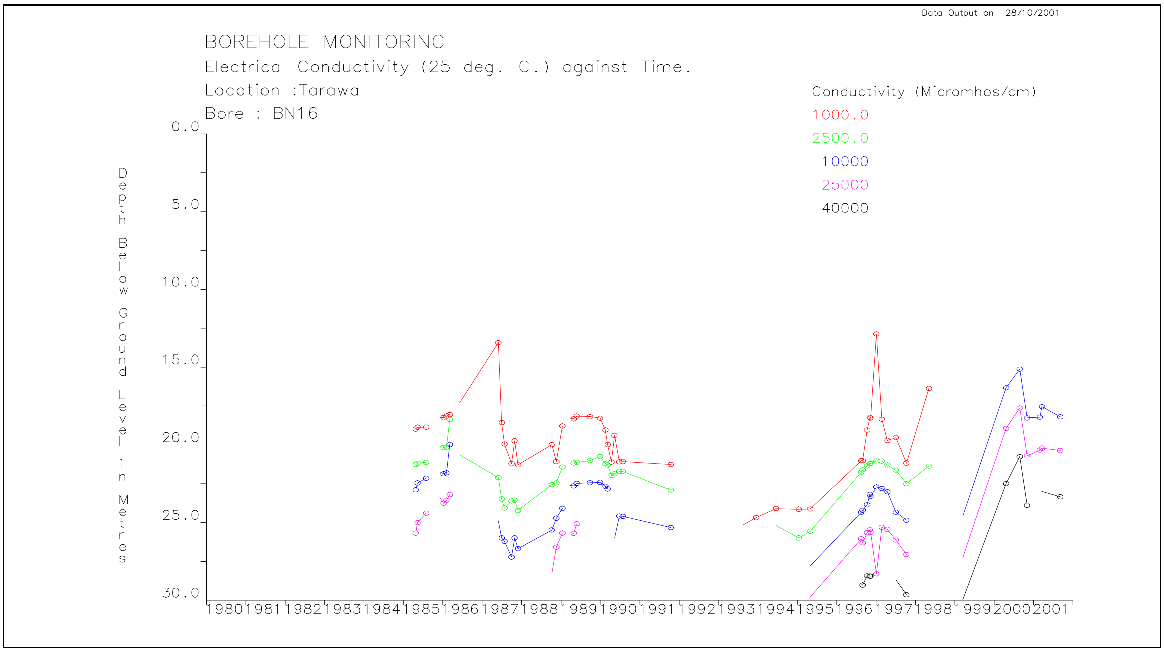


Figure 7: Borehole BN 16 showing salinity (EC) variations from 1985 – 2001.

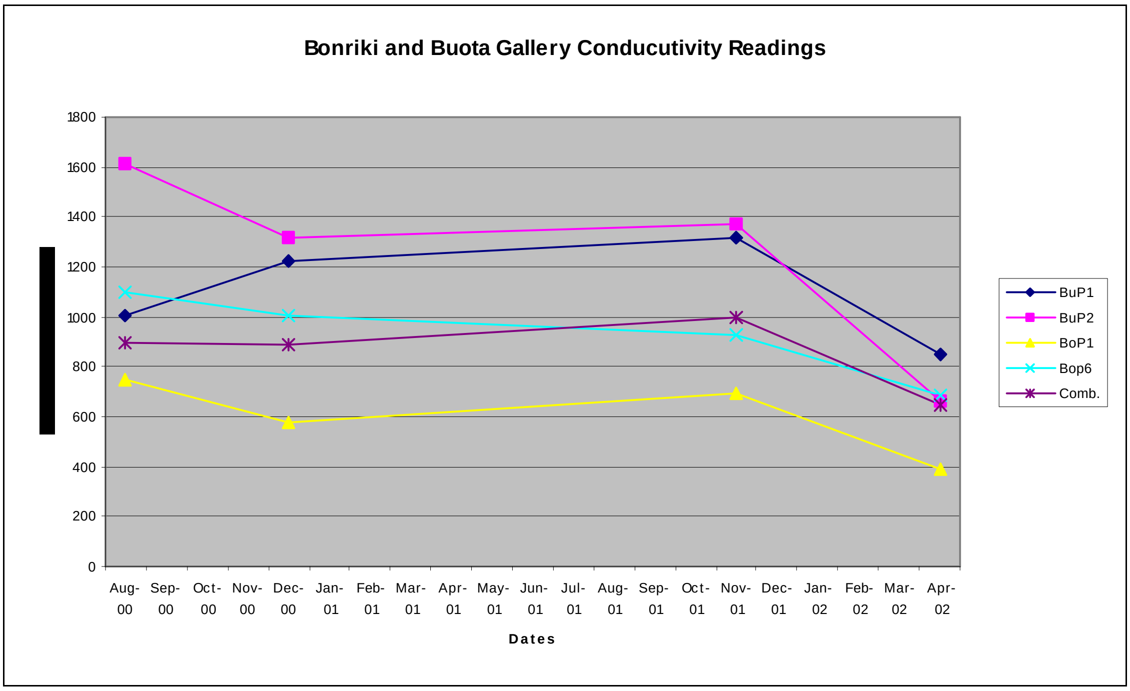


Figure 8: Salinity (EC) of Gallery Wells during the 1998-2000 drought and the 2002 rain.

The interesting feature of Figure 8 is that the EC readings of the galleries did not change much during the drought. The most important EC reading is that for the blended water from all the galleries taken at the chlorination unit. This is the kind of water quality that reaches PUB water consumers and should be acceptable for drinking. The highest reading during the drought was 1000 us/cm, which is acceptable for drinking purposes. Another interesting feature is that after heavy rain in late 2001 and early 2002, the EC reading of the blended water dropped from 1000 us/cm to 650 us/cm. The latter EC reading is one of the lowest measured in recent years. This shows the relatively quick recovery of the freshwater lenses from stressed (high salinity) conditions to more normal salinity condition.

It can be concluded that the infiltration galleries are performing well in meeting their design objectives of minimising the drawdown of the water level to avoid up-coning of saline water and hence avoid an increase of salinity in the pumped water.

5. Other Water Sources for South Tarawa

5.1 Rainwater

Apart from the groundwater sources at Bonriki and Buota, the people of Tarawa are using rainwater as a supplementary water source. Also groundwater wells are used by individual households to supplement the PUB water. There are households on South Tarawa, especially in areas where the PUB water does not reach, which have to rely solely on groundwater wells and rainwater. This water (groundwater well and rainwater) is not treated and can pose a health hazard to people using it. There is evidence of a high incidence of diarrhoea disease on South Tarawa because people still use untreated groundwater from wells and rainwater (which can also be contaminated from bird droppings and unhygienic guttering system).

Rainfall utilization as a source of water, for drinking as well as for other purposes, has been in practice in Kiribati for many years. Water tanks of all sorts of materials and sizes have been installed by individuals and by public institutions, churches, etc., to collect rainwater through roof gutters. The vital importance of utilizing rainwater as much as possible has long been recognised by the I-Kiribati, as evidenced by the recent enactment of regulations obliging house owners to construct gutters and tanks for the collection and storage of rainwater.

Table 3: Mean Monthly and Annual Rainfall (mm), 1951-80 for some of the Gilbert Group Islands

Island	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Butaritari	291	334	380	337	297	264	276	220	163	158	204	301	3227
Tarawa	304	227	234	172	137	132	149	116	113	99	114	194	1991
Banaba	271	226	172	144	114	103	118	101	89	110	108	215	1771
Abemama	221	189	135	238	85	101	119	96	88	81	96	184	1633
Beru	205	127	101	99	91	84	113	100	72	68	83	147	1290
Arorae	232	139	114	148	124	93	132	108	98	73	97	192	1550
Kiritimati	95	64	99	177	81	87	77	42	31	33	40	44	870

In principle, direct utilization of rainwater is a more efficient way of freshwater production than groundwater extraction, since fresh groundwater can only be extracted where sizeable lenses occur, and then only a small percentage of the mean annual rainfall on these lenses can be safely extracted over the long term. Rainwater catchments, by comparison, can catch up to 90% of the precipitation.

On the other hand, due to the marked unevenness of precipitation, frequently manifested in months-long droughts, the use of rainwater for consumption requires construction of large storage facilities, whereas the atoll aquifers - albeit relatively limited in size and sensitive to improperly designed and operated extraction - have an inherent storage capacity that enables a constant withdrawal, based of their sustainable yield estimates.

Consequently, rainwater collection from roofs can be regarded as a supplementary, rather than a main source of water, because the tanks normally built, or normally affordable by individuals and by institutions, do not have sufficient volume to store and supply water during prolonged drought periods.

5.2 Desalination

Desalination technology was introduced in the country at the height of the 1998-2000 droughts. In early 1999, two desalination plants were procured and funded by the government. One plant with the capacity of some 10 m^3/day was installed on Banaba Island to help alleviate the water shortage problem there. Another plant with the capacity of 110 m^3/day was installed on Betio, the most populated islet on South Tarawa, to help alleviate the water shortage problem. Toward the end of 1999, the government of the Peoples Republic of China donated two desalination plants with a capacity of 50 m3/day each. These two plants were installed at the Central Hospital and one at the government owned Hotel, in South Tarawa.

The desalination plants installed at the Hotel and the Central Hospital are now not working due to mechanical and electrical faults. The desalination plant installed on Betio is still working well. The water produced from the Betio desalination plant is pumped direct to the Betio reservoir and is used only for Betio residents.

The PUB experience with the desalination plant on Betio that it is quite simple to operate and maintain provided spare parts are readily available. A good preventive maintenance schedule is very important for the sustainability of the desalination system. Another factor is that one should purchase the desalination plant from a reliable manufacturer with a long history of success. This ensures that spare parts are always available when an order is made.

The problem with the desalination plants at the Central Hospital and the Otintaai hotel is that the PUB finds it very difficult to contact the company who manufacture the plant for spare parts and technical advice. On the other hand the manufacturer of the desalination plant installed on Betio, is in touch with PUB regarding the status of the plants operations and maintenance advice.

6. Groundwater Management and Protection

The most important groundwater sources on South Tarawa are the two water lenses at Bonriki and Buota. These are the only groundwater sources that are currently used for the South Tarawa Water Supply System. The protection of these water sources is of paramount important for the security of the people’s health and well being.

A current major issue is that landowners are residing on the water reserves and this can have an adverse impact on the safety of the drinking water. Removing the landowners from the area is politically impossible. Under the on-going ADB loan funded SAPHE project, a committee on water resources protection has been set up comprising of government officials and representatives from the landowners. Removing or evicting these landowners under the law is possible but in Kiribati government cannot use force. In Kiribati, community consensus and participation on certain issues, such as land and development projects, are necessary and much patience and time consuming groundwork is required before successful implementation is achieved. Land is a very sensitive issue as it is the pride of families to own a piece of land, acquired from their ancestors.

The idea behind the setting up of the Water Resources Protection Committee is to involve the concerned community in the decision making process to protect the water resource. The landowners select members of the committee representing the landowners and their role in the committee is to canvass support in convincing people who are living on the reserve to leave voluntarily. This is a very difficult task, and it will take time before the concerned landowners realise that they should leave the water reserve for the good of the South Tarawa community.

The problem of people living on the water reserve can be very dangerous, as habitation requires a toilet and setting up pigpens and other potentially polluting activities. Allowing habitation on the water reserve will exacerbate the pollution of groundwater in the area. This will mean an increase of water treatment costs, and most water consumers will not be happy to use water that has been contaminated by some people.

Under the on-going Sanitation and Public Health Environment (SAPHE) project, the Asian Development Bank will fund a Technical Assistant to work full time with the committee to work very closely with landowners with the objective of encouraging them to leave the water reserve areas.

7. Cost of Water Resources Development

The available options for water resources development in Kiribati are groundwater, desalination and rainwater. The unit costs of using these sources are discussed below.

Desalination technology was introduced in the country in 1999 to address the water shortage problem on some part of Tarawa the 110 m^3/day capacity desalination plants was installed on the island of Betio. The total cost of the investment was around AUD$300,000 (Australian Dollar AUD$). This includes the cost of the plant itself, construction of the saltwater intake well, construction of the building for the plant and labour cost.

The unit cost of running the plant in terms of electricity cost only is AUD$2.81/$m^3$. Including labour and supervision costs of AUD$1.84/$m^3$ to the total operating cost is AUD$4.65/$m^3$. The cost of electricity is considered an internal electricity consumption of PUB and therefore does not constitute the physical cost, however it should be accounted for in the true costs. The unit cost for spare parts is AUD$0.73/$m^3$ and when included means that the actual unit cost for the operation and maintenance of the desalination plant is AUD$5.38/$m^3$. The PUB bases the calculation for the unit cost of the desalination plant on the operations and maintenance data for the past two years.

The use of rainwater as the main water use would be very expensive in Kiribati, as it would involve a huge investment to construct large-tanks to achieve sustainability in the long droughts. The marked unevenness of rainfall with droughts lasting many months makes the use of rainwater not a viable main water source. However, it must always be considered as a supplementary water source.

The cost of constructing tanks of sufficient capacity to sustain demands during droughts by all the residents of an urban area such as South Tarawa, would be beyond the reach by the majority, and even more so - by village dwellers. There is also the concern that in times of prolonged drought individual rain collection systems cannot be relied upon by the authorities to cover the minimum demand.

In the study for South Tarawa (AGDHC, 1982) the possibility of constructing central collection tanks in the built-up areas of Betio, Bairiki, Bikenibeu and other major centres in order to fill them with rainwater collected from public buildings and other large roofs, and pump this water into the existing system, was considered and rejected. Such a solution entails a rather complicated and costly operation regime and several storage tanks and pumps.

In Kiribati the typical installation cost of the rainwater is on average AUD$30.00/$m^3$. This is based on the cost of the tank and other accessories (normally 15,000 litres capacity tank, roofing material and guttering for roof area of 130 m^2). The cost of the whole building is neglected in the calculation.

The use of groundwater as a major water source is by the far the cheapest option for the water reticulation system (AGDHC 1982). Based on the PUB data the unit cost of running the water supply system using groundwater is AUD$1.40/$m^3$ (this includes the cost of electricity which is AUD$0.17/$m^3$). However, there are other costs, which are not included in the calculation. The land leases for the water reserves are not included because they are not paid out from the PUB budget but rather by the Government. Including the land lease cost in the unit cost of groundwater production and distribution inflates the unit cost to AUD$2.40/$m^3$. However, with the current government policy, the consumers are supposed to pay only AUD$1.40/$m^3$ to the PUB.

It can be concluded then that out of the three water sources options for the main water supply, the cheapest option is groundwater. The electricity cost of running the desalination plant is AUD$2.81/$m^3$, while for groundwater it is only AUD$0.17/$m^3$. This clearly shows that the cost of running the desalination plant is about 16 times more expensive in terms of energy costs than groundwater. Also, if the total operation and maintenance costs are considered, the desalination option (AUD$5.38/ m^3) is more than twice as expensive than the groundwater option (AUD$2.40/ m^3). Rainwater as a main water sources, cannot be relied upon during the droughts, which are common in Kiribati. However, people and institutions are encouraged to construct their own rainwater tanks at their own expense to supplement other water supplies.

8. Constant Flow Method of Water Distribution

The problem of low water pressure in the water supply system is closely associated with limited water resources. To increase the water pressure one has to run the water supply system 24 hours a day so that the water reaches all consumers on the reticulation system. This will obviously lead to excessive water usage and wastage.

On South Tarawa with the current limited groundwater resources developed for pumping, the PUB cannot run the system 24 hours a day. The PUB is forced to run an intermittent water supply for only one hour a day as a measure to conserve water. However, the problem with an intermittent water supply is that an equitable distribution of water cannot be achieved. Those living close to elevated tank/service reservoirs will receive more water than those living downstream who receive little water or nothing at all.

A primary objective of the South Tarawa Water Supply System operations is to provide an equitable supply of water to all customers preferably through individual house connections.

Until the present, water has been rationed by supplying each service reservoir area intermittently for one hour each day. The main problems with this system of operation are that:

?? there is a risk of contamination from backflow into the empty pipes during the periods when water is not being supplied;
?? equitable distribution is difficult with most water going to customers close to the service reservoir and more remote customers receiving little or no water;
?? meters will not operate effectively because of the large amounts of air in the pipes; and
?? water stored in the home in informal containers is at risk of contamination.

A promising alternative is to have a constant flow system with flow restricting devices on each connection. A similar system has been successfully implemented in Kiritimati Island, in the eastern part of Kiribati, under an Australian aid program. The system ensures that each household receives a constant but low flow of water that is fed into small tanks and stored until required. Different sized flow restrictors can be provided according to household water needs and monthly charges can be set accordingly. A water allowance can be calculated for households for each of the various localities in Tarawa based on the availability of alternative sources and household size. For example a larger allowance could apply to Betio where shallow wells are contaminated. Householders could apply, if they wish, for an increased or decreased allowance depending on individual circumstances. This system provides an equitable distribution of the limited water supply and has the advantage of having the pipe network full at all times providing continuous supply and protection of water quality from backflow contamination. Again the water stored in the tanks at each home is subject to possible contamination but an effective tank design with a cover together with customer education programs make such risks negligible.

Water meters are not able to accurately register the very low flows involved in the constant flow system. However meters are not necessary on household connections as flows can be readily assessed with a small measuring flask held under the tank inlet.

Supply to larger institutional and commercial customers will generally be metered. It has been found that large institutional and commercial customers can be provided with a metered connection without affecting domestic customers in the vicinity. Similarly community taps can be provided to low-income areas without affecting domestic customers in the vicinity.

8.1 Pilot Study

To test the viability of the constant flow system, a pilot trial was conducted on Nanikaai village, South Tarawa. Nanikaai was ideal for the study, as it is a discrete area supplied by its own elevated tank and can be simply isolated from the rest of the adjacent supply systems by closing two existing valves. All of the households in Nanikaai have connections to the PUB water supply and most people pay their water bills regularly. There are only a few small commercial and institutional customers in the area and normal household constant flow connections are expected to be adequate for these. The residents of Nanikaai rely almost entirely on the PUB supply for their water as the groundwater in this location is salty and very few households can afford rainwater tanks.

The Nanikaai pilot study area contains 102 households with the population of 682 (2000 census) and is shown in Figure 9 below.

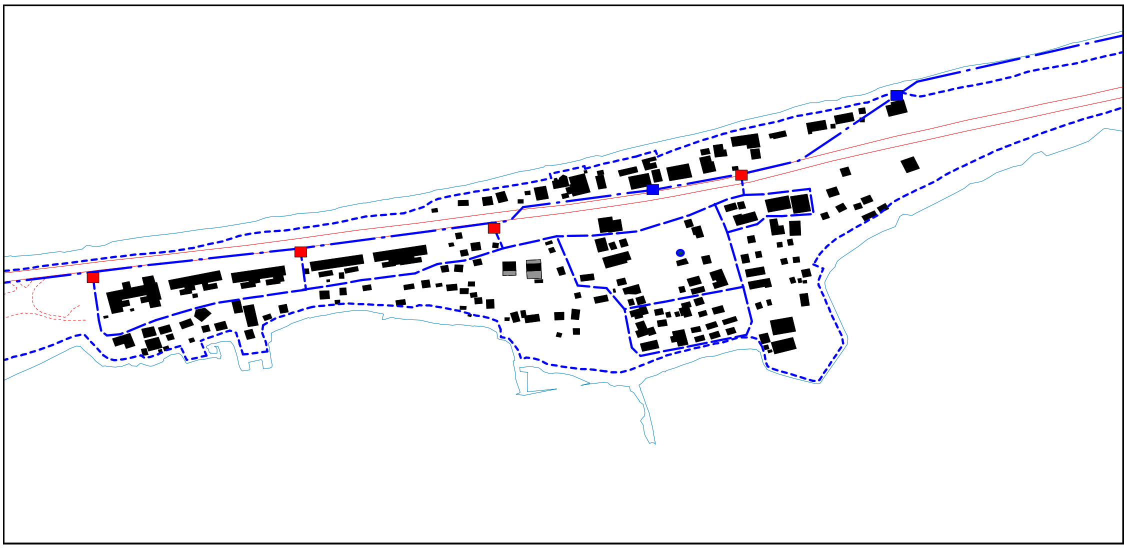


Figure 9: Nanikaai Pilot Study Area.

The pilot study was run from 9th February to 20th June 2002. Activities during the trial period were as follows:

- ?? Consumers surveys (One at the start and one in the middle of the trial period)
- ?? Checking water flows into each household tanks (Weekly)
- ?? Water meter readings for households with water meters (Weekly)
- ?? Checking water level and bulk water meter reading (Daily)
- ?? Leak detection and repair.

The pilot trials of the constant flow house connections are being managed by PUB technical staff. The household tanks have a total capacity of 500 litres, while the flow arte to each household is restricted to 250 litres per day for small households (< 8) and 430 litres per day for households with more than 10 members. The 500 litre tank was placed on a one meter high concrete stand. Local contractors were engaged for construction of tank stands and tank installation.

The pilot area is being monitored to gauge customer acceptance and technical performance. The main problem encountered at the initial stages of the pilot project implementation is the high leakages in the Nanikaai reticulation system. This resulted in the high water demand/usage as recorded on the water meter installed at the base of the elevated tank. The total water usage was in the range of 60 to 80 m^3/day. It was found that most leaks were found at the 50 mm tapping saddles in almost all house connections. After fixing the leaks the water usage at Nanikaai dropped to 45 to 50 m3/day.

The consumer survey was conducted at the initial and middle stages of the project implementation and the result showed that more than half (58%) of households of Nanikaai are satisfied with the constant flow method. The remaining 42% of households basically wanted a higher flow rate so that they can have access to more water. A close scrutiny of the 42% shows that more than 50% of these households had less than 10 members, which means the negative response to the pilot study, is not genuine.

Based on the results of the pilot works, it has been recommended that the constant flow system be extended to serve all other areas in South Tarawa incorporating the modifications that have evolved from the pilot study. These include the fixing of new tapping saddles with a new HDPE pipe to the house and a more comprehensive leak detection on the pipe network in the area concerned.

9. Future Water Resources Development

The population of South Tarawa is growing at a very fast rate (5% per annum) according to the recent population census in the year 2000. Based on that trend the population of South Tarawa could reach 47,000 in the year 2005 and 60,000 by the year 2010. With the limited water resources, it would be very difficult to provide this number of people with clean and potable water.

Table 4 depicts the projected population of South Tarawa over the next 20 years based on two scenarios, using high and low population projections.

Table 4: Population and water demand projection for South Tarawa

High Projection	Current	Projections			
Year	2000	2005	2010	2015	2020
Population	36227	46516	59728	76693	98475
Water Demand(m^3/day)	1159	1489	1911	2454	3151
Low Projection	Current	Projections			
Year	2000	2005	2010	2015	2020
Population	36227	42090	48901	56815	66010
Water Demand (m^3/day)	1159	1347	1565	1818	2112

Table 4 above was derived with the following assumptions:

?? The high projection use 5% as an annual growth rate based on the 2000 census results
?? The low projection use 3% as an annual growth rate based on the average growth rate since the past census results
?? The water demand is based on 40 litres per head per day.
?? It is assumed that the Water Supply System covers 80% of the total population of South Tarawa. The remaining 20% rely solely on rainwater and groundwater wells, as is the current case. It is assumed that major water users such as Hotels, Hospitals, Schools and Industries rely on Desalination.

It appears that the current groundwater sources at Bonriki and Buota can cope with the water demand to the year 2010 using the low population projections. However, as recommended in Alam et al 2002, if Bonriki and Buota water lenses are fully developed, including additional galleries on Bonriki in currently unpumped areas, the total sustainable yield could reach 1950 m^3/day, which would meet the water demand in the year 2010 using the high population project of 1911 m^3/day.

Beyond 2010, new water sources would have to be developed or be found. The following paragraphs discuss alternative water sources to meet water demand beyond the year 2010, not necessarily in an order of priority.

?? ***Development of groundwater resources further into North Tarawa. Table 5 below depicts potential groundwater resources in North Tarawa. The main disadvantage of developing groundwater resources in North Tarawa is the landownership issue. Landowner's consensus on sensitive issues such as land is time consuming and requires a lot of patience. The***

proposal to set up the Water Resources Protection Committee is a good starting point before further groundwater resource development can be initiated.

The landownership problem encountered at Teaoraereke in the early 1990's when government remove those living on the reserve by force and the current settlement problem on Bonriki and Buota are good examples of what the government need to tackle when considering major development of groundwater resources.

Table 5: Groundwater Resources in North Tarawa (based on Falkland, 1992).

Water Source	**Estimated Sustainable Yield (m^3/day)**
Abatao	300
Tabiteuea	250
Marenanuka	150
Abaokoro	50
Nooto	200
Taratai	600
Tearinibai	250
Nuatabu	150
Buariki	1500
Total	**3,450**

?? ***Desalination technology has been proved to be a viable option for water resources development in small island countries where adequate funding and appropriate expertise is available . The main obstacle in the use of this technology is that it requires a lot of energy. Kiribati experience has shown that the electricity cost is about 16 times more than the conventional groundwater pumping. However, it was found that it was very easy to operate and maintain, provided that spare parts are readily available from a reliable manufacturer.***

Desalination technology will remain the only other alternative main water source, should the use of groundwater become too expensive in view of ***opportunity costs*** incurred by the landowners demand for more compensation and increase in land leases.

Developed countries who manufacture desalination plants should consider ways of reducing the cost of operating desalination plants and spares so that it can be cheaper in the future for under-developing countries with limited water resources.

?? ***Rainwater in Kiribati is considered only as a supplementary water source. This is due to the uneven distribution of rainfall within and between the years. Droughts lasting many months (10 months or more) are common in Kiribati. This means then that one has to construct large storages to sustain water demands in long droughts. This would be very costly and well beyond the reach of individuals and community groups. However, people are encouraged under the Law (building permit regulations) to include a tank of sufficient size (Minimum 5*** m^3***) when constructing a new building. This will help relieve water demand on the PUB water supply.***

At the same time government buildings and large community buildings are strongly encouraged to construct large tanks to collect and store rainwater for internal use and for use by the public during the droughts. While the tank should be considered as an investment in the water sector, its cost should be seen as an integral part of the building.

10. Conclusions

The performance of the South Tarawa Water Supply system, which is serving more than 60% of the 38,000 people living on South Tarawa, is an exemplary case of groundwater supply using fully developed groundwater lenses (Bonriki and Buota). The use of properly constructed infiltration galleries and the use of positive displacement pumps to maintain constant flows are an effective groundwater development method. They cause minimal thinning effects to the fragile freshwater lenses on a small coral atoll. The current developed lens area is just over 1 km^2 on both Bonriki and Buota with a total water production rate of 1100 m^3/day. The salinity (conductivity) readings of the combined water pumped from the galleries remained low and never exceeded 1000 ? S/cm during the 1998/2001 drought, which is the worst drought in recorded Kiribati history. Even though some infiltration gallery wells had conductivity readings exceeding 1000 ? s/cm, they never exceeded 2000 ? s/cm. The important fact is that maximum conductivity reading of water supplied to PUB water consumers received during the drought was 1000 ? S/cm compared with the allowable conductivity readings for drinking water in Kiribati of 2500 ? s/cm. It is also less than the more stringent salinity condition in the WHO guidelines for drinking water (equivalent to about 1400 ? S/cm).

The borehole network in the freshwater lenses on Bonriki and Buota has enabled the PUB to monitor the thickness of the water lens over a period of more than 10 years of records. Some data is available for more than 20 years ago. With these records and with the assistance of external experts, we are able to review the sustainable yield estimates of the Bonriki and Buota from time to time. Looking at the Bonriki water lens, the sustainable yield estimates have increased from 750 m^3/day in 1982 to some 1350 m^3/day in the year 2002 for the area currently being pumped and up to some 1600 m3/day if an additional area in Bonriki was pumped using galleries. Without the monitoring records, we cannot review the sustainable yields.

The constant flow method of water distribution is an answer to the present low water pressure problem in the South Tarawa Water Supply System and the unequitable water distribution to PUB water consumers. The method has been successfully tested in one area on South Tarawa and was found to work well. The water can reach all water consumers at a slow flow rate. Even though the available water does not meet all water requirements (i.e. washing, cooking, drinking and bathing) it should be a good test case for people to conserve water and to live with limited water resources. This can also be applied on small island countries in the Pacific with limited water resources.

The use of groundwater resources as the main water source for the public water supply remains the cheapest and most appropriate option for Kiribati. However, other water sources such as desalination should be considered for future generations, as groundwater will, most probably, be insufficient to meet projected future water demands. Developed countries are requested to assist in reducing the capital costs of desalination plants by assisting or providing subsidies to private companies who manufacture desalination plants. Ways of reducing energy costs for running desalination plants should be sought with appropriate research and development.

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