# CHALLENGES WITH PROVIDING RESILIENT SEWERAGE INFRASTRUCTURE IN DEVELOPING COUNTRIES

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## ABSTRACT

The challenge of providing reliable sewerage infrastructure in developing countries such as Kiribati is immense. Budgets come mainly from aid money, with design usually carried out by ex-pat engineers sourced worldwide. Funds are limited, and often some reduction of scope is required to fit the available funds.

While many robust schemes have been built in various countries, assets often suffer gradual deterioration. Money for maintenance and upkeep is expected to come from country's internal budgets, but the funds are often inadequate to maintain the assets, and local staff sometimes lack the knowledge required to maintain treatment standards.

A sewerage scheme built in South Tarawa, Kiribati in 1985 required repair/rebuilding in 2003, and now requires further substantial work to restore functionality after deterioration and damage by wave action.

Recently, bids were called for the rehabilitation of sewerage systems and ocean outfalls replacement. Following review of bids received, experience is shared relating to the particular requirements, trials and challenges to providing sewerage infrastructure in developing countries.

Comment is made on how these observations could be applied to New Zealand. Further comments are provided on observations with respect to sea level rise facing Kiribati and whether we in New Zealand are adequately acknowledging and addressing this issue!

## KEYWORDS

**Sewerage, infrastructure, outfalls, resilience, developing nations, climate change.**

## 1 INTRODUCTION

Various aid agencies (Asian Development Bank, World Bank, African Development Bank and many others) sponsor various projects in developing countries in the form of grants or 'loans'. Many of these projects provide vital water and wastewater infrastructure to improve the health and lives of millions of people, often living in very poor conditions.

Normally, the government of the beneficiary country contributes funds as well, and provides staff and administrative support. The government often administers and runs the project.

Many engineers and other professionals are contracted or seconded on a long term or short term basis to provide specialist support or advice on particular aspects of a project, usually being domiciled in the beneficiary country for a period of time.

I have personally been involved in several projects in Fiji and Kiribati and share some experience and a few insights.

## 2 RESILIENT INFRASTRUCTURE DEFINITION

"Resilience" means "the capability of a strained body to recover its size and shape after deformation caused especially by compressive stress, or an ability to recover from or adjust easily to misfortune or change"

(Websters). Resilient infrastructure should therefore be able to cope with (maintain service) or recover (return to service) after severe weather, heavy surf, and abuse from the public.

Following recent review work assignments overseas, experience is shared relating to how some items of infrastructure have failed, how it could be fixed or prevented, and the challenges facing the provision of resilient infrastructure in developing countries, with comment on how these observations could be applied to situations in New Zealand.

Infrastructure needs to not only be resilient against the forces of nature, but also from anthropogenic problems, such as poor maintenance, power failures, and adherence to traditional customs.

# 3 PROJECT EXAMPLE - SOUTH TARAWA SEWERAGE (KIRIBATI)

## 3.1 BACKGROUND

The nation Kiribati (pronounced *kirr-i-bas*) consists of many coral atolls in the central Pacific in three main island groups. The most highly populated island is the Tarawa atoll, in the Gilbert Island group, which is also the capital, and the highest point is only 3 metres above sea level. The island is a long, ribbon-like landform, just 1°26′ north of the Equator, over 30km east to west, but no more than 900m wide.

South Tarawa, the nation’s capital, is one of the most densely populated areas on earth, due to migration of people from outlying islands to the “good life” and relative prosperity of the city. South Tarawa (population 50,182, 2010 census) consists of a number of islets around the southern rim of the atoll which have been connected by causeways in recent times.

*Figure 1: Location of Kiribati*

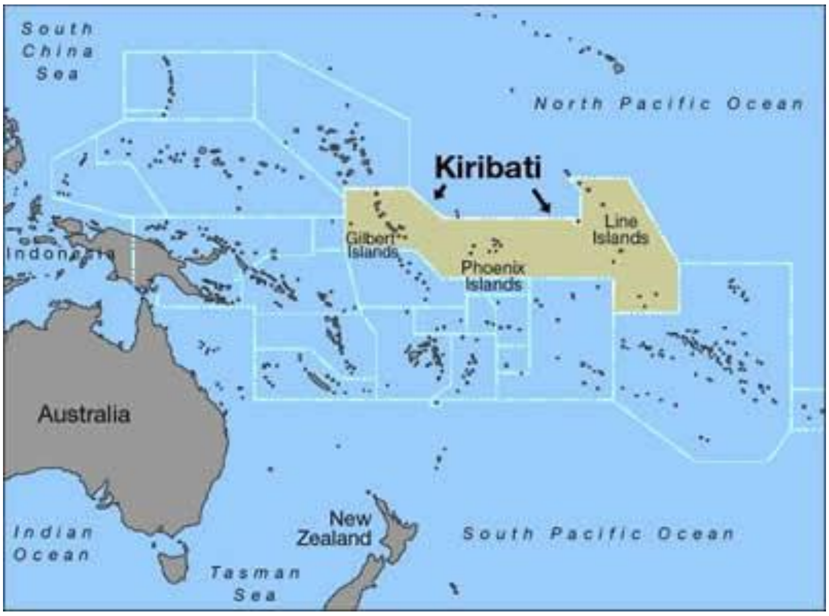
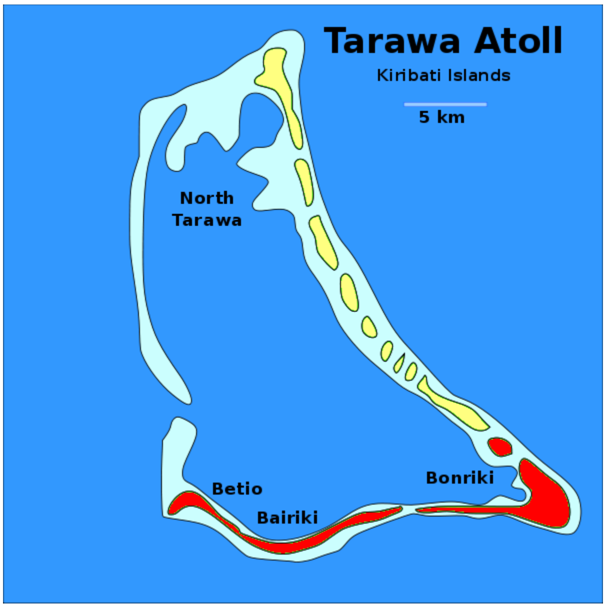


*Figure 2:* *Tarawa Atoll (figure Wikipedia, Tarawa)*




Tarawa is located in the dry belt of the equatorial climate zone and has a maritime tropical climate with two main seasons and mean daily temperatures ranging from 26°C to 32°C. Between October and March, easterly trade winds predominate and rainfall is generally higher, while between April and September, more variable winds occur including westerly's (which can be strong) and lower rainfall. The island is subject to intermittent droughts, when the drier season can extend well beyond the months of April to September. Unlike many other Pacific islands, Tarawa rarely experiences cyclones.

*Photograph 1:* South Tarawa with Bikenibeu foreground), Banraeaba, and Bairiki & Betio in the distance

As well as having a high population density, South Tarawa is severely polluted from human excrement and rubbish. The local people have a historical custom of relieving themselves on the beach or in the lagoon.

While this may have had little effect in past centuries on sparsely populated islands, it is a disaster at South Tarawa's heavily populated shores. This situation alone results in more pollution at South Tarawa than that which comes from the dysfunctional sewerage system.

To add to the bacteriological pollution, all kinds of plastic, paper and metal rubbish has been thrown onto the foreshore, and washed into areas by the waves. Truly, South Tarawa is a tropical paradise lost!

## 3.2 EXISTING INFRASTRUCTURE

Most of the island has no sewerage, other than some form of septic tanks. People depend on scarce groundwater, which is becoming increasingly contaminated with saltwater or bacteria. Roofwater is used in some places.

Sewerage infrastructure serves three of the more densely populated areas, Betio, Bairiki and Bikenibeu (pronounced *Bay-sio, Bair-iki, Biken-e-boo*) and involves a traditional gravity collection system.

Due to shortage of fresh water, toilet flushing is accomplished by saltwater from the ocean, reticulated by small bore pipes to houses. The raw sewage is then screened and discharged to the ocean by three short outfalls, at Betio, Bairiki and Bikenibeu.

Considerable damage had occurred to key components of the infrastructure:

- Damage to the saltwater intakes, leading to infiltration with sand, subsequent pump failure and blockage and non-operation of the saltwater flushing system.

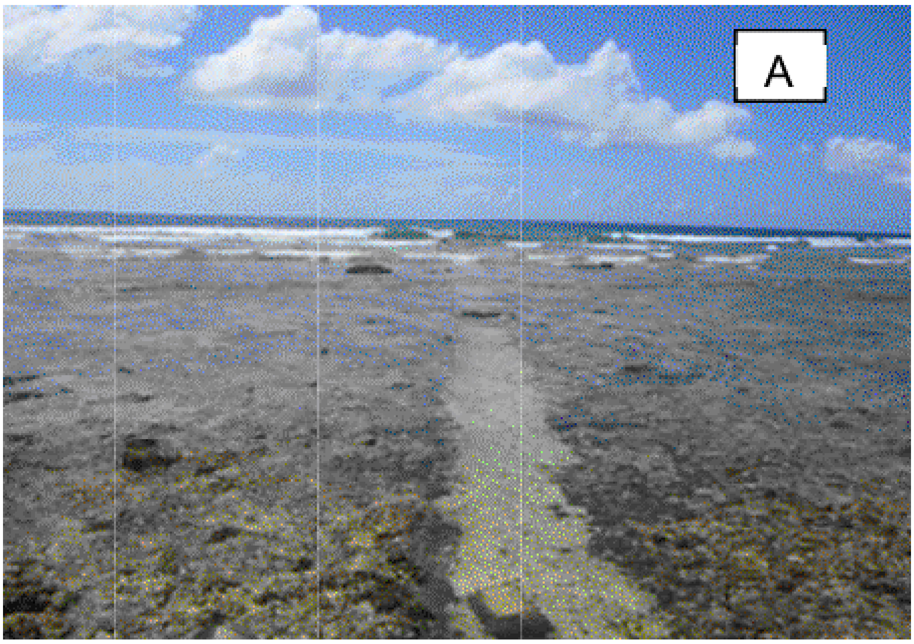
- Sewage, sulphide and saltwater attack to manholes and pipes in the gravity drainage system. Due to leakage, there is significant pollution to groundwater, as well as infiltration of water into the sewerage system.

- Failure of sewage pumps and control systems. Many of the automatic pump start and stop floats no longer function, instead, many pumps are operated manually on an ad-hoc basis by Public Utilities Board (PUB) staff in the field.

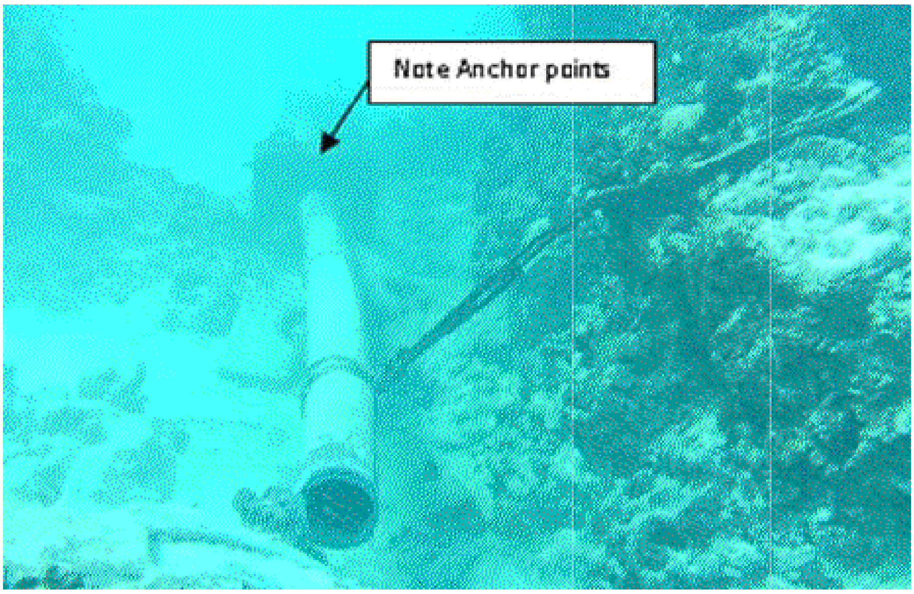
- All of the ocean outfalls have suffered irreparable damage with leakage occurring in the intertidal zone and little effluent being pumped beyond the reef.

- The existing outfalls were constructed as over-the-reef type outfalls. Each outfall was installed in a shallow trench dug into the foreshore coral, then through the reef, and down the reef slope. Due to inadequate construction or installation techniques and heavy surf action, breakage and leaks have occurred. Untreated sewage is therefore disposed of near the shore, resulting in a health hazard.

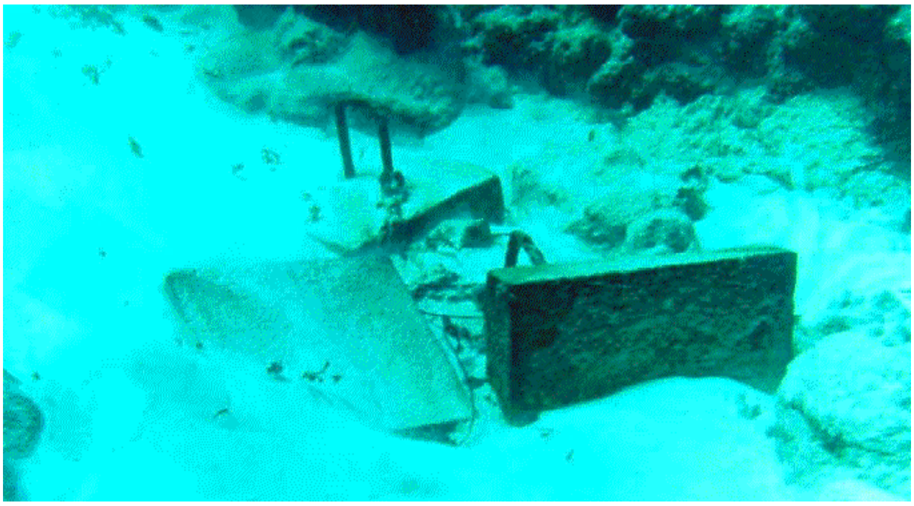
*Photograph 2:* The route of the Betio Outfall clearly visible in the foreshore, Photo from the Basic Environmental Impact Assessment (BEIA)



*Photograph 3: Damaged Bairiki Outfall pipeline - (BEIA)*




*Photograph 4: Fallen Concrete Outfall Collars (BEIA)*



The above situations would be deemed unacceptable in most developed countries. Yet many water and wastewater projects in developing countries operate far below their intended level of service due to poor construction and lack of skills, resources and funds to properly operate and maintain the assets.

The Asian Development Bank (ADB), along with the Australian aid organisation AusAID, are contributing funds for repair of the saltwater collection, storage and reticulation, sewerage pumping stations and reticulation, and ocean outfalls.

## 3.3 PROJECT DESCRIPTION

The first main contract will replace the saltwater intake galleries with an improved design, to ensure sand does not enter the water and damage the pumps. Salt water is stored in towers, some of which require repair to the supporting structure.

The saltwater pipe network is to be repaired, with new valves connecting to toilets, or to a ballcock next to the toilet, to assist flushing.

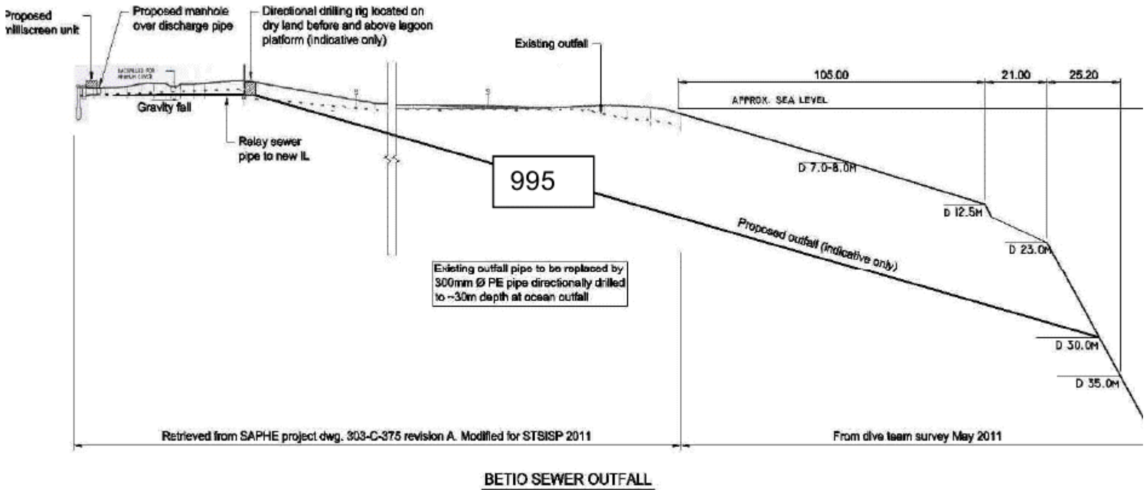
The sewer pipe network is also to be repaired, with localised repairs to the most badly damaged part. Funds do not permit a total restoration to as new condition. This, however, is also true of many sewer rehabilitation projects in the developed world.

The concrete structures of the 21 pumping stations are to be restored, and the pumping stations are to be fitted with duty/standby stainless steel pumps, to resist the harsh salt/sewage environment. Any non-stainless components would have a very limited life.

Each of the three terminal pumping stations located close to the ocean outfalls, will lift the sewage into an elevated screen. A new elevated milliscreen will be installed, from which sewage will then flow by gravity down the ocean outfall and out to sea.

The second main contract is to replace the three main ocean outfalls. Due to poor performance of the existing over-the-reef outfall, the preferred installation method for the new outfalls is by directional drilling. The design concept is for the outfall to be constructed by drilling from the land at an angle down, through the reef and exiting at around 30m below sea level, as per Figure 3 below.

*Figure 3: Diagram of the Proposed Betio Outfall (BEIA)*




While some may baulk at the thought of screened raw sewage being disposed of to the ocean, the environmental impact is relatively minor if the outfall is properly constructed. Once past the edge of the coral reef, the sea floor drops steeply down a slope to ocean depths of around 2,000m.

The screened sewage is planned to be released 30m below sea level, down the reef slope on the ocean side of the coral reef. The sewage will be mixed with seawater, and transported predominantly to the west by the westward flowing current in the area. As the south shore of Tarawa Island is mainly east-west, there is less scope for sewage to be pushed back to shore.

However, this is not true if the outfall is damaged, as the existing outfalls are. Sewage is currently being discharged on the top of the reef, and between the reef and the shore, worsening the water pollution problem at South Tarawa.

Modeling has predicted a significant improvement in water quality in the vicinity of the outfalls at Bairiki and Betio over the status quo after the outfalls are operating (BEIA). There is less improvement at Bikenibeu as there is a larger population outside the sewered area.

There is another very significant aspect to the overall project beyond engineering, the community engagement "human" aspect of pollution may actually be more significant than the issues with the sewerage infrastructure due to the customary habits of many of the local people. There is little benefit in providing a good sewerage system if a large proportion of the population do not use it. I heard of a case in Bairiki where a public toilet had to be closed due to vandalism, which had made the toilet too dirty and undesirable to use.

For this reason, a critical part of the aid project includes a community consultation and education programme, aimed at changing attitudes to sanitation, increasing toilet use, and eventually eradicating direct defecation to the environment.

## 3.4 CHALLENGES TO OVERCOME

The overall project faces significant challenges, just by the sheer size and location of the work.

- The isolation of Kiribati, results in a cost premium for materials, skilled labour and machinery. All heavy construction equipment and any significant items have to be brought in from overseas, including most qualified and experienced workers. There is a shortage of suitable accommodation, and most food must be imported (there are abundant supplies of local fish though!).

- As the island is a coral atoll, all the natural sand and rock is derived from natural coral. All crushed aggregate, sand and cement for building must be imported.

- Getting geotechnical investigations carried out is extremely time consuming and expensive. There are no local drilling rigs or geotechnical capability, and all equipment and personnel need to be brought to the island. Consequently, projects may often be carried out with little or no geotechnical investigation, relying on past experience, and the fact that all natural strata is coral derived, and therefore is relatively predictable. However, when drilling deeper than 20m to 30m harder less weathered coral limestone layers may be present.

- The shortage of natural fresh water means saltwater must be used for flushing, leading to more severe attack of the pipes and pumps.

- Any significant volumes of fresh water required by the contractor would usually need to be generated by the contractor's own portable RO plant.

- The climate makes work difficult, and productivity low. Daily temperature maximums vary from 30-35°C year round with high humidity (usually feels like 38-48°C).

- The coral is not uniform, and can have voids, filled with sand, and harder and softer layers. This could make directional drilling problematic.

- The reef is exposed to ocean swells, and any work in that area is demanding. Working at 30-45m depth, requires specialist divers, with a hyperbaric chamber for decompression.

- Changing attitudes to public defecation and increasing the use of toilets.

- Other logistical issues arise, including slow delivery of post/courier documents, slow and erratic internet communication, and a general lack of fast, well maintained printers, copiers and scanners on the island. Cellphone communications, while relatively good, are also expensive by international standards.

- Travel around the island by road is slow. There is only one main road in very poor condition, which is in the process of being repaired, delays are common and can occur at any time.

There are many more minor issues, but overall the cost of carrying out major project work is significantly higher than in developed counties. Contractors who underestimate these costs can run the risk of losing large sums of money.

## 3.5 APPROPRIATE TECHNOLOGY

The provision of appropriate technology is important. The use of high-tech equipment such as mechanised treatment plants, PLC's, chemically assisted processes, increases the risk that if a simple problem occurs, the entire piece of equipment or system may become dysfunctional. Some examples are:

- Standby pumps may often remain unused for a period, the when called on to operate may not work. Instead of being fixed, they would often be abandoned. Many pumping station therefore operate on a single operational pump.

- If the PLC programming develops a bug, or problem, there may be no-one who can fix it. The plant or pumps will then be operated manually, whenever the operator remembers.

- Equipment is often not maintained, because the operating manual may not be properly studied or may not be referred to at all. When the equipment breaks down, it will often not be repaired, but just bypassed.

I have seen scenarios like this in various water and wastewater facilities in developing Pacific nations. It is unfortunate that the infrastructure provided by aid money to improve the lives of the local people can in some cases fall into disrepair within a short time after final handover.

One way to minimise this wastage is to purposely use low technology, even if the quality may not be as high as what modern technology can achieve. For instance, I developed a Sewerage Master Plan for a remote community in Fiji several years ago. A relatively high treatment standard was required, but rather than a mechanised plant, a conceptual design was developed for a multi-stage pond system with natural rock filters, which uses no electricity, and will produce a relatively good effluent with little reliance on operator input.

For Kiribati, ocean outfalls are more appropriate then mechanised treatment plants. A treatment plant would cost more to construct, use more energy, require skilled operator input, and would take up valuable land needed for housing or community purposes.

Simple hard wired pump controls are also generally more reliable, easier to repair locally and less prone to electronic damage. High humidity and warm temperatures in tropical locations can shorten the life of electronic equipment. I heard of an occasion where air conditioner controllers failed due to spiders making a home near the electronic circuit board. Excrement from the spiders damaged the circuitry, meaning a repairman had to come from overseas to replace the units. The circuit boards were encased with silicon, which solved the problem!

A tenderer proposed the use of variable speed drives to replace the saltwater towers. The VSD'd would maintain a set pressure in the saltwater reticulation, rather than relying on elevated water towers. However, the use of VSD's would be more difficult to maintain and repair should a problem develop. The suggestion was not adopted for South Tarawa, as the saltwater towers have operated successfully for many years.

The old adage "Keep it simple" is very appropriate in remote island nations like Kiribati, and can also be beneficial in many cases in New Zealand.

Fortunately, there is good news, in that development partners are increasingly taking sustainability concerns on board as a result of the partial failure of past infrastructure projects. For example, funding of maintenance as well as capex, is becoming increasingly acceptable for projects or investments that are unlikely to achieve full cost recovery (e.g. sewerage which has substantial public health and environmental benefits that may not be captured by what people are willing or able to pay in tariffs and charges) (ADB).

In addition, O&M contracts to follow capital works are also becoming more common, but of course these have long-term cost implications. The ADB and others are also looking at government budget support as a means of ensuring that funds are available to minimise asset degradation and maintain critical infrastructure services.

## 3.6 PROJECT STATUS

The sanitation improvement project at South Tarawa is in the process of re-bidding. Bids came in over the available budget, and some bids had to be disqualified because of non-compliance with parts of the bid documents.

In part this was caused by the remoteness of Kiribati, where a bidder had used a local company to assemble the document in Tarawa, which then took longer than expected due to insufficient supply of paper and other consumables. While these commodities are taken for granted in most places, sourcing paper and other printer consumables in locations such as Tarawa can be challenging.

In addition, delivery of commercial documents by courier can be erratic. There are only a limited number of flights in and out of Tarawa each week, and due to the state of public roads (which are currently being upgraded by another ADB aid project) delivery of important tender documents was late.

Local politics also come into play, with various local companies keen to be selected for involvement in major projects.

# 4 CLIMATE CHANGE ISSUES

A discussion about Kiribati would not be complete without reference to the issue of climate change and in particular, sea level rise. Kiribati has been in the news recently as a nation that could possibly “disappear” completely within 50 or so years if global sea level continue to rise.

Regardless of your personal view (and I have heard both sides) no one can deny that the climate is slowly changing, and that glacial ice is melting in many parts of the world. Records since 1870 show a steady and accelerating general rise in global average sea levels, interspersed with brief periods of sea level fall (Ahlenius, H, 2007). There is a strong possibility that sea level rise will be a major issue worldwide in the next 50 to 100 years, and one that it would not be wise to ignore.

## 4.1 KING TIDES AND SALTWATER INTRUSION

At South Tarawa, king tides are often a cause of problems, with waves overtopping sea walls. While I was there one of the hotels (not where I was staying) had several rooms flooded when the nearby sea wall on the lagoon side was overtopped. Water invades the land, in some cases even entering villages and meeting houses. In addition, what little crops are grown on the island are at risk from the increasing salinity of the soil.

Fresh water supplies are almost exhausted on the island. Fresh water accumulates in groundwater lenses under each larger section of island, fed by rain, and range from 1m to 9 metres deep in places. Recent studies show that the freshwater lenses under Bairiki is now almost gone, and the island is quite small. Betio is a larger island, but the substantial freshwater lens under this island is now contaminated with fecal pollution and brackish intrusion. The last remaining freshwater reservoir under the airport at Bonriki to the east is shrinking due to saltwater intrusion and the treat of pollution from people settling there. Any slight rise in sea level will worsen the freshwater supply situation.

The people of South Tarawa are in the process of preparing to leave the island, as most of the island is no more than 2 metres above sea level. Young people are concentrating on education, to enable them to face better prospects in the world at large, and some new houses are being built on stilts, over the water, rather than on land.

### 4.1.1 WHAT ABOUT NEW ZEALAND??

In New Zealand, we have large areas of development close to sea level or close to the coast which will also be susceptible to rises in sea level. While much valuable work has been done by to identify the problem and consider solutions, little practical change has taken place yet at a regulatory level.

We could take the bold step of restricting or limiting the type of development that takes place on low-lying land, but this has largely fallen into the “too hard basket” with central government not wanting to take an unpopular stance, and local authorities lacking clear guidance.

In other counties, some progress is being made, particularly in the Netherlands (who are particularly at risk) and also in various States of Australia, where limitations on development are being put in place in certain low-lying areas.

The challenge here in New Zealand is for political entities to look beyond short term policies and current issues, and consider the ramifications of building new infrastructure in vulnerable situations, as sea levels continue to slowly rise.

# 5 CONCLUSIONS

There are challenges to the provision of sewage infrastructure in a culture which has relied, until recent times on natural dispersion of wastes and a low population density to avoid signs of pollution. With increasing population, more intensive means of dealing with sewage is required.

The provision of basic sanitation (collection, conveyance, gross solids removal and disposal) is the minimum required to provide reasonable health and sanitation and moderate impact to the environment. If funds are limited, it is better to provide some level of improvement to as many people as practical, rather than an excellent degree of sanitation to just a few.

It is my view that aid projects should focus on technologically appropriate and sustainable solutions for each country, rather than trying to implement technologies which struggle to cope with growth in developed nations. In particular, sewerage infrastructure needs to be connected with public education, focusing on schools, to teach the inhabitants good sanitation, conservation of water, learning to utilise technology, and retaining skills in their own country.

For every dollar that is spent on the capital value of infrastructure improvement, a sizable amount should be also allocated to ongoing operation, maintenance and technological support, to ensure the infrastructure built delivers the greatest improvement in living standards for the local people. It is encouraging to see that development partners are increasingly taking sustainability concerns on board.

It is hoped for future projects, that funding by development partners for O&M, general maintenance and education, as well as capex will become increasingly common, and as a result, fewer failures and better utilisation of new water and sewerage infrastructure projects will occur.

The main purpose of this paper is to bring attention to the significant challenges and issues facing the provision of resilient wastewater infrastructure in the Pacific, not the least of which is the human factor!

## ACKNOWLEDGEMENTS

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## REFERENCES

Project Documents produced by:

Republic of Kiribati, Ministry of Public Works and Utilities and their consultant SMEC (Snowy Mountains Engineering Corporation International Ltd). South Tarawa Sanitation Sector Improvement Project, Sewer System and Ocean Outfalls Rehabilitation Subprojects

- Final Bidding Document, Republic of Kiribati, Ministry of Public Works and Utilities, South Tarawa Sanitation Sector Improvement Project, Final Bidding Document, For the Rehabilitation of Sewerage and Saltwater Systems in Betio, Bairiki and Bikenibeu
- BEIA, 'South Tarawa Sanitation Sector Improvement Project, Sewer System and Ocean Outfalls Rehabilitation Subprojects, Basic Environmental Impact Assessment' (2013), the Kiribati Ministry of Public Works and Utilities and their consultant SMEC (Snowy Mountains Engineering Corporation International Ltd)

**Websites:**

Wikipedia article, Tarawa, last modified on 31 December 2013
< http://en.wikipedia.org/wiki/Tarawa>

Ahlenius, H. 2007, UNEP/GRID Arendal, Trends in sea level 1870-2007, accessed 16 July 2014,
< http://www.grida.no/graphicslib/detail/trends-in-sea-level-1870-2006_9987>